Example 1: Reviewing General Linear Models and Interaction Terms
(complete syntax, data, and output available for SAS, STATA, and R electronically)

These example data come from Hoffman (2015) chapter 2, which examined prediction of cognition (as measured by an information test outcome) from age (centered at 85 years), grip strength (centered at 9 pounds), sex (with men as the reference group) and subsequent dementia status (none = 1, future = 2, and current = 3, with none as the reference) in a sample of 550 older adults. This example first uses a main-effects only model to demonstrate two ways of generating predicted outcomes (via individual-specific estimates or using fake people). It then illustrates how to include and interpret different kinds of interactions: first for age by grip strength, and then adding sex by dementia status.

<u>SAS</u> Syntax for Importing and Preparing Data for Analysis:

```
* Defining global variable for file location to be replaced in code below;
* \\Client\ precedes path in Virtual Desktop outside H drive;
  %LET filesave= C:\Dropbox\22_PSQF6270\PSQF6270_Example1;
* Location for SAS files for these models (uses macro variable filesave);
  LIBNAME filesave "&filesave.";

* Import chapter 2 example data into work library as Example1;
DATA work.Example1; SET filesave.SAS_Chapter2;
* Center quantitative predictors;
  age85 = age-85;
  grip9 = grip-9;
* Create dummy-coded binary indicator predictors for dementia groups;
  demNF=.; demNC=.; * Create two new empty variables;
  IF demgroup=1 THEN DO; demNF=0; demNC=0; END; * Recode if demgroup=none;
  IF demgroup=2 THEN DO; demNF=1; demNC=0; END; * Recode if demgroup=future;
  IF demgroup=3 THEN DO; demNF=0; demNC=1; END; * Recode if demgroup=current;
* Label new variables -- note semi-colon is only at the end of ALL labels;
  LABEL
  age85=      "age85: Age in Years (0=85)"
  grip9=      "grip9: Grip Strength in Pounds (0=9)"
  sexMW=      "sexMW: Sex (0=M, 1=W)"
  demNF=      "demNF: Dementia Predictor for None=0 vs Future=1"
  demNC=      "demNC: Dementia Predictor for None=0 vs Current=1"
  cognition= "cognition: Cognition Outcome"
  demgroup=  "demgroup: Dementia Group 1N 2F 3C";

* Filter to only cases complete on all variables to be used below;
  IF NMISS(cognition,age,grip,sexmw,demgroup)>0 THEN DELETE;
RUN;
```

<u>STATA</u> Syntax for Importing and Preparing Data for Analysis:

```
// Defining global variable for file location to be replaced in code below
// \\Client\ precedes path in Virtual Desktop outside H drive
   global filesave "C:\Dropbox\22_PSQF6270\PSQF6270_Example1"

// Open chapter 2 STATA dataset and clear away any existing data
   use "$filesave\STATA_Chapter2.dta", clear // Has converted all variables to lower-case

// Center quantitative predictors
   gen age85 = age-85
   gen grip9 = grip-9

// Create dummy-coded binary indicator predictors for dementia groups
   gen demnf=.  // Create two new empty variables
   gen demnc=.
// Recode if demgroup = none
   replace demnf=0 if demgroup==1
```

```
   replace demnc=0 if demgroup==1
// Recode if demgroup = future
   replace demnf=1 if demgroup==2
   replace demnc=0 if demgroup==2
// Recode if demgroup = current
   replace demnf=0 if demgroup==3
   replace demnc=1 if demgroup==3

// Label all variables
   label variable age85     "age85: Age in Years (0=85)"
   label variable grip9     "grip9: Grip Strength in Pounds (0=9)"
   label variable sexmw     "sexmw: Sex (0=Men, 1=Women)"
   label variable demnf     "demnf: Dementia Predictor for None=0 vs Future=1"
   label variable demnc     "demnc: Dementia Predictor for None=0 vs Current=1"
   label variable cognition "cognition: Cognition Outcome"
   label variable demgroup  "demgroup: Dementia Group 1N 2F 3C"

// Filter to only cases complete on all variables to be used below
   egen nmiss=rowmiss(cognition age grip sexmw demgroup)
   drop if nmiss>0
```

R Syntax for Importing and Preparing Data for Analysis:

```
# Define variables for working directory and data name
filesave = "C:\\Dropbox/22_PSQF6270/PSQF6270_Example1/"
filename = "SAS_Chapter2.sas7bdat"
setwd(dir=filesave)

# Import chapter 2 SAS data as Example1
Example1 = read_sas(data_file=paste0(filesave,filename))
# Convert to data frame without labels to use for analysis
Example1 = as.data.frame(Example1)
# Sort data by PersonID
Example1 = sort_asc(data=Example1,PersonID)

# Center quantitative predictors
Example1$age85 = Example1$age-85
Example1$grip9 = Example1$grip-9

# Create dummy-coded binary indicator predictors for dementia groups
Example1$demNF = NA; Example1$demNC = NA  # Create two new empty variables
# Recode if demgroup=none
Example1$demNF[which(Example1$demgroup==1)]=0
Example1$demNC[which(Example1$demgroup==1)]=0
# Recode if demgroup=future
Example1$demNF[which(Example1$demgroup==2)]=1
Example1$demNC[which(Example1$demgroup==2)]=0
# Recode if demgroup=current
Example1$demNF[which(Example1$demgroup==3)]=0
Example1$demNC[which(Example1$demgroup==3)]=1

# Label all variables as comments only (not actually added to data)
#age85=     "age85: Age in Years (0=85)"
#grip9=     "grip9: Grip Strength in Pounds (0=9)"
#sexMW=     "sexMW: Sex (0=M, 1=W)"
#demNF=     "demNF: Dementia Predictor for None=0 vs Future=1"
#demNC=     "demNC: Dementia Predictor for None=0 vs Current=1"
#cognition= "cognition: Cognition Outcome"
#demgroup=  "demgroup: Dementia Group 1N 2F 3C"

# Filter to only cases complete on all variables to be used below
Example1 = Example1[complete.cases(Example1[ , 1:6]),]
```

Syntax and SAS Output for Descriptive Statistics

```
TITLE "SAS Descriptive Statistics";
PROC MEANS DATA=work.Example1 NOLABELS NONOBS NDEC=3 MEAN STDDEV VAR MIN MAX;
     VAR cognition age grip sexMW; * For quantitative variables;
RUN;
PROC FREQ DATA=work.Example1;  * For categorical variables;
     TABLE sexMW*demgroup / NOROW NOCOL; * Remove row and column totals;
RUN; TITLE;

display "STATA Descriptive Statistics"
format cognition age grip sexmw demnf demnc %4.3f      // to control precision
summarize cognition age grip sexmw demnf demnc, format // for quantitative variables
summarize cognition age grip sexmw demnf demnc, detail // detail to get variance
tabulate sexmw demgroup                                // for categorical variables

print("R Descriptive Statistics")
describe(x=Example1[ , c("cognition","age","grip","sexMW")]) # for quantitative variables
table(x=Example1$sexMW,Example1$demgroup,useNA="ifany")      # for categorical variables
```

SAS (Old-School Listing) Output—which I still use because it's easier to annotate:

The MEANS Procedure

Variable	Mean	Std Dev	Variance	Minimum	Maximum
cognition	24.822	10.989	120.759	0.000	44.000
age	84.927	3.430	11.765	80.016	96.967
grip	9.113	2.983	8.898	0.000	19.000
sexMW	0.587	0.493	0.243	0.000	1.000

The FREQ Procedure

sexMW(sexMW: Sex (0=M, 1=W))by demgroup(demgroup: Dementia Group 1N 2F 3C)

Frequency Percent	1	2	3	Total
0	168 30.55	40 7.27	19 3.45	227 41.27
1	231 42.00	69 12.55	23 4.18	323 58.73
Total	399 72.55	109 19.82	42 7.64	550 100.00

SAS Syntax and Output for Eq 2.8 Main-Effects Only GLM Predicting Cognition:
Demonstrating how to get predicted outcomes using ESTIMATE statements and plot them

$$Cognition_i = \beta_0 + \beta_1(Age_i - 85) + \beta_2(Grip_i - 9) + \beta_3(SexMW_i) + \beta_4(DemNF_i) + \beta_5(DemNC_i) + e_i$$

Linear combination for difference of future vs current dementia:

$$(\beta_0 + \beta_5) - (\beta_0 + \beta_4) = \beta_5 - \beta_4$$

```
TITLE1 "SAS Eq 2.8: Main-Effects-Only GLM Predicting Cognition";
TITLE2 "Demonstrating how to get predicted outcomes using ESTIMATE statements";
PROC GLM DATA=work.Example1 NAMELEN=100;
MODEL cognition = age85 grip9 sexMW demNF demNC / ALPHA=.05 CLPARM SOLUTION SS3;
```

```
* CONTRAST lumps together fixed effects for joint tests -- indicate DFnum by commas;
CONTRAST "DFnum=5 F-test for Model R2"    age85 1, grip9 1, sexMW 1, demNF 1, demNC 1;
CONTRAST "DFnum=2 F-test for Demgroup"    demNF 1, demNC 1; * Omnibus group main effect;

* ESTIMATE creates a single linear combination of fixed effects;
ESTIMATE "Mean Diff: Future vs Current"   demNF -1 demNC 1; * Beta5-Beta4;

* Pred cognition outcomes holding sexMW=men, demNF=none, and demNC=none;
ESTIMATE "Yhat for Age=80 Grip=6"  intercept 1 age85 -5 grip9 -3 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=80 Grip=9"  intercept 1 age85 -5 grip9  0 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=80 Grip=12" intercept 1 age85 -5 grip9  3 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=85 Grip=6"  intercept 1 age85  0 grip9 -3 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=85 Grip=9"  intercept 1 age85  0 grip9  0 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=85 Grip=12" intercept 1 age85  0 grip9  3 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=90 Grip=6"  intercept 1 age85  5 grip9 -3 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=90 Grip=9"  intercept 1 age85  5 grip9  0 sexMW 0 demNF 0 demNC 0;
ESTIMATE "Yhat for Age=90 Grip=12" intercept 1 age85  5 grip9  3 sexMW 0 demNF 0 demNC 0;
ODS OUTPUT Estimates=work.EstMainEffects; * Save ESTIMATEs to dataset for plotting;
RUN; QUIT; TITLE1; TITLE2;
```

SAS Eq 2.8: Main-Effects-Only GLM Predicting Cognition

Model Summary

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**5**	18385.97930	3677.19586	**41.75**	<.0001
Error	**544**	47910.55888	**88.07088**		
Corrected Total	549	66296.53818			

R-Square	Coeff Var	Root MSE	cognition Mean
0.277329	37.80790	9.384609	24.82182

Requested CONTRAST F-tests

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
DFnum=5 F-test for Model R2	5	18385.97930	3677.19586	**41.75**	<.0001 → is above
DFnum=2 F-test for Demgroup	2	11811.30155	5905.65077	**67.06**	<.0001 → is new

Model-Estimated Fixed Effects (normally is last)

Parameter	Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits		
Intercept	29.26432541	0.69850792	41.90	<.0001	27.89222232	30.63642850	**Beta0**
age85	-0.40573396	0.11889717	-3.41	0.0007	-0.63928775	-0.17218017	**Beta1**
grip9	0.60422556	0.14977568	4.03	<.0001	0.31001605	0.89843507	**Beta2**
sexMW	-3.65737421	0.89143262	-4.10	<.0001	-5.40844590	-1.90630252	**Beta3**
demNF	-5.72197100	1.01907848	-5.61	<.0001	-7.72378184	-3.72016016	**Beta4**
demNC	-16.47981327	1.52275357	-10.82	<.0001	-19.47101037	-13.48861616	**Beta5**

Interpret these fixed effects:

Intercept β_0 =

Slope for Age β_1 =

Slope for Grip Strength β_2 =

Slope for sexMW β_3 =

Slope for demNF β_4 =

Slope for demNC β_5 =

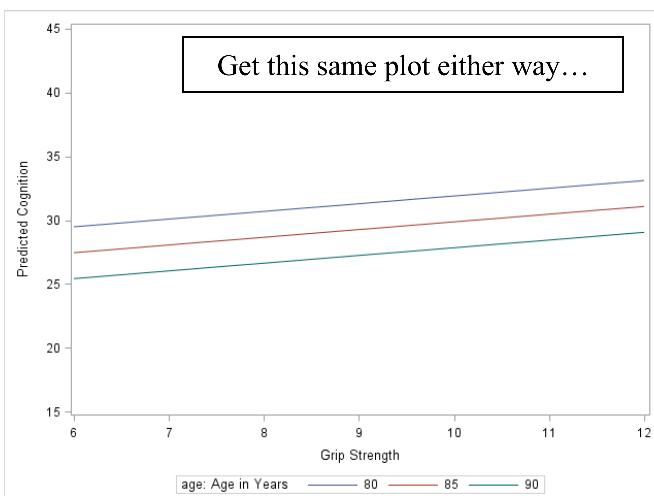
Requested ESTIMATE Linear Combinations of Model-Estimated Fixed Effects

Parameter	Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Mean Diff: Future vs Current	-10.7578423	1.70795708	-6.30	<.0001	-14.1128410	-7.4028435
Yhat for Age=80 Grip=6	29.4803185	1.15590606	25.50	<.0001	27.2097326	31.7509045
Yhat for Age=80 Grip=9	31.2929952	0.92090860	33.98	<.0001	29.4840228	33.1019676
Yhat for Age=80 Grip=12	33.1056719	0.87396571	37.88	<.0001	31.3889110	34.8224327
Yhat for Age=85 Grip=6	27.4516487	0.93731216	29.29	<.0001	25.6104543	29.2928432
Yhat for Age=85 Grip=9	29.2643254	0.69850792	41.90	<.0001	27.8922223	30.6364285
Yhat for Age=85 Grip=12	31.0770021	0.70785742	43.90	<.0001	29.6865335	32.4674707
Yhat for Age=90 Grip=6	25.4229789	1.06198691	23.94	<.0001	23.3368816	27.5090763
Yhat for Age=90 Grip=9	27.2356556	0.91355395	29.81	<.0001	25.4411302	29.0301810
Yhat for Age=90 Grip=12	29.0483323	0.97218055	29.88	<.0001	27.1386447	30.9580199

```
* Labeling saved ESTIMATES for use in plot;
* INDEX finds value in parentheses for that column;
DATA work.EstMainEffects; SET work.EstMainEffects;
     WHERE INDEX(Parameter,"Yhat")>0; * Only for predicted values;
     IF INDEX(Parameter,"Age=80")>0  THEN age=80;
     IF INDEX(Parameter,"Age=85")>0  THEN age=85;
     IF INDEX(Parameter,"Age=90")>0  THEN age=90;
     IF INDEX(Parameter,"Grip=6")>0  THEN grip=6;
     IF INDEX(Parameter,"Grip=9")>0  THEN grip=9;
     IF INDEX(Parameter,"Grip=12")>0 THEN grip=12; RUN;

* Plot ESTIMATES -- grip as X by age;
PROC SGPLOT DATA=work.EstMainEffects;
     SERIES x=grip y=Estimate / GROUP=age;
     XAXIS LABEL="Grip Strength" VALUES=(6 TO 12 BY 1);
     YAXIS LABEL="Predicted Cognition" VALUES=(15 TO 45 BY 5); RUN; QUIT;
```

SAS continued: Demonstrating how to get predicted outcomes using "fake people" and plot them

```
DATA work.FakePeople; * Create new blank data set;
* INPUT: list variables in order of entry, transformations happen to entered data;
  INPUT PersonID age grip sexMW demgroup;
* Center quantitative predictors;
  age85=age-85; grip9=grip-9;
* Create dummy-coded binary indicator predictors for dementia groups;
  demNF=.; demNC=.; * Create two new empty variables;
  IF demgroup=1 THEN DO; demNF=0; demNC=0; END; * Recode if demgroup=none;
  IF demgroup=2 THEN DO; demNF=1; demNC=0; END; * Recode if demgroup=future;
  IF demgroup=3 THEN DO; demNF=0; demNC=1; END; * Recode if demgroup=current;
* Enter data -- each row is a fake person for which to create a predicted outcome;
DATALINES;
-99 80  6  0  1
-99 80  9  0  1
-99 80 12  0  1
-99 85  6  0  1
-99 85  9  0  1
-99 85 12  0  1
-99 90  6  0  1
-99 90  9  0  1
-99 90 12  0  1
; RUN;

* Add fake people to real data;
DATA work.Example1;
SET work.FakePeople work.Example1;
RUN;
```



```
TITLE1 "SAS Main-Effects-Only GLM Predicting Cognition";
TITLE2 "Using dataset with fake people to get predicted outcomes as saved variable";
PROC GLM DATA=work.Example1 NAMELEN=100;
MODEL cognition = age85 grip9 sexMW demNF demNC / ALPHA=.05 CLPARM SOLUTION SS3;
* We are ignoring the extra effects we would normally request for dementia for now;
* Request columns of predicted outcome and SE for all cases for plotting;
  OUTPUT OUT=work.PredMain PREDICTED=Yhat STDP=SEyhat; RUN; QUIT; TITLE1; TITLE2;

* Plot saved predicted values for fake people -- grip as X by age;
PROC SGPLOT DATA=work.PredOutcomes; WHERE PersonID=-99; * Only for fake people;
     SERIES x=grip y=Yhat / GROUP=age;
     XAXIS LABEL="Grip Strength" VALUES=(6 TO 12 BY 1);
     YAXIS LABEL="Predicted Cognition" VALUES=(15 TO 45 BY 5); RUN; QUIT;
```

STATA Syntax and Output for Eq 2.8 Main-Effects-Only GLM Predicting Cognition:

Demonstrating how to get predicted outcomes using MARGINS statement and plot them

$$Cognition_i = \beta_0 + \beta_1(Age_i - 85) + \beta_2(Grip_i - 9) + \beta_3(SexMW_i) + \beta_4(DemNF_i) + \beta_5(DemNC_i) + e_i$$

Linear combination for difference of future vs current dementia:

$$(\beta_0 + \beta_5) - (\beta_0 + \beta_4) = \beta_5 - \beta_4$$

```
display "STATA Eq 2.8: Main-Effects-Only GLM Predicting Cognition"
regress cognition c.age85 c.grip9 c.sexmw c.demnf c.demnc, level(95)

// TEST lumps together fixed effects for joint tests -- indicate DFnum by ()
test (c.age85=0)(c.grip9=0)(c.sexmw=0)(c.demnf=0)(c.demnc=0) // DFnum=5 F-test for Model R2
test (c.demnf=0)(c.demnc=0)    // DFnum=2 Omnibus F-test for Demgroup

// LINCOM creates a single linear combination of fixed effects
lincom c.demnf*-1 + c.demnc*1 // Mean Diff: Future vs. Current = B5-B4

// Pred cognition outcomes holding sexmw=men, demnf=none, and demnc=none
   // one margins replaces 9 ESTIMATEs in SAS; vsquish compresses output empty lines
   // predictor=(from(by)to), c.=quantitative predictor
      margins, at(c.age85=(-5(5)5) c.grip9=(-3(3)3) c.sexmw=0 c.demnf=0 c.demnc=0) vsquish
   // Get and save plot of predicted outcomes
      marginsplot, xdimension(grip9) name(predicted_means, replace)
      graph export "$filesave\STATA plots\STATA Main-Effect-Only GLM Plot.png", replace
```

```
STATA Eq 2.8: Main-Effects-Only GLM Predicting Cognition
```

Model Summary

```
      Source |       SS           df       MS      Number of obs   =       550
-------------+----------------------------------   F(5, 544)       =     41.75
       Model |  18385.9793         5  3677.19586   Prob > F        =    0.0000
    Residual |  47910.5589       544  88.0708803   R-squared       =    0.2773
-------------+----------------------------------   Adj R-squared   =    0.2707
       Total |  66296.5382       549  120.758722   Root MSE        =    9.3846
```

Model-Estimated Fixed Effects

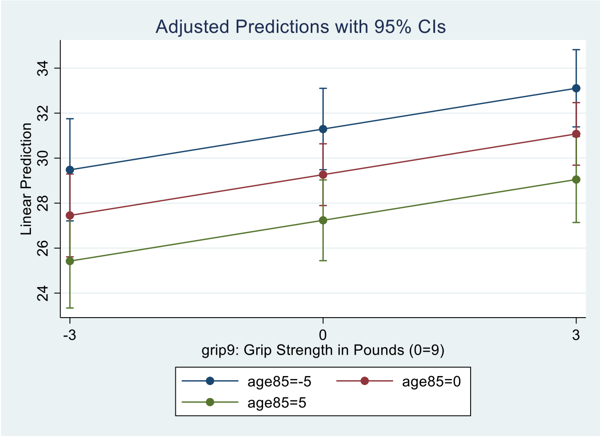
```
------------------------------------------------------------------------------
   cognition |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       age85 |   -.405734   .1188972    -3.41   0.001    -.6392878   -.1721802  Beta1
       grip9 |   .6042256   .1497757     4.03   0.000      .310016    .8984351  Beta2
       sexmw |  -3.657374   .8914326    -4.10   0.000    -5.408446   -1.906303  Beta3
       demnf |  -5.721971   1.019078    -5.61   0.000    -7.723782    -3.72016  Beta4
       demnc |  -16.47981   1.522754   -10.82   0.000    -19.47101   -13.48862  Beta5
       _cons |   29.26433   .6985079    41.90   0.000     27.89222    30.63643  Beta0 =LAST!
------------------------------------------------------------------------------
```

Requested TEST F-tests and LINCOM linear combinations of model-estimated fixed effects

```
.    test (c.age85=0)(c.grip9=0)(c.sexmw=0)(c.demnf=0)(c.demnc=0) // DFnum=5 F-test for
Model R2
 ( 1)  age85 = 0
 ( 2)  grip9 = 0
 ( 3)  sexmw = 0
 ( 4)  demnf = 0
 ( 5)  demnc = 0
       F(  5,   544) =   41.75
            Prob > F =    0.0000

.    test (c.demnf=0)(c.demnc=0)   // DFnum=2 F-test for Demgroup
 ( 1)  demnf = 0
 ( 2)  demnc = 0
       F(  2,   544) =   67.06
            Prob > F =    0.0000

.    lincom c.demnf*-1 + c.demnc*1 // Mean Diff: Future vs. Current = B5-B4
 ( 1)  - demnf + demnc = 0
------------------------------------------------------------------------------
   cognition |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |  -10.75784   1.707957    -6.30   0.000    -14.11284   -7.402844
------------------------------------------------------------------------------
```

Requested MARGINS for predicted outcomes
Although annoying that they are not labeled here, a long table preceded this MARGINS result that says what the predictor values are for each of these 9 predicted outcomes.

```
---------------------------------------------
             |            Delta-method
             |     Margin   Std. Err.      t
-------------+-------------------------------
   _at     1 |   29.48032   1.155906    25.50
           2 |     31.293   .9209086    33.98
           3 |   33.10567   .8739657    37.88
           4 |   27.45165   .9373122    29.29
           5 |   29.26433   .6985079    41.90
           6 |     31.077   .7078574    43.90
           7 |   25.42298   1.061987    23.94
           8 |   27.23566    .913554    29.81
           9 |   29.04833   .9721806    29.88
---------------------------------------------
```



R Syntax and Output for Eq 2.8 Main-Effects Only GLM Predicting Cognition:
Demonstrating how to get predicted outcomes using GLHT or fake people and plot them

$$Cognition_i = \beta_0 + \beta_1(Age_i - 85) + \beta_2(Grip_i - 9) + \beta_3(SexMW_i) + \beta_4(DemNF_i) + \beta_5(DemNC_i) + e_i$$

Linear combination for difference of future vs current dementia:

$$(\beta_0 + \beta_5) - (\beta_0 + \beta_4) = \beta_5 - \beta_4$$

```
print("R Eq 2.8: Main-Effects-Only GLM Predicting Cognition")
ModelMain = lm(data=Example1, formula=cognition~1+age85+grip9+sexMW+demNF+demNC)
summary(ModelMain); anova(ModelMain) # anova to get residual variance

print("Get DFnum=5 F-test of Model R2 for demonstration purposes")
MainFR2 = glht(model=ModelMain,
               linfct=c("age85=0","grip9=0","sexMW=0","demNF=0","demNC=0"))
summary(MainFR2, test=Ftest()) # ask for joint hypothesis test instead of separate
```

```
print("Get DFnum=2 F-test for demgroup") # Omnibus group main effect
mainFdem = glht(model=ModelMain, linfct=c("demNF=0","demNC=0"))
summary(mainFdem, test=Ftest()) # ask for joint hypothesis test instead of separate

print("Get missing demgroup difference: Future vs Current")
summary(glht(model=ModelMain, linfct=rbind(c(0,0,0,0,-1,1))),
        test=adjusted("none")) # Beta5-Beta4

print("Demonstrating how to get predicted outcomes using glht statements")
print("Pred cognition outcomes holding sexMW=men, demNF=none, and demNC=none")
summary(glht(model=ModelMain, linfct=rbind(
            "Yhat for Age=80 Grip=6"  = c(1,-5,-3, 0,0,0),  # in order of fixed effects
            "Yhat for Age=80 Grip=9"  = c(1,-5, 0, 0,0,0),
            "Yhat for Age=80 Grip=12" = c(1,-5, 3, 0,0,0),
            "Yhat for Age=85 Grip=6"  = c(1, 0,-3, 0,0,0),
            "Yhat for Age=85 Grip=9"  = c(1, 0, 0, 0,0,0),
            "Yhat for Age=85 Grip=12" = c(1, 0, 3, 0,0,0),
            "Yhat for Age=90 Grip=6"  = c(1, 5,-3, 0,0,0),
            "Yhat for Age=90 Grip=9"  = c(1, 5, 0, 0,0,0),
            "Yhat for Age=90 Grip=12" = c(1, 5, 3, 0,0,0))),test=adjusted("none"))
```

R Eq 2.8: Main-Effects-Only GLM Predicting Cognition

Model Summary and Model-Estimated Fixed Effects

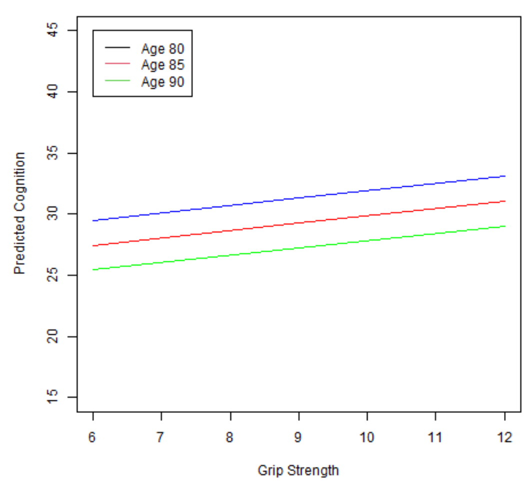
```
Residuals:
      Min         1Q    Median         3Q        Max 
-28.48699  -5.95656   0.11287   6.82997  20.54671 

Coefficients:
             Estimate Std. Error  t value  Pr(>|t|)    
(Intercept)  29.26433    0.69851  41.8955 < 2.2e-16 ***
age85        -0.40573    0.11890  -3.4125 0.0006917 ***
grip9         0.60423    0.14978   4.0342 6.263e-05 ***
sexMW        -3.65737    0.89143  -4.1028 4.707e-05 ***
demNF        -5.72197    1.01908  -5.6148 3.140e-08 ***
demNC       -16.47981    1.52275 -10.8224 < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9.3846 on 544 degrees of freedom
Multiple R-squared:  0.27733,     Adjusted R-squared:  0.27069 
F-statistic: 41.753 on 5 and 544 DF,  p-value: < 2.22e-16

Response: cognition
           Df  Sum Sq  Mean Sq  F value     Pr(>F)    
age85       1  1926.2  1926.18  21.8708 3.6833e-06 ***
grip9       1  3039.2  3039.17  34.5082 7.3976e-09 ***
sexMW       1  1609.3  1609.32  18.2731 2.2602e-05 ***
demNF       1  1496.1  1496.10  16.9875 4.3498e-05 ***
demNC       1 10315.2 10315.20 117.1239 < 2.22e-16 ***
Residuals 544 47910.6    88.07                        
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Requested GLHT F-tests and linear combinations of model-estimated fixed effects

```
Linear Hypotheses:
            Estimate
age85 == 0  -0.40573
grip9 == 0   0.60423
sexMW == 0  -3.65737
demNF == 0  -5.72197
demNC == 0 -16.47981
```

```
Global Test:
       F DF1 DF2      Pr(>F)
1 41.753   5 544 2.1562e-36

Linear Hypotheses:
           Estimate
demNF == 0   -5.722
demNC == 0  -16.480

Global Test:
       F DF1 DF2      Pr(>F)
1 67.056   2 544 9.3117e-27

Linear Hypotheses:
       Estimate Std. Error t value  Pr(>|t|)
1 == 0  -10.758      1.708 -6.2987 6.198e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Adjusted p values reported -- none method)
```

```
###### CREATING PREDICTED OUTCOMES USING FP = FAKE PEOPLE ######

# Create columns of values to be changed across fake people
FakeAge = c(80,80,80,85,85,85,90,90,90)
FakeGrip = c(6,9,12,6,9,12,6,9,12)
# Create dataset using just-created columns and constants for other model variables
FP = data.frame(PersonID=-99, age=FakeAge, grip=FakeGrip, sexMW=0, demgroup=1)
# Center quantitative predictors
FP$age85=FP$age-85
FP$grip9=FP$grip-9
# Create dummy-coded binary indicator predictors for dementia groups
FP$demNF=NA; FP$demNC=NA
# Demgroup=none
FP$demNF[which(FP$demgroup==1)]=0; FP$demNC[which(FP$demgroup==1)]=0
# Demgroup=future
FP$demNF[which(FP$demgroup==2)]=1; FP$demNC[which(FP$demgroup==2)]=0
# Demgroup=current
FP$demNF[which(FP$demgroup==3)]=0; FP$demNC[which(FP$demgroup==3)]=1

# Merge predicted values from main-effects-only model into FP data
FP = data.frame(FP, yhatmain=predict(object=ModelMain, newdata=FP))

# Make and save plot: open file, make plot, close file
png(file = "R Main-Effects-Only GLM Plot.png")
plot(y=FP$yhatmain, x=FP$grip, type="n",
     ylim=c(15,45), xlim=c(6,12),
     xlab="Grip Strength",
     ylab="Predicted Cognition")
lines(x=FP$grip[1:3], y=FP$yhatmain[1:3],
      type="l", col="blue1")
lines(x=FP$grip[4:6], y=FP$yhatmain[4:6],
      type="l", col="red1")
lines(x=FP$grip[7:9], y=FP$yhatmain[7:9],
      type="l", col="green1")
legend(x=6, y=45,
       legend=c("Age 80","Age 85","Age 90"),
       col=1:3, lty=1) #lty=linetype
dev.off()  # close file
```



SAS Syntax and Output: Eq 2.9 GLM Adding Age by Grip Strength Interaction

$$Cognition_i = \beta_0 + \beta_1(Age_i - 85) + \beta_2(Grip_i - 9) + \beta_3(SexMW_i) + \beta_4(DemNF_i) + \beta_5(DemNC_i) + \beta_6(Age_i - 85)(Grip_i - 9) + e_i$$

```
TITLE1 "SAS Eq 2.9: GLM Adding Age by Grip Strength Interaction";
TITLE2 "Using dataset with fake people to get predicted outcomes as saved variable";
* Estimate model on data with fake people to make predictions;
PROC GLM DATA=work.Example1 NAMELEN=100;
MODEL cognition = age85 grip9 sexMW demNF demNC age85*grip9
                       / ALPHA=.05 CLPARM SOLUTION SS3;
ESTIMATE "Mean Diff: Future vs Current" demNF -1 demNC 1; * Beta5-Beta4;
CONTRAST "DFnum=2 F-test for Demgroup"  demNF 1, demNC 1; * Omnibus group main effect;
CONTRAST "DFnum=3 F-test for age, grip, age*grip"  age85 1, grip9 1, age85*grip9 1;
* Request columns of predicted outcome and SE for all cases for plotting;
  OUTPUT OUT=work.PredAgeGrip PREDICTED=Yhat STDP=SEyhat;

* Simple slopes for age per grip, grip per age;
```

We can use the model equation to calculate the **simple age slope** at any *grip strength* (as the moderator):

Simple Age Slope = $\beta_1(Age_i - 85) + \beta_6(Age_i - 85)(Grip_i - 9)$

= $[\beta_1 + \beta_6(Grip_i - 9)]$ that multiplies $(Age_i - 85)$

```
ESTIMATE "Age Slope at Grip =  6" age85 1 age85*grip9 -3;
ESTIMATE "Age Slope at Grip =  9" age85 1 age85*grip9  0;
ESTIMATE "Age Slope at Grip = 12" age85 1 age85*grip9  3;
```

We can also use the model equation to calculate the **simple grip strength slope** at any *age* (as the moderator):

Simple Grip Slope = $\beta_2(Grip_i - 9) + \beta_6(Age_i - 85)(Grip_i - 9)$

= $[\beta_2 + \beta_6(Age_i - 85)]$ that multiplies $(Grip_i - 9)$

```
ESTIMATE "Grip Slope at Age = 80" grip9 1 age85*grip9 -5;
ESTIMATE "Grip Slope at Age = 85" grip9 1 age85*grip9  0;
ESTIMATE "Grip Slope at Age = 90" grip9 1 age85*grip9  5;
```

If you are using "fake people" then you do NOT also need to write these ESTIMATE statements.

```
* Pred cognition outcomes holding sexMW=men, demNF=none, and demNC=none;
  ESTIMATE "Yhat for Age=80 Grip=6"  intercept 1 age85 -5 grip9 -3 age85*grip9  15;
  ESTIMATE "Yhat for Age=80 Grip=9"  intercept 1 age85 -5 grip9  0 age85*grip9   0;
  ESTIMATE "Yhat for Age=80 Grip=12" intercept 1 age85 -5 grip9  3 age85*grip9 -15;
  ESTIMATE "Yhat for Age=85 Grip=6"  intercept 1 age85  0 grip9 -3 age85*grip9   0;
  ESTIMATE "Yhat for Age=85 Grip=9"  intercept 1 age85  0 grip9  0 age85*grip9   0;
  ESTIMATE "Yhat for Age=85 Grip=12" intercept 1 age85  0 grip9  3 age85*grip9   0;
  ESTIMATE "Yhat for Age=90 Grip=6"  intercept 1 age85  5 grip9 -3 age85*grip9 -15;
  ESTIMATE "Yhat for Age=90 Grip=9"  intercept 1 age85  5 grip9  0 age85*grip9   0;
  ESTIMATE "Yhat for Age=90 Grip=12" intercept 1 age85  5 grip9  3 age85*grip9  15;
RUN; TITLE1; TITLE2;
```

SAS Eq 2.9: GLM Adding Age by Grip Interaction

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**6**	19185.04106	3197.50684	**36.85**	<.0001
Error	**543**	47111.49712	**86.76150**		
Corrected Total	549	66296.53818			

R-Square	Coeff Var	Root MSE	cognition Mean
0.289382	37.52580	9.314586	24.82182

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
DFnum=2 F-test for Demgroup	2	11747.60589	5873.80294	**67.70**	<.0001
DFnum=3 F-test for age, grip, age*grip	3	3799.85696	1266.61899	**14.60**	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits		
Intercept	29.40780315	0.69490615	42.32	<.0001	28.04276953	30.77283677	**Beta0**
age85	-0.33396058	0.12035656	-2.77	0.0057	-0.57038207	-0.09753908	**Beta1**
grip9	0.61941863	0.14874241	4.16	<.0001	0.32723761	0.91159964	**Beta2**
sexMW	-3.45563720	0.88727488	-3.89	0.0001	-5.19854887	-1.71272552	**Beta3**
demNF	-5.92254309	1.01363159	-5.84	<.0001	-7.91366261	-3.93142358	**Beta4**
demNC	-16.30040485	1.51254730	-10.78	<.0001	-19.27156564	-13.32924405	**Beta5**
age85*grip9	0.12301848	0.04053626	3.03	0.0025	0.04339138	0.20264558	**Beta6**

Interpret these fixed effects:

Simple main effect of Age β_1 =

Simple main effect of Grip Strength β_2 =

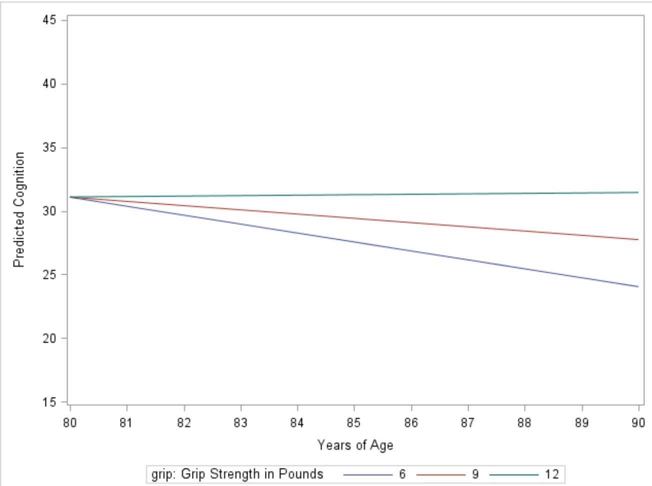
Interpret Age by Grip Strength β_6 → Age as Simple Slope, Grip as Moderator:

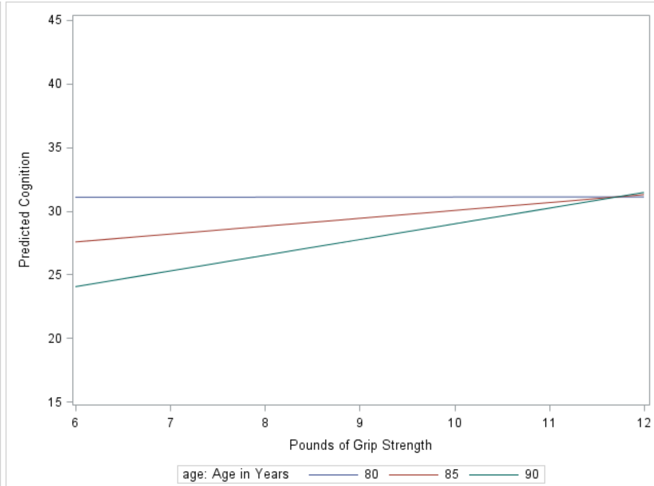
Interpret Age by Grip Strength β_6 → Grip as Simple Slope, Age as Moderator:

Table of Extra Requested Linear Combinations of Model-Estimated Fixed Effects

Parameter	Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Mean Diff: Future vs. Current	-10.3778618	1.69983087	-6.11	<.0001	-13.7169116	-7.0388119
Age Slope at Grip = 6	-0.7030160	0.15336958	-4.58	<.0001	-1.0042864	-0.4017456
Age Slope at Grip = 9	-0.3339606	0.12035656	-2.77	0.0057	-0.5703821	-0.0975391
Age Slope at Grip = 12	0.0350949	0.18715387	0.19	0.8513	-0.3325394	0.4027291
Grip Slope at Age = 80	0.0043262	0.24733508	0.02	0.9861	-0.4815246	0.4901770
Grip Slope at Age = 85	0.6194186	0.14874241	4.16	<.0001	0.3272376	0.9115996
Grip Slope at Age = 90	1.2345110	0.25540829	4.83	<.0001	0.7328017	1.7362204
Yhat for Age=80 Grip=6	31.0646273	1.26047290	24.65	<.0001	28.5886270	33.5406277
Yhat for Age=80 Grip=9	31.0776060	0.91678862	33.90	<.0001	29.2767193	32.8784928
Yhat for Age=80 Grip=12	31.0905847	1.09240761	28.46	<.0001	28.9447221	33.2364473
Yhat for Age=85 Grip=6	27.5495473	0.93087754	29.60	<.0001	25.7209850	29.3781095
Yhat for Age=85 Grip=9	29.4078031	0.69490615	42.32	<.0001	28.0427695	30.7728368
Yhat for Age=85 Grip=12	31.2660590	0.70533225	44.33	<.0001	29.8805450	32.6515731
Yhat for Age=90 Grip=6	24.0344672	1.14908030	20.92	<.0001	21.7772801	26.2916544
Yhat for Age=90 Grip=9	27.7380003	0.92172276	30.09	<.0001	25.9274212	29.5485794
Yhat for Age=90 Grip=12	31.4415333	1.24617867	25.23	<.0001	28.9936117	33.8894549

```
* Plot saved predicted values for fake people -- age as X;
PROC SGPLOT DATA=work.PredAgeGrip; WHERE PersonID=-99; * Only for fake people;
     SERIES x=age y=Yhat / GROUP=grip;
     XAXIS LABEL="Years of Age" VALUES=(80 TO 90 BY 1);
     YAXIS LABEL="Predicted Cognition" VALUES=(15 TO 45 BY 5); RUN; QUIT;

* Plot saved predicted values for fake people -- grip as X;
PROC SGPLOT DATA=work.PredAgeGrip; WHERE PersonID=-99; * Only for fake people;
     SERIES x=grip y=Yhat / GROUP=age;
     XAXIS LABEL="Pounds of Grip Strength" VALUES=(6 TO 12 BY 1);
     YAXIS LABEL="Predicted Cognition" VALUES=(15 TO 45 BY 5); RUN; QUIT;
```





STATA Syntax: Eq 2.9 GLM Adding Age by Grip Strength Interaction

$$\boldsymbol{Cognition_i} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}(\boldsymbol{Age_i} - \mathbf{85}) + \boldsymbol{\beta_2}(\boldsymbol{Grip_i} - \mathbf{9}) + \boldsymbol{\beta_3}(\boldsymbol{SexMW_i}) + \boldsymbol{\beta_4}(\boldsymbol{DemNF_i}) + \boldsymbol{\beta_5}(\boldsymbol{DemNC_i}) + \boldsymbol{\beta_6}(\boldsymbol{Age_i} - \mathbf{85})(\boldsymbol{Grip_i} - \mathbf{9}) + \boldsymbol{e_i}$$

```
display "STATA Eq 2.9: GLM Adding Age by Grip Strength Interaction"
regress cognition c.age85 c.grip9 c.sexmw c.demnf c.demnc c.age85#c.grip9, level(95)
  lincom c.demnf*-1 + c.demnc*1 // Mean Diff: Future vs. Current = Beta5-Beta4
  test (c.demnf=0)(c.demnc=0)   // DFnum=2 Omnibus F-test for main effect of demgroup
  test (c.age85=0)(c.grip9=0)(c.age85#c.grip9=0) // DFnum=3 F-test for age, grip, age*grip
// Simple slopes for age per grip, grip per age
```

We can use the model equation to calculate the **simple age slope** at any *grip strength* (as the moderator):

Simple Age Slope = $\boldsymbol{\beta_1}(\boldsymbol{Age_i} - \mathbf{85}) + \boldsymbol{\beta_6}(\boldsymbol{Age_i} - \mathbf{85})(\boldsymbol{Grip_i} - \mathbf{9})$

= $[\boldsymbol{\beta_1} + \boldsymbol{\beta_6}(\boldsymbol{Grip_i} - \mathbf{9})]$ that multiplies $(\boldsymbol{Age_i} - \mathbf{85})$

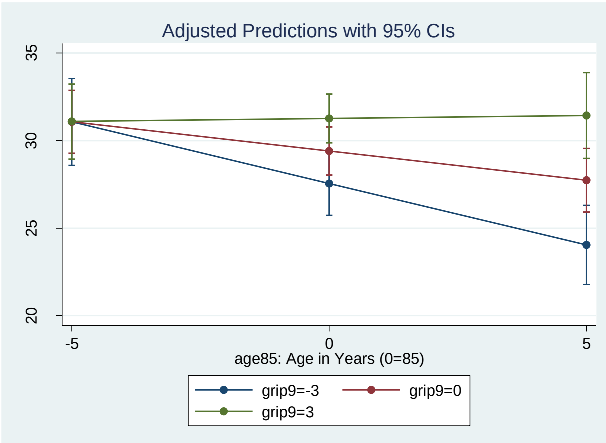
```
   lincom c.age85*1 + c.age85#c.grip9*-3  // Age Slope at Grip =  6
   lincom c.age85*1 + c.age85#c.grip9*0   // Age Slope at Grip =  9
   lincom c.age85*1 + c.age85#c.grip9*3   // Age Slope at Grip = 12
// dydx in margins provides simple slopes for that variable by (from(by)to) moderator
   margins, at(c.grip9=(-3(3)3)) dydx(c.age85) vsquish // Age Slope per Grip
```

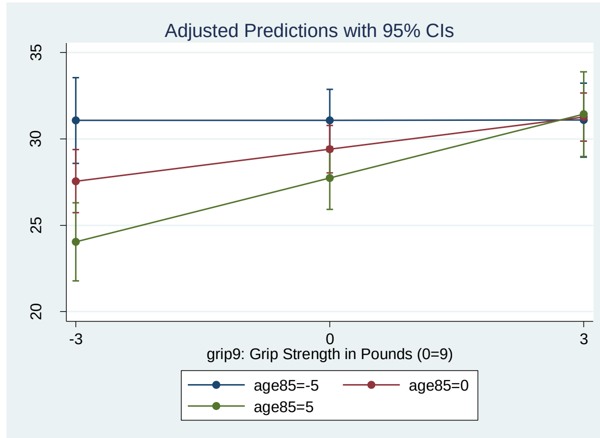
We can also use the model equation to calculate the **simple grip strength slope** at any *age* (as the moderator):

Simple Grip Slope = $\boldsymbol{\beta_2}(\boldsymbol{Grip_i} - \mathbf{9}) + \boldsymbol{\beta_6}(\boldsymbol{Age_i} - \mathbf{85})(\boldsymbol{Grip_i} - \mathbf{9})$

= $[\boldsymbol{\beta_2} + \boldsymbol{\beta_6}(\boldsymbol{Age_i} - \mathbf{85})]$ that multiplies $(\boldsymbol{Grip_i} - \mathbf{9})$

```
   lincom c.grip9*1 + c.age85#c.grip9*-5  // Grip Slope at Age = 80
   lincom c.grip9*1 + c.age85#c.grip9*0   // Grip Slope at Age = 85
   lincom c.grip9*1 + c.age85#c.grip9*5   // Grip Slope at Age = 90
// dydx in margins provides simple slopes for that variable by (from(by)to) moderator
   margins, at(c.age85=(-5(5)5)) dydx(c.grip9) vsquish // Grip per Age

// one margins replaces 8 ESTIMATEs in SAS; vsquish compresses output empty lines
// predictor=(from(by)to), c.=quantitative predictor
   margins, at(c.age85=(-5(5)5) c.grip9=(-3(3)3) c.sexmw=0 c.demnf=0 c.demnc=0) vsquish
   marginsplot, xdimension(age85)    // Get and save plot for pred outcomes by age
   graph export "$filesave\STATA plots\STATA Grip by Age=x GLM Plot.png", replace
   marginsplot, xdimension(grip9)    // Get and save plot for pred outcomes by grip
   graph export "$filesave\STATA plots\STATA Age by Grip=x GLM Plot.png", replace
```





R Syntax: Eq 2.9 GLM Adding Age by Grip Strength Interaction

$$Cognition_i = \beta_0 + \beta_1(Age_i - 85) + \beta_2(Grip_i - 9) + \beta_3(SexMW_i) + \beta_4(DemNF_i) + \beta_5(DemNC_i) + \beta_6(Age_i - 85)(Grip_i - 9) + e_i$$

```
print("R Eq 2.9: GLM Adding Age by Grip Strength Interaction")
ModelAgeGrip = lm(data=Example1, formula=cognition~1+age85+grip9+sexMW+demNF+demNC
                                           +age85:grip9)
summary(ModelAgeGrip); anova(ModelAgeGrip) # anova to get residual variance

print("Get missing demgroup difference: Future vs Current")
summary(glht(model=ModelAgeGrip, linfct=rbind(c(0,0,0,0,-1,1)))) # Beta5-Beta4

print("Get DFnum=2 F-test for demgroup") # Omnibus group main effect
AgeGripFdem = glht(model=ModelAgeGrip,linfct=c("demNF=0","demNC=0"))
summary(AgeGripFdem, test=Ftest()) # ask for joint hypothesis test instead of separate

print("Get DFnum=3 F-test for age, grip, and age*grip")
AgeGripF = glht(model=ModelAgeGrip, linfct=c("age85=0","grip9=0","age85:grip9=0"))
summary(AgeGripF, test=Ftest()) # ask for joint hypothesis test instead of separate
```

We can use the model equation to calculate the **simple age slope** at any *grip strength* (as the moderator):

Simple Age Slope = $\beta_1(Age_i - 85) + \beta_6(Age_i - 85)(Grip_i - 9)$

= $[\beta_1 + \beta_6(Grip_i - 9)]$ that multiplies $(Age_i - 85)$

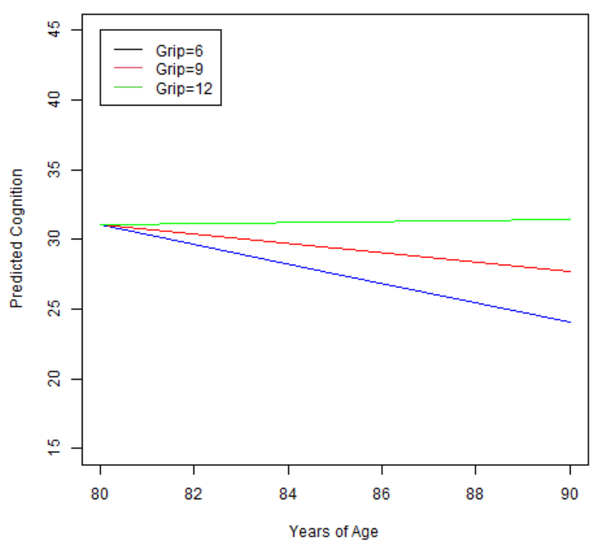
We can also use the model equation to calculate the **simple grip strength slope** at any *age* (as the moderator):

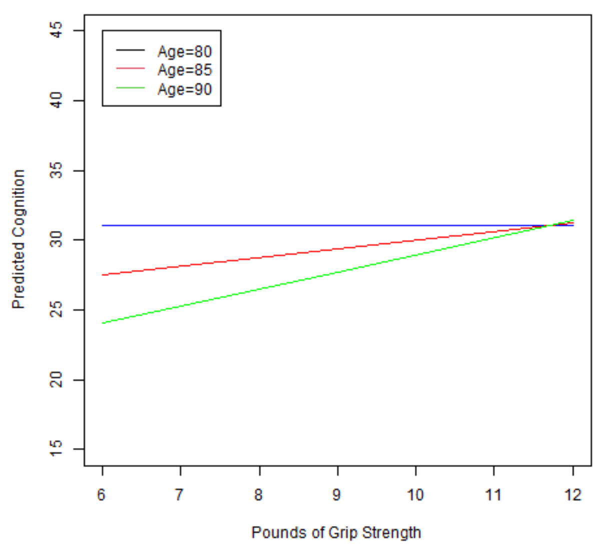
Simple Grip Slope = $\beta_2(Grip_i - 9) + \beta_6(Age_i - 85)(Grip_i - 9)$

= $[\beta_2 + \beta_6(Age_i - 85)]$ that multiplies $(Grip_i - 9)$

```
print("Simple slopes for age per grip, grip per age")
summary(glht(model=ModelAgeGrip, linfct=rbind(
           "Age Slope at Grip = 6"  = c(0,1,0,0,0,0,-3),  # in order of fixed effects
           "Age Slope at Grip = 9"  = c(0,1,0,0,0,0, 0),
           "Age Slope at Grip = 12" = c(0,1,0,0,0,0, 3),
           "Grip Slope at Age = 80" = c(0,0,1,0,0,0,-5),
           "Grip Slope at Age = 85" = c(0,0,1,0,0,0, 0),
           "Grip Slope at Age = 90" = c(0,0,1,0,0,0, 5))),test=adjusted("none"))
print("Simple slopes over range of moderator values using reghelper package")
simple_slopes(model=ModelAgeGrip, levels=list(age85=c(-5,0,5,'sstest'),
                                              grip9=c(-3,0,3,'sstest')))
```

```
# If you are NOT using fake people, you have to write these to create predicted outcomes
print("Pred cognition outcomes holding sexMW=men, demNF=none, and demNC=none")
summary(glht(model=ModelAgeGrip, linfct=rbind(
            "Yhat for Age=80 Grip=6"  = c(1,-5,-3, 0,0,0, 15),  # in order of fixed effects
            "Yhat for Age=80 Grip=9"  = c(1,-5, 0, 0,0,0,  0),
            "Yhat for Age=80 Grip=12" = c(1,-5, 3, 0,0,0,-15),
            "Yhat for Age=85 Grip=6"  = c(1, 0,-3, 0,0,0,  0),
            "Yhat for Age=85 Grip=9"  = c(1, 0, 0, 0,0,0,  0),
            "Yhat for Age=85 Grip=12" = c(1, 0, 3, 0,0,0,  0),
            "Yhat for Age=90 Grip=6"  = c(1, 5,-3, 0,0,0, -15),
            "Yhat for Age=90 Grip=9"  = c(1, 5, 0, 0,0,0,  0),
            "Yhat for Age=90 Grip=12" = c(1, 5, 3, 0,0,0,  15))),test=adjusted("none"))

# Merge predicted values from age*grip model into FP data
FP = data.frame(FP, yhatAgeGrip=predict(object=ModelAgeGrip, newdata=FP))

# Make and save plots
png(file = "R Grip by Age=x GLM Plot.png")  # open file
plot(y=FP$yhatAgeGrip, x=FP$age, type="n", ylim=c(15,45), xlim=c(80,90),
     xlab="Years of Age", ylab="Predicted Cognition")
FP = sort_asc(data=FP,grip) # 3 rows per grip
lines(x=FP$age[1:3], y=FP$yhatAgeGrip[1:3], type="l", col="blue1")
lines(x=FP$age[4:6], y=FP$yhatAgeGrip[4:6], type="l", col="red1")
lines(x=FP$age[7:9], y=FP$yhatAgeGrip[7:9], type="l", col="green1")
legend(x=80, y=45, legend = c("Grip=6", "Grip=9", "Grip=12"), col=1:3, lty=1) #lty=linetype
dev.off()  # close file

png(file = "R Age by Grip=x GLM Plot.png")  # open file
plot(y=FP$yhatAgeGrip, x=FP$grip, type="n", ylim=c(15,45), xlim=c(6,12),
     xlab="Pounds of Grip Strength", ylab="Predicted Cognition")
FP = sort_asc(data=FP,age) # 3 rows per age now
lines(x=FP$grip[1:3], y=FP$yhatAgeGrip[1:3], type="l", col="blue1")
lines(x=FP$grip[4:6], y=FP$yhatAgeGrip[4:6], type="l", col="red1")
lines(x=FP$grip[7:9], y=FP$yhatAgeGrip[7:9], type="l", col="green1")
legend(x=6, y=45, legend = c("Age=80", "Age=85", "Age=90"), col=1:3, lty=1) #lty=linetype
dev.off()  # close file
```





Bonus: Regions of Significance for the Age*Grip Interaction

To get all the information needed to calculate regions of significance for the age*grip interaction, we need to change to SAS PROC MIXED, which does GLMs but has many other options, including COVB for the asymptotic covariance matrix of the fixed effects, in which the diagonal is their squared standard errors, and the off-diagonals give the covariances among their SEs. COVB is provided in STATA as "estat vce" after estimating a model with fixed effects (as given in the STATA syntax below).

```
TITLE1 "SAS Eq 2.9: GLM Adding Age by Grip Interaction in MIXED to Get COVB";
* Estimate model on data with fake people to make predictions;
PROC MIXED DATA=work.Example1 COVTEST NOCLPRINT NAMELEN=100 METHOD=REML;
     MODEL cognition = age85 grip9 sexMW demNF demNC age85*grip9 / SOLUTION DDFM=BW COVB;
     * Saving info for regions to datasets: fixed effects and COVB;
     ODS OUTPUT SolutionF=FixAgeGrip COVB=CovBAgeGrip;
RUN; TITLE1;

display "STATA Eq 2.9: GLM with Age by Grip Interaction adding VCE for regions"
regress cognition c.age85 c.grip9 c.sexmw c.demnf c.demnc c.age85#c.grip9, level(95)
  estat vce  // Asymptotic covariance matrix of fixed effects for regions
```

From COVB using SAS MIXED instead of GLM (bolded values needed for %*regions* macro):

Covariance Matrix for Fixed Effects

Row	Effect	Col1	Col2	Col3	Col4	Col5	Col6	Col7
1	Intercept	0.4829	0.000454	-0.03075	-0.4507	-0.1820	-0.2263	0.001916
2	age85	0.000454	**0.01449**	0.003317	0.005024	-0.00413	-0.00115	0.000959
3	grip9	-0.03075	0.003317	**0.02212**	0.05374	-0.01339	-0.00030	0.000203
4	sexMW	-0.4507	0.005024	0.05374	0.7873	-0.07102	0.02371	0.002695
5	demNF	-0.1820	-0.00413	-0.01339	-0.07102	1.0274	0.2129	-0.00268
6	demNC	-0.2263	-0.00115	-0.00030	0.02371	0.2129	2.2878	0.002396
7	age85*grip9	0.001916	**0.000959**	**0.000203**	0.002695	-0.00268	0.002396	**0.001643**

See excel sheet for calculations, as provided by the SAS macro %Regions below:

```
* Call SAS macro for regions of significance for main effects of interaction;
%Regions(FixData=FixAgeGrip, CovBData=CovBAgeGrip, Pred=age85, Mod=grip9,
         ModCenter=9, Interact=age85*grip9, Order=6)
```

```
Regions of significance for age85*grip9 interaction:
The age85 slope will be significant at centered values of grip9 BELOW the lower bound
and ABOVE the upper bound, which translate to these uncentered lower and upper bounds.

Centered     Centered     Uncentered     Uncentered
  Lower        Upper        Lower          Upper
 0.66541      9.52041      9.66541        18.5204
```

So the age slope will be significantly negative below grip = 9.67 pounds, nonsignificant between grip = 9.67 and 18.52 pounds, and significantly positive after grip = 18.52 pounds.

```
* Call SAS macro for regions of significance for main effects of interaction;
%Regions(FixData=FixAgeGrip, CovBData=CovBAgeGrip, Pred=grip9, Mod=age85,
         ModCenter=85, Interact=age85*grip9, Order=6);
```

```
Regions of significance for age85*grip9 interaction:
The grip9 slope will be significant at centered values of age85 BELOW the lower bound
and ABOVE the upper bound, which translate to these uncentered lower and upper bounds.

Centered     Centered     Uncentered     Uncentered
  Lower        Upper        Lower          Upper
-14.8174     -2.28519      70.1826        82.7148
```

So the grip strength slope will be significantly negative below age = 70.19 years, nonsignificant between age = 70.19 and 82.71 years, and significantly positive after age = 82.71 years.

R has several routines that will compute regions of significance, such as this one:

```
print("Regions of significance using interactions package") # plots broke my computer
johnson_neyman(model=ModelAgeGrip, pred="age85", modx="grip9", digits=3, plot=FALSE)
johnson_neyman(model=ModelAgeGrip, pred="grip9", modx="age85", digits=3, plot=FALSE)

JOHNSON-NEYMAN INTERVAL
When grip9 is OUTSIDE the interval [0.665, 9.521], the slope of age85 is p < .05.
Note: The range of observed values of grip9 is [-9.000, 10.000]

JOHNSON-NEYMAN INTERVAL
When age85 is OUTSIDE the interval [-14.873, -2.281], the slope of grip9 is p < .05.
Note: The range of observed values of age85 is [-4.984, 11.967]
```

<u>Equation 2.13, adding sex*dementia interaction:</u>

$$\boldsymbol{Cognition_i = \beta_0 + \beta_1(Age_i - 85) + \beta_2(Grip_i - 9)}$$
$$\boldsymbol{+\beta_3(SexMW_i) + \beta_4(DemNF_i) + \beta_5(DemNC_i)}$$
$$\boldsymbol{+\beta_6(Age_i - 85)(Grip_i - 9)}$$
$$\boldsymbol{+\beta_7(SexMW_i)(DemNF_i)}$$
$$\boldsymbol{+\beta_8(SexMW_i)(DemNC_i) + e_i}$$

Dementia Group	Men	Women	Marginal Mean
None	29.07	26.20	27.63
Future	23.01	20.30	21.66
Current	17.10	6.35	11.72
Marginal Mean	23.03	17.62	σ_e^2 = 85.97

We can use the model equation to calculate the **simple sex slope** for any *dementia group* (as the moderator):

Simple Sex Slope = $\boldsymbol{\beta_3(SexMW_i) + \beta_7(SexMW_i)(DemNF_i) + \beta_8(SexMW_i)(DemNC_i)}$
= $[\boldsymbol{\beta_3 + \beta_7(DemNF_i) + \beta_8(DemNC_i)}]$ that multiplies $(\boldsymbol{SexMW_i})$

We can use the model equation to calculate the **simple dementia slope** for any *sex* (as the moderator):

Simple None vs. Future Slope = $\boldsymbol{\beta_4(DemNF_i) + \beta_7(SexMW_i)(DemNF_i)}$
= $[\boldsymbol{\beta_4 + \beta_7(SexMW_i)}]$ that multiplies $(\boldsymbol{DemNF_i})$

Simple None vs. Current Slope = $\boldsymbol{\beta_5(DemNC_i) + \beta_8(SexMW_i)(DemNC_i)}$
= $[\boldsymbol{\beta_5 + \beta_8(SexMW_i)}]$ that multiplies $(\boldsymbol{DemNC_i})$

Simple Future vs. Current Slope = $[\boldsymbol{\beta_5 + \beta_8(SexMW_i)}] - [\boldsymbol{\beta_4 + \beta_7(SexMW_i)}]$

SAS Syntax and Output: GLM Adding Sex by Dementia Group Interaction (see code online for plotting with a new set of fake people)

```
TITLE1 "SAS Eq 2.13: GLM Adding Sex by Dementia Group Interaction";
TITLE2 "Dummy-Coded Predictors for Sex (0=Men) and Demgroup (0=None)";
PROC GLM DATA=work.Example1 NAMELEN=100;
MODEL cognition = age85 grip9 sexMW demNF demNC age85*grip9
                  sexMW*demNF sexMW*demNC / ALPHA=.05 CLPARM SOLUTION SS3;
CONTRAST "Omnibus DF=2 F-test for Sex*Demgroup Interaction"  sexMW*demNF 1, sexMW*demNC 1;
* In CONTRASTs below, linear combinations are created within a comma set (still 1 DF);
CONTRAST "Omnibus DF=2 F-test for Dementia Simple Main Effect for Men"
         demNF 1 sexMW*demNF 0, demNC 1 sexMW*demNC 0;
CONTRAST "Omnibus DF=2 F-test for Dementia Simple Main Effect for Women"
         demNF 1 sexMW*demNF 1, demNC 1 sexMW*demNC 1;
* Request columns of predicted outcome and SE for all cases for plotting;
OUTPUT OUT=work.PredSexDem PREDICTED=Yhat STDP=SEyhat;
```

```
* Predicted cognition outcomes --adjusted cell means-- holding age=85 and grip=9;
ESTIMATE "Yhat for Men   None"       intercept 1 sexMW 0 demNF  0 demNC 0 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "Yhat for Women None"       intercept 1 sexMW 1 demNF  0 demNC 0 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "Yhat for Men   Future"     intercept 1 sexMW 0 demNF  1 demNC 0 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "Yhat for Women Future"     intercept 1 sexMW 1 demNF  1 demNC 0 sexMW*demNF  1 sexMW*demNC 0;
ESTIMATE "Yhat for Men   Current"    intercept 1 sexMW 0 demNF  0 demNC 1 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "Yhat for Women Current"    intercept 1 sexMW 1 demNF  0 demNC 1 sexMW*demNF  0 sexMW*demNC 1;

* DF=1 simple slopes for sex per demgroup;
ESTIMATE "Sex Diff for None"                     sexMW 1 demNF  0 demNC 0 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "Sex Diff for Future"                   sexMW 1 demNF  0 demNC 0 sexMW*demNF  1 sexMW*demNC 0;
ESTIMATE "Sex Diff for Current"                  sexMW 1 demNF  0 demNC 0 sexMW*demNF  0 sexMW*demNC 1;

* DF=1 simple slopes for demgroup per sex;
ESTIMATE "None-Future Diff for Men"              sexMW 0 demNF  1 demNC 0 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "None-Future Diff for Women"            sexMW 0 demNF  1 demNC 0 sexMW*demNF  1 sexMW*demNC 0;
ESTIMATE "None-Current Diff for Men"             sexMW 0 demNF  0 demNC 1 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "None-Current Diff for Women"           sexMW 0 demNF  0 demNC 1 sexMW*demNF  0 sexMW*demNC 1;
ESTIMATE "Future-Current Diff for Men"           sexMW 0 demNF -1 demNC 1 sexMW*demNF  0 sexMW*demNC 0;
ESTIMATE "Future-Current Diff for Women"         sexMW 0 demNF -1 demNC 1 sexMW*demNF -1 sexMW*demNC 1;

* DF=1 differences in simple slopes = interactions;
ESTIMATE "A: Sex Effect differ btw None and Future?"                    sexMW*demNF  1 sexMW*demNC 0;
ESTIMATE "A: None-Future Effect differ btw Men and Women?"              sexMW*demNF  1 sexMW*demNC 0;
ESTIMATE "B: Sex Effect differ btw None and Current?"                   sexMW*demNF  0 sexMW*demNC 1;
ESTIMATE "B: None-Current Effect differ btw Men and Women?"             sexMW*demNF  0 sexMW*demNC 1;
ESTIMATE "C: Sex Effect differ btw Future and Current?"                 sexMW*demNF -1 sexMW*demNC 1;
ESTIMATE "C: Future-Current Effect differ btw Men and Women?"           sexMW*demNF -1 sexMW*demNC 1;
RUN; QUIT; TITLE1; TITLE2;
```

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**8**	19785.46147	2473.18268	**28.77**	<.0001
Error	**541**	46511.07671	**85.97242**		
Corrected Total	549	66296.53818			

R-Square	Coeff Var	Root MSE	cognition Mean
0.298439	37.35476	9.272131	24.82182

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Omnibus DF=2 Dementia*Sex Interaction Test	2	600.420410	300.210205	3.49	0.0311
Omnibus DF=2 Dementia Simple Main Effect for Men	2	3213.270817	1606.635408	18.69	<.0001
Omnibus DF=2 Dementia Simple Main Effect for Women	2	9140.125913	4570.062957	53.16	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits		
Intercept	29.07014634	0.74849920	38.84	<.0001	27.59982548	30.54046719	**Beta0**
age85	-0.33479877	0.11988755	-2.79	0.0054	-0.57030091	-0.09929663	**Beta1**
grip9	0.61789286	0.14807943	4.17	<.0001	0.32701175	0.90877397	**Beta2**
sexMW	-2.87559408	1.01123720	-2.84	0.0046	-4.86202658	-0.88916158	**Beta3**
demNF	-6.05590147	1.63512607	-3.70	0.0002	-9.26787546	-2.84392748	**Beta4**
demNC	-11.97073055	2.24495370	-5.33	<.0001	-16.38062470	-7.56083640	**Beta5**
age85*grip9	0.12215159	0.04035286	3.03	0.0026	0.04288410	0.20141909	**Beta6**
sexMW*demNF	0.16426999	2.07047524	0.08	0.9368	-3.90288588	4.23142586	**Beta7**
sexMW*demNC	-7.87509954	3.02453647	-2.60	0.0095	-13.81637383	-1.93382526	**Beta8**

Interpret these fixed effects:

Simple main effect of Sex β_3 =

Simple main effect of Dem None vs Future β_4 =

Simple main effect of Dem None vs Current β_5 =

Interpret Sex by DemNF β_7 → Sex as Simple Effect, DemNF as Moderator:

Interpret Sex by DemNC β_8 → Sex as Simple Effect, DemNC as Moderator:

Interpret Sex by DemNF β_7 → DemNF as Simple Effect, Sex as Moderator:

Interpret Sex by DemNC β_8 → DemNC as Simple Effect, Sex as Moderator:

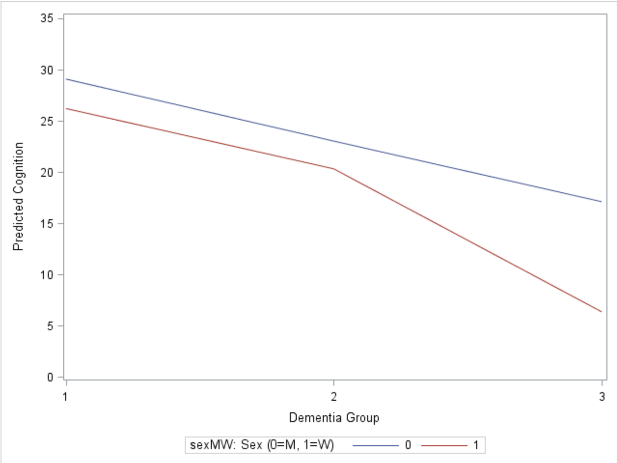
Parameter	Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Adjusted cell means (for age=85 and grip=9)						
Yhat for Men None	29.0701463	0.74849920	38.84	<.0001	27.5998255	30.5404672
Yhat for Women None	26.1945523	0.63883397	41.00	<.0001	24.9396532	27.4494513
Yhat for Men Future	23.0142449	1.49276013	15.42	<.0001	20.0819286	25.9465611
Yhat for Women Future	20.3029208	1.11863329	18.15	<.0001	18.1055238	22.5003177
Yhat for Men Current	17.0994158	2.14021810	7.99	<.0001	12.8952599	21.3035717
Yhat for Women Current	6.3487222	1.94788049	3.26	0.0012	2.5223863	10.1750580
DF=1 simple effects of sex per dementia group						
Sex Difference for No Dementia	-2.8755941	1.01123720	-2.84	0.0046	-4.8620266	-0.8891616
Sex Difference for Future Dementia	-2.7113241	1.87406883	-1.45	0.1485	-6.3926673	0.9700192
Sex Difference for Current Dementia	-10.7506936	2.89932314	-3.71	0.0002	-16.4460040	-5.0553832
DF=1 simple effects of dementia group per sex						
None-Future Difference for Men	-6.0559015	1.63512607	-3.70	0.0002	-9.2678755	-2.8439275
None-Future Difference for Women	-5.8916315	1.27776082	-4.61	<.0001	-8.4016120	-3.3816510
None-Current Difference for Men	-11.9707305	2.24495370	-5.33	<.0001	-16.3806247	-7.5608364
None-Current Difference for Women	-19.8458301	2.02858306	-9.78	<.0001	-23.8306947	-15.8609655
Future-Current Difference for Men	-5.9148291	2.58676242	-2.29	0.0226	-10.9961581	-0.8335000
Future-Current Difference for Women	-13.9541986	2.23891711	-6.23	<.0001	-18.3522347	-9.5561625
DF=1 differences in simple effects = interactions						
A: Sex Effect differ btw None and Future?	0.1642700	2.07047524	0.08	0.9368	-3.9028859	4.2314259
A: None-Future Effect differ btw Men and Women?	0.1642700	2.07047524	0.08	0.9368	-3.9028859	4.2314259
B: Sex Effect differ btw None and Current?	-7.8750995	3.02453647	-2.60	0.0095	-13.8163738	-1.9338253
B: None-Current Effect differ btw Men and Women?	-7.8750995	3.02453647	-2.60	0.0095	-13.8163738	-1.9338253
C: Sex Effect differ btw Future and Current?	-8.0393695	3.41516478	-2.35	0.0189	-14.7479779	-1.3307612
C: Future-Current Effect differ btw Men and Women?	-8.0393695	3.41516478	-2.35	0.0189	-14.7479779	-1.3307612

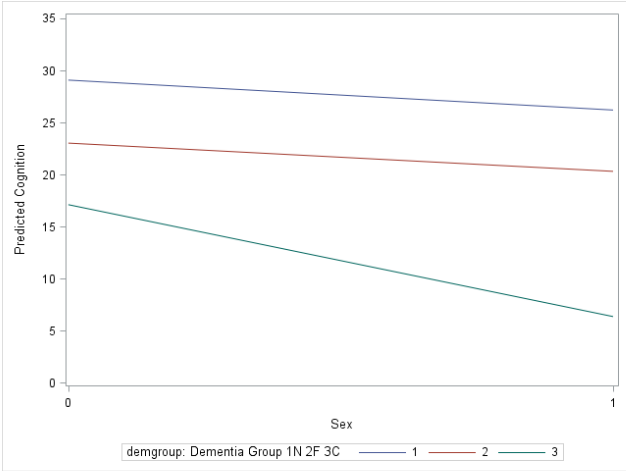
Values in gray italics are typical marginal ANOVA results (that are useless)…

Dementia Group Means	Men Mean	Women Mean	*MARGINAL MEAN*	Sex Difference
None Mean	29.07	26.20	*27.63*	−2.87 (*p*=.0046)
Future Mean	23.01	20.30	*21.66*	−2.71 (*p*=.1485)
Current Mean	17.10	6.35	*11.72*	−10.75 (*p*=.0002)
MARGINAL	*23.03*	*17.62*		*−5.45 (p<.0001)*
Dementia Group Differences	**Men Diff**	**Women Diff**	***MARGINAL DIFF***	**Simple Effect Difference**
None-Future Diff	−6.06 (*p*=.0002)	−5.90 (*p*<.0001)	*−5.97 (p<.0001)*	A =0.16 (*p*=.9368)
None-Current Diff	−11.97 (*p*<.0001)	−19.85 (*p*<.0001)	*−15.91 (p<.0001)*	B= −7.88 (*p*=.0095)
Future-Current Diff	−5.91 (*p*=.0226)	−13.95 (*p*<.0001)	*−9.93 (p<.0001)*	C= −8.04 (*p*=.0189)

```
* Plot saved predicted values for fake people -- dementia as X;
PROC SGPLOT DATA=work.PredSexDem;
     WHERE PersonID=-98; * Only for new fake people;
     SERIES x=demgroup y=Yhat / GROUP=sexMW;
     XAXIS LABEL="Dementia Group" VALUES=(1 TO 3 BY 1);
```

```
     YAXIS LABEL="Predicted Cognition" VALUES=(0 TO 35 BY 5);
RUN; QUIT;

* Plot saved predicted values for fake people -- sex as X;
PROC SGPLOT DATA=work.PredSexDem;
     WHERE PersonID=-98; * Only for new fake people;
     SERIES x=sexMW y=Yhat / GROUP=demgroup;
     XAXIS LABEL="Sex" VALUES=(0 TO 1 BY 1);
     YAXIS LABEL="Predicted Cognition" VALUES=(0 TO 35 BY 5);
RUN; QUIT;
```





STATA Syntax: GLM Adding Sex by Dementia Group Interaction

```
display "STATA Eq 2.13: GLM Adding Sex by Dementia Group Interaction"
display "Dummy-Coded Predictors for Sex (0=Men) and Demgroup (0=None)"
regress cognition c.age85 c.grip9 c.sexmw c.demnf c.demnc c.age85#c.grip9 ///
            c.sexmw#c.demnf c.sexmw#c.demnc, level(95)

// Omnibus DF=2 F-test for Sex*Demgroup Interaction
   test (c.sexmw#c.demnf=0) (c.sexmw#c.demnc=0)
// In TESTs below, linear combinations are created within parentheses (still 1 DF each)
   // Omnibus DF=2 F-test for Dementia Simple Main Effect for Men
      test (c.demnf*1 + c.sexmw#c.demnf*0 =0)(c.demnc*1 + c.sexmw#c.demnc*0=0)
   // Omnibus DF=2 F-Test for Dementia Simple Main Effect for Women
      test (c.demnf*1 + c.sexmw#c.demnf*1 =0)(c.demnc*1 + c.sexmw#c.demnc*1=0)

// Predicted cognition outcomes --adjusted cell means-- holding age=85 and grip=9
   margins, at(c.age85=0 c.grip9=0 c.sexmw=(0(1)1) c.demnf=0 c.demnc=0) // yhats for None
   margins, at(c.age85=0 c.grip9=0 c.sexmw=(0(1)1) c.demnf=1 c.demnc=0) // yhats for Future
   margins, at(c.age85=0 c.grip9=0 c.sexmw=(0(1)1) c.demnf=0 c.demnc=1) // yhats for Current

// DF=1 simple slopes for sex per demgroup
lincom c.sexmw*1 + c.sexmw#c.demnf*0 + c.sexmw#demnc*0  // Sex Diff for No Dementia
lincom c.sexmw*1 + c.sexmw#c.demnf*1 + c.sexmw#demnc*0  // Sex Diff for Future Dementia
lincom c.sexmw*1 + c.sexmw#c.demnf*0 + c.sexmw#demnc*1  // Sex Diff for Current Dementia
// DF=1 simple slopes for demgroup per sex
lincom c.demnf*1  + c.demnc*0 + c.sexmw#c.demnf*0  + c.sexmw#c.demnc*0 // None-Future Diff for Men
lincom c.demnf*1  + c.demnc*0 + c.sexmw#c.demnf*1  + c.sexmw#c.demnc*0 // None-Future Diff for Women
lincom c.demnf*0  + c.demnc*1 + c.sexmw#c.demnf*0  + c.sexmw#c.demnc*0 // None-Current Diff for Men
lincom c.demnf*0  + c.demnc*1 + c.sexmw#c.demnf*0  + c.sexmw#c.demnc*1 // None-Current Diff for Women
lincom c.demnf*-1 + c.demnc*1 + c.sexmw#c.demnf*0  + c.sexmw#c.demnc*0 // Future-Current Diff for Men
lincom c.demnf*-1 + c.demnc*1 + c.sexmw#c.demnf*-1 + c.sexmw#c.demnc*1 // Future-Current Diff for Women

// DF=1 differences in simple slopes = interactions
lincom c.sexmw#c.demnf*1  + c.sexmw#c.demnc*0  // A: Sex Effect differ btw None and Future?
lincom c.sexmw#c.demnf*1  + c.sexmw#c.demnc*0  // A: None-Future Effect differ btw Men and Women?
lincom c.sexmw#c.demnf*0  + c.sexmw#c.demnc*1  // B: Sex Effect differ btw None and Current?
lincom c.sexmw#c.demnf*0  + c.sexmw#c.demnc*1  // B: None-Current Effect differ btw Men and Women?
lincom c.sexmw#c.demnf*-1 + c.sexmw#c.demnc*1  // C: Sex Effect differ btw Future and Current?
lincom c.sexmw#c.demnf*-1 + c.sexmw#c.demnc*1  // C: Future-Current Effect differ btw Men and Women?
```

```
// To make pictures, need to represent demgroup as program-categorical predictor instead
display "STATA Eq 2.13: Adding Sex by Dementia Group Interaction"
display "Program-Categorical Predictor for Demgroup Instead"
regress cognition c.age85 c.grip9 c.sexmw i.demgroup c.age85#c.grip9 c.sexmw#i.demgroup, level(95)
// Get predicted cognition outcomes --adjusted cell means-- holding age=85 and grip=9
   margins i.demgroup, at(c.age85=0 c.grip9=0 c.sexmw=(0(1)1))
   marginsplot, xdimension(demgroup)  // Get and save plot for pred outcomes by demgroup
   graph export "$filesave\STATA plots\STATA Sex by Demgroup=x GLM Plot.png", replace
   marginsplot, xdimension(sexmw)  // Get and save plot for pred outcomes by sexmw
   graph export "$filesave\STATA plots\STATA Demgroup by Sex=x GLM Plot.png", replace
```

R Syntax: GLM Adding Sex by Dementia Group Interaction (see code online for plotting)

```
print("R Eq 2.13: GLM Adding Sex by Dementia Group Interaction")
print("Dummy-Coded Predictors for Sex (0=Men) and Demgroup (0=None)")
ModelSexDem = lm(data=Example1, formula=cognition~1+age85+grip9+sexMW+demNF+demNC
                                     +age85:grip9 +sexMW:demNF +sexMW:demNC)
summary(ModelSexDem); anova(ModelSexDem) # anova to get residual variance

print("Omnibus DFnum=2 F-test for Sex*Demgroup Interaction")
SexDemFint = glht(model=ModelSexDem, linfct=c("sexMW:demNF=0","sexMW:demNC=0"))
summary(SexDemFint, test=Ftest()) # ask for joint hypothesis test instead of separate

print("Omnibus DF=2 F-test for Dementia Simple Main Effect for Men")
DemforM = glht(model=ModelSexDem, linfct=rbind(c(0,0,0,0,1,0,0,0,0),c(0,0,0,0,0,1,0,0,0)))
summary(DemforM, test=Ftest()) # ask for joint hypothesis test instead of separate

print("Omnibus DF=2 F-test for Dementia Simple Main Effect for Women")
DemforW = glht(model=ModelSexDem, linfct=rbind(c(0,0,0,0,1,0,0,1,0),c(0,0,0,0,0,1,0,0,1)))
summary(DemforW, test=Ftest()) # ask for joint hypothesis test instead of separate

# If you are NOT using fake people, you have to write these to create predicted outcomes
print("Pred cognition outcomes --adjusted cell means-- holding age=85 and grip=9")
summary(glht(model=ModelSexDem, linfct=rbind(
  "Yhat for Men   None"    = c(1,0,0,0,0,0,0,0,0),  # in order of fixed effects
  "Yhat for Women None"    = c(1,0,0,1,0,0,0,0,0),
  "Yhat for Men Future"    = c(1,0,0,0,1,0,0,0,0),
  "Yhat for Women Future"  = c(1,0,0,1,1,0,0,1,0),
  "Yhat for Men Current"   = c(1,0,0,0,0,1,0,0,0),
  "Yhat for Women Current" = c(1,0,0,1,0,1,0,0,1))),test=adjusted("none"))

print("DF=1 simple slopes for sex per demgroup, demgroup per sex, and interactions")
summary(glht(model=ModelSexDem, linfct=rbind(
  "Sex Diff for No Dementia"      = c(0,0,0,1, 0,0,0, 0,0),  # in order of fixed effects
  "Sex Diff for Future Dementia"  = c(0,0,0,1, 0,0,0, 1,0),
  "Sex Diff for Current Dementia" = c(0,0,0,1, 0,0,0, 0,1),

  "None-Future Diff for Men"      = c(0,0,0,0, 1,0,0, 0,0),
  "None-Future Diff for Women"    = c(0,0,0,0, 1,0,0, 1,0),
  "None-Current Diff for Men"     = c(0,0,0,0, 0,1,0, 0,0),
  "None-Current Diff for Women"   = c(0,0,0,0, 0,1,0, 0,1),
  "Future-Current Diff for Men"   = c(0,0,0,0,-1,1,0, 0,0),
  "Future-Current Diff for Women" = c(0,0,0,0,-1,1,0,-1,1),

  "A: Sex effect differ btw None and Future?"           = c(0,0,0,0,0,0,0, 1,0),
  "A: None-Future effect differ btw Men and Women?"     = c(0,0,0,0,0,0,0, 1,0),
  "B: Sex effect differ btw None and Current?"          = c(0,0,0,0,0,0,0, 0,1),
  "B: None-Current effect differ btw Men and Women?"    = c(0,0,0,0,0,0,0, 0,1),
  "C: Sex effect differ btw Future and Current?"        = c(0,0,0,0,0,0,0,-1,1),
  "C: Future-Current effect differ btw Men and Women?" = c(0,0,0,0,0,0,0,-1,1))),
                                                            test=adjusted("none"))
```

Example Results Section for Final Model [notes about what also to include]:

Note: The description of how the betas were used to create the simple effects is not typically included in a results section, but I included it here for pedagogical reasons.

We estimated a general linear model (as shown in Equation 1) to examine the extent to which cognition could be predicted from main effects of age (centered such that 0 = 85 years), grip strength (centered such that 0 = 9 pounds per square inch), sex (0 = men, 1= women), and dementia status (none vs. future; none vs. current), as well as an interaction between age and grip strength, and an interaction between sex and dementia status. The model accounted for a significant amount of variance in cognition, $F(8, 541) = 28.77$, MSE = 85.97, $p < .0001$, $R^2 = .298$. Table 1 provides the model results, including the fixed effects estimated directly in the model, as well as their linear combinations in order to provide simple slopes by which to describe the sex by dementia group interaction. [Effect sizes should also be reported, but they are not our focus today.]

Equation 1 for final model:

$$\begin{aligned}\boldsymbol{Cognition_i} = {} & \boldsymbol{\beta_0} + \boldsymbol{\beta_1}(\boldsymbol{Age_i - 85}) + \boldsymbol{\beta_2}(\boldsymbol{Grip_i - 9}) + \boldsymbol{\beta_3}(\boldsymbol{SexMW_i}) + \boldsymbol{\beta_4}(\boldsymbol{DemNF_i}) + \boldsymbol{\beta_5}(\boldsymbol{DemNC_i}) \\ & + \boldsymbol{\beta_6}(\boldsymbol{Age_i - 85})(\boldsymbol{Grip_i - 9}) + \boldsymbol{\beta_7}(\boldsymbol{SexMW_i})(\boldsymbol{DemNF_i}) + \boldsymbol{\beta_8}(\boldsymbol{SexMW_i})(\boldsymbol{DemNC_i}) + \boldsymbol{e_i}\end{aligned}$$

Results from this model can be interpreted as follows. The intercept $\beta_0 = 29.07$ is the expected cognition outcome for an 85-year-old man with 9 pounds of grip strength who will not be diagnosed with dementia later in the study.

The simple main effect of age $\beta_1 = 0.33$ indicated that cognition is predicted to be significantly lower by 0.33 for every additional year of age (in persons with grip strength of 9 pounds). The simple main effect of grip strength $\beta_2 = 0.62$ indicated that cognition is predicted to be significantly greater by 0.62 for every additional pound of grip strength (in persons who are age 85). As shown in [figure], the age by grip strength interaction $\beta_6 = 0.12$ indicated the age slope predicting cognition became significantly less negative by 0.12 for each additional pound of grip strength (as shown by the differences in slopes of the lines). Equivalently, the grip strength slope predicting cognition became significantly more positive by 0.12 for each additional year of age (as shown by the differences in the vertical distance between the lines). [Regions of significance and simple slopes could also be reported here, as described at the end of in chapter 2.]

The main and interactive effects of sex by dementia group are presented next, as illustrated in [figure], in which the sex differences are shown by the vertical distances between the lines, and the dementia group differences are shown by the differences within the lines. Given the significant sex by dementia group interaction, $F(2, 541) = 3.49$, MSE = 85.97, $p = .031$, simple slopes and their differences (i.e., interaction contrasts) for both sex and dementia group are reported next.

First, there was a significant simple main effect of sex ($\beta_3 = -2.88$) such that in the no dementia group, cognition was significantly lower by 2.88 in women than in men. The sex difference in cognition was equivalent in no dementia and future dementia groups, as shown by the nonsignificant sex by no dementia vs. future dementia interaction ($\beta_7 = 0.16$). However, the resulting sex difference in cognition favoring men in the future dementia group (of $\beta_3 + \beta_7 = -2.88 + 0.16 = -2.71$) was not significant, likely a result of the small number of persons with future dementia (only 20% of the sample). In addition, the sex difference in cognition was significantly larger in the current dementia group than in the no dementia group, as shown by the significant sex by no dementia vs. current dementia interaction ($\beta_8 = -7.88$), and the resulting sex difference in the current dementia group (of $\beta_3 + \beta_8 = 2.88 - 7.88 = -10.75$) was also significant. The sex difference in cognition was also significantly larger in the current dementia group than in the future dementia group (as found by $\beta_8 - \beta_7 = -7.88 - 0.16 = -8.04$).

Second, with respect to differences among dementia groups, a significant omnibus group difference was found both in men, $F(2, 541) = 18.69$, MSE = 85.97, $p < .001$, and in women, $F(2, 541) = 53.16$, MSE = 85.97, $p < .001$. More specifically, cognition was significantly lower in the future dementia than no dementia group, both in men ($\beta_4 = -6.06$) and women ($\beta_4 + \beta_7 = -6.06 + 0.16 = -5.89$). This group difference was equivalent across sexes, as indicated by the nonsignificant sex by no dementia vs. future dementia interaction ($\beta_4 = 0.16$). Cognition was also significantly lower in the current dementia than no dementia group, both in men ($\beta_5 = -11.97$) and women ($\beta_5 + \beta_8 = -11.97 - 7.88 = -19.85$). This group difference was significantly larger in women, as indicated by the sex by no dementia vs. current dementia interaction ($\beta_8 = -7.88$). Finally, cognition was also significantly lower in the current dementia group than future diagnosis group, both in men ($\beta_5 - \beta_4 = -11.97 + 6.06 = -5.91$) and women ($\beta_5 + \beta_8 - \beta_4 - \beta_7 = -11.97 - 7.88 + 6.06 + 0.16 = -13.95$). This group difference was significantly larger in women, as indicated by the additional interaction contrast (of $\beta_8 - \beta_7 = -7.88 - 0.16 = -8.04$).

Table 1: Model Results (bold values indicate *p* < .05)

	Model Fixed Effects	Est	SE	*p* <
<u>Model for the Means</u>				
β_0	Intercept	29.07	0.75	.001
β_1	Age Slope (0 = 85 years)	**−0.33**	0.12	.005
β_2	Grip Strength Slope (0 = 9 lbs)	**0.62**	0.15	.001
β_6	Age by Grip Interaction	**0.12**	0.04	.003
	Sex (0 = Men, 1 = Women) Differences:			
β_3	No Diagnosis	**−2.88**	1.01	.005
$\beta_3 + \beta_7$	Future Diagnosis	−2.71	1.87	.149
$\beta_3 + \beta_8$	Current Diagnosis	**−10.75**	2.90	.001
	Dementia Group Differences:			
	None vs. Future Diagnosis			
β_4	Men	**−6.06**	1.64	.001
$\beta_4 + \beta_7$	Women	**−5.89**	1.28	.001
β_7	Sex by None vs. Future	0.16	2.07	.937
	None vs. Current Diagnosis			
β_5	Men	**−11.97**	2.25	.001
$\beta_5 + \beta_8$	Women	**−19.85**	2.02	.001
β_8	Sex by None vs. Current	**−7.88**	3.02	.010
	Future vs. Current Diagnosis			
$-\beta_4 + \beta_5$	Men	**−5.91**	2.59	.023
$-\beta_4 + \beta_5 - \beta_7 + \beta_8$	Women	**−13.95**	2.24	.001
$-\beta_7 + \beta_8$	Sex by Future vs. Current	**−8.04**	3.42	.019