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

These example data come from Hoffman (2015) chapter 2, which examined prediction of a cognition outcome from age (centered at 85 years), grip strength (centered at 9 pounds), sex (with men as the reference group) and eventual 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 and demonstrates how to generate predicted outcomes (for hypothetical people) for plotting purposes. 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>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\24_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
```

<u>R</u> Syntax for Importing and Preparing Data for Analysis (after loading packages *readxl, TeachingDemos*, *psych*, *multcomp*, *prediction*, *reghelper*, and *interactions* as shown online):

```
# Define variables for working directory and data name
filesave = "C:\\Dropbox/24_PSQF6270/PSQF6270_Example1/"
filename = "Excel_Chapter2.xlsx"
setwd(dir=filesave)

# Import chapter 2 Excel data as Example1
Example1 = read_excel(path=paste0(filesave,filename))
# Convert to data frame 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
# Labels for all variables given as comments only (not actually added to data)
# Filter to only cases complete on all variables to be used below
Example1 = Example1[complete.cases(Example1[ ,
                       c("cognition","age","grip","sexMW","demgroup")]),]
```

STATA Syntax and Output for Descriptive Statistics

```
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
```

```
    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
   cognition |        550      24.822      10.989      0.000     44.000
         age |        550      84.927       3.430     80.016     96.967
        grip |        550       9.113       2.983      0.000     19.000
       sexmw |        550       0.587       0.493      0.000      1.000
       demnf |        550       0.198       0.399      0.000      1.000
-------------+---------------------------------------------------------
       demnc |        550       0.076       0.266      0.000      1.000

sexmw: Sex |  demgroup: Dementia Group 1N 2F 3C
   (0=Men, |
  1=Women) |         1          2          3 |     Total
-----------+---------------------------------+----------
     0.000 |       168         40         19 |       227
     1.000 |       231         69         23 |       323
-----------+---------------------------------+----------
     Total |       399        109         42 |       550
```

R Syntax and Output for Descriptive Statistics

```
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
```

```
> describe(x = Example1[, c("cognition", "age", "grip", "sexMW")])
          vars   n  mean    sd median trimmed   mad   min   max range  skew kurtosis   se
cognition    1 550 24.82 10.99  25.00   25.18 11.86  0.00 44.00 44.00 -0.26    -0.62 0.47
age          2 550 84.93  3.43  84.33   84.49  2.88 80.02 96.97 16.95  1.10     0.72 0.15
grip         3 550  9.11  2.98   9.00    9.11  2.97  0.00 19.00 19.00 -0.01    -0.17 0.13
sexMW        4 550  0.59  0.49   1.00    0.61  0.00  0.00  1.00  1.00 -0.35    -1.88 0.02

> table(x = Example1$sexMW, Example1$demgroup, useNA = "ifany")
x     1   2   3
  0 168  40  19
  1 231  69  23
```

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

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

RQ: How do age in years, grip strength in pounds, binary sex, and three-group dementia status each uniquely predict cognition?

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: GLM with Main Effects Only Predicting Cognition"
regress cognition c.age85 c.grip9 c.sexmw c.demnf c.demnc, level(95)
```

Model Summary and Model-Estimated Fixed Effects

```
      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

------------------------------------------------------------------------------
   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!
------------------------------------------------------------------------------
```

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

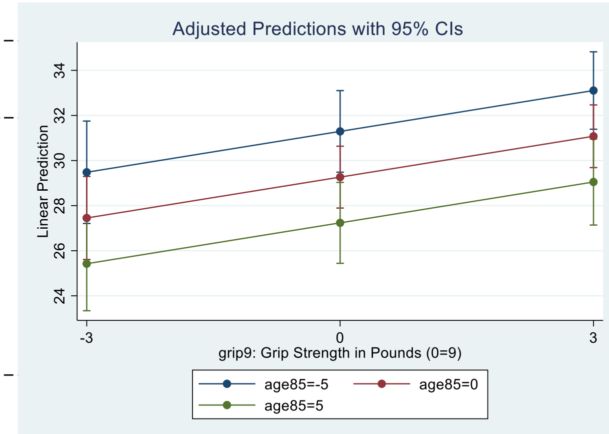
```
// LINCOM creates a single linear combination of fixed effects
lincom c.demnf*-1 + c.demnc*1 // Mean Diff: Future vs. Current = B5-B4
------------------------------------------------------------------------------
   cognition |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+------------------------------------------------------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

// 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
       F(  5,   544) =   41.75 → Same as given by default for model above
            Prob > F =    0.0000

test (c.demnf=0)(c.demnc=0)   // DFnum=2 Omnibus F-test for Demgroup
       F(  2,   544) =   67.06 → Is new information (not given by default)
            Prob > F =    0.0000
```

Requested MARGINS for predicted outcomes

```
// Pred cognition outcomes holding sexmw=men, demnf=none, and demnc=none
// predictor=(from(by)to), c.=quantitative predictor, vsquish compresses output empty lines
   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
```

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    P>|t|
-------------+----------------------------------------------
         _at |
          1  |    29.48032    1.155906    25.50    0.000
          2  |      31.293    .9209086    33.98    0.000
          3  |    33.10567    .8739657    37.88    0.000
          4  |    27.45165    .9373122    29.29    0.000
          5  |    29.26433    .6985079    41.90    0.000
          6  |      31.077    .7078574    43.90    0.000
          7  |    25.42298    1.061987    23.94    0.000
          8  |    27.23566     .913554    29.81    0.000
          9  |    29.04833    .9721806    29.88    0.000
------------------------------------------------------------
```



<u>R</u> Syntax and Output for Eq 2.8: GLM with Main Effects Only Predicting Cognition:

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

RQ: How do age in years, grip strength in pounds, binary sex, and three-group dementia status each uniquely predict cognition?

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

Model-Estimated Fixed Effects

```
Coefficients:
             Estimate Std. Error  t value                Pr(>|t|)
(Intercept)  29.26433    0.69851  41.8955 < 0.00000000000000022  Beta0
age85        -0.40573    0.11890  -3.4125             0.0006917  Beta1
grip9         0.60423    0.14978   4.0342          0.0000626304  Beta2
sexMW        -3.65737    0.89143  -4.1028          0.0000470693  Beta3
demNF        -5.72197    1.01908  -5.6148          0.0000000314  Beta4
demNC       -16.47981    1.52275 -10.8224 < 0.00000000000000022  Beta5
---
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
```

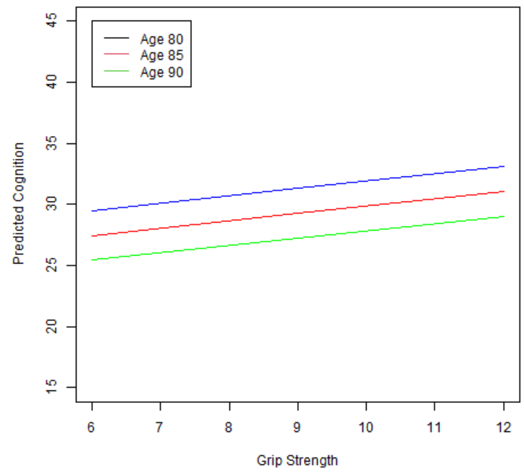
ANOVA Table—Printed *Just* to Get the Residual Variance (= Mean Square Error or Residual)

```
Analysis of Variance Table → Type I sequential SS below, which are not helpful here!
           Df  Sum Sq  Mean Sq  F value                Pr(>F)
age85       1  1926.2  1926.18  21.8708       0.0000036833209
grip9       1  3039.2  3039.17  34.5082       0.0000000073976
sexMW       1  1609.3  1609.32  18.2731       0.0000226023607
demNF       1  1496.1  1496.10  16.9875       0.0000434979953
demNC       1 10315.2 10315.20 117.1239 < 0.000000000000000222
Residuals 544 47910.6    88.07 → This is residual variance (all we need)
```

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

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

Linear Hypotheses:
       Estimate Std. Error t value        Pr(>|t|)
1 == 0  -10.758      1.708 -6.2987 0.0000000006198

print("Get DFnum=5 F-test of Model R2 only 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

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

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

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

print("Pred cognition outcomes holding sexMW=men, demNF=none, and demNC=none")
print("Provides predicted outcomes from min,max,by=increment of predictors")
PredMain = summary(prediction(model=ModelMain, type="response",
           at=list(sexMW=0, demNF=0, demNC=0, age85=seq(-5,5,by=5), grip9=seq(-3,3,by=3))))
PredMain # print predicted outcomes

# Threw a warning that predictions went out of bounds!
Warning messages:
1: In check_values(data, at) :
  A 'at' value for 'age85' is outside observed data range (-4.9835067729703,11.9672831683989)!

at(sexMW) at(demNF) at(demNC) at(age85) at(grip9) Prediction     SE     z          p lower upper
        0         0         0        -5        -3      29.48 1.1559 25.50 1.776e-143 27.21 31.75
        0         0         0         0        -3      27.45 0.9373 29.29 1.491e-188 25.61 29.29
        0         0         0         5        -3      25.42 1.0620 23.94 1.201e-126 23.34 27.50
        0         0         0        -5         0      31.29 0.9209 33.98 4.315e-253 29.49 33.10
        0         0         0         0         0      29.26 0.6985 41.90  0.000e+00 27.90 30.63
        0         0         0         5         0      27.24 0.9136 29.81 2.662e-195 25.45 29.03
        0         0         0        -5         3      33.11 0.8740 37.88  0.000e+00 31.39 34.82
        0         0         0         0         3      31.08 0.7079 43.90  0.000e+00 29.69 32.46
        0         0         0         5         3      29.05 0.9722 29.88 3.627e-196 27.14 30.95

# Create data frame with uncentered version of predictors for plotting
PredMain = data.frame(PredMain) # first remove () from variable names
PredMain = data.frame(PredMain, grip=PredMain$at.grip9.+9, age=PredMain$at.age85.+85)
PredMain = sort_asc(data=PredMain,age) # sort data by age for plot

# Save plot: open file, make plot, close file
png(file = "R Main-Effects-Only GLM Plot.png")
plot(y= PredMain$Prediction, x=PredMain$grip, type="n", ylim=c(15,45), xlim=c(6,12),
```

```
     xlab="Grip Strength",ylab="Predicted Cognition")
lines(x=PredMain$grip[1:3],
   y=PredMain$Prediction[1:3], type="l", col="blue1")
lines(x=PredMain$grip[4:6],
   y=PredMain$Prediction[4:6], type="l", col="red1")
lines(x=PredMain$grip[7:9],
   y=PredMain$Prediction[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
```



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

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

RQs: Does the effect of age on cognition vary by grip strength? Does the effect of grip strength on cognition vary by age?

```
display "STATA Eq 2.9: GLM Add Age by Grip Strength Interaction"
regress cognition c.age85 c.grip9 c.sexmw c.demnf c.demnc c.age85#c.grip9, level(95)
```

Model Summary and Model-Estimated Fixed Effects

```
      Source |       SS           df       MS      Number of obs   =       550
-------------+----------------------------------   F(6, 543)       =     36.85
       Model |  19185.0411         6  3197.50684   Prob > F        =    0.0000
    Residual |  47111.4971       543  86.7615048   R-squared       =    0.2894
-------------+----------------------------------   Adj R-squared   =    0.2815
       Total |  66296.5382       549  120.758722   Root MSE        =    9.3146
------------------------------------------------------------------------------
   cognition |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       age85 |  -.3339606   .1203566    -2.77   0.006    -.5703821   -.0975391 Beta1
       grip9 |   .6194186   .1487424     4.16   0.000     .3272376    .9115996 Beta2
       sexmw |  -3.455637   .8872749    -3.89   0.000    -5.198549   -1.712726 Beta3
       demnf |  -5.922543   1.013632    -5.84   0.000    -7.913663   -3.931424 Beta4
       demnc |   -16.3004   1.512547   -10.78   0.000    -19.27157   -13.32924 Beta5
c.age85#c.grip9 | .1230185  .0405363     3.03   0.003     .0433914    .2026456 Beta6
       _cons |    29.4078   .6949062    42.32   0.000     28.04277    30.77284 Beta0
------------------------------------------------------------------------------
```

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

```
  lincom c.demnf*-1 + c.demnc*1 // Mean Diff: Future vs. Current = Beta5-Beta4
------------------------------------------------------------------------------
   cognition |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |  -10.37786   1.699831    -6.11   0.000    -13.71691   -7.038812
------------------------------------------------------------------------------

test (c.demnf=0)(c.demnc=0)   // DFnum=2 Omnibus F-test for main effect of demgroup
       F(  2,   543) =   67.70
            Prob > F =    0.0000

test (c.age85=0)(c.grip9=0)(c.age85#c.grip9=0) // DFnum=3 F-test for age, grip, age*grip
       F(  3,   543) =   14.60
            Prob > F =    0.0000
```

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 $(Age_i - 85)$

```
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
------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
age85    _at |
          1  |   -.703016   .1533696    -4.58   0.000    -1.004286   -.4017456
          2  |  -.3339606   .1203566    -2.77   0.006    -.5703821   -.0975391
          3  |   .0350949   .1871539     0.19   0.851    -.3325394    .4027291
------------------------------------------------------------------------------
```

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

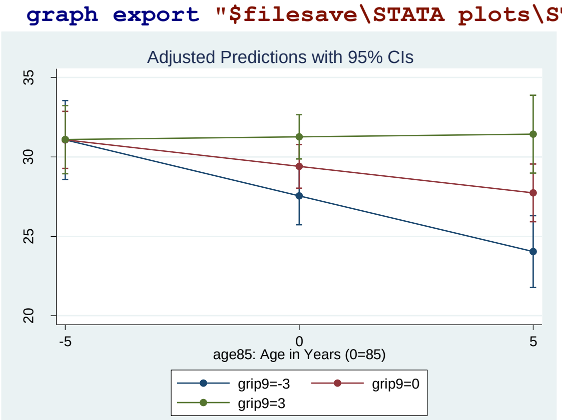
Simple Grip Slope = $\beta_2(Grip_i - 9) + \beta_6(Age_i - 85)(Grip_i - 9)$

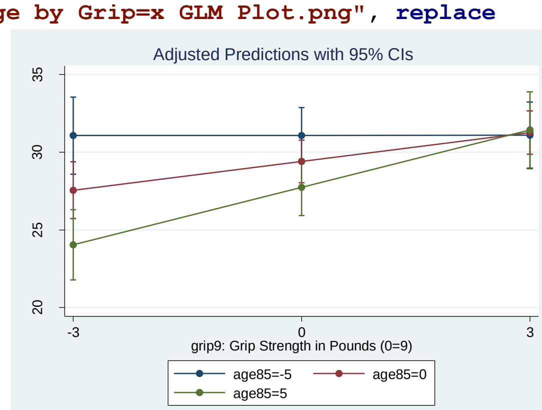
= $[\beta_2 + \beta_6(Age_i - 85)]$ that multiplies $(Grip_i - 9)$

```
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
------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
grip9    _at |
          1  |   .0043262   .2473351     0.02   0.986    -.4815246     .490177
          2  |   .6194186   .1487424     4.16   0.000     .3272376    .9115996
          3  |   1.234511   .2554083     4.83   0.000     .7328017     1.73622
------------------------------------------------------------------------------
```

Requested MARGINS for predicted outcomes

```
// predictor=(from(by)to), c.=quantitative predictor, vsquish compresses output empty lines
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
```





Bonus: How to get the Asymptotic Covariance Matrix for Regions of Significance for the Age*Grip Interaction BOLD values below get used (diagonal = SE^2, off-diagonals = SE covariances); see excel file!

```
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
```

```
Covariance matrix of coefficients of regress model
                  |
             e(V) |      age85       grip9       sexmw       demnf       demnc  c.age85#c.grip9   _cons
------------------+--------------------------------------------------------------------------------------
            age85 |   .0144857
            grip9 |  .00331698    .0221243
            sexmw |    .005024   .05374269   .78725672
            demnf | -.00413095  -.01338766  -.07101552    1.027449
            demnc | -.00115115  -.00030106   .02370811   .21291169   2.2877993
 c.age85#|c.grip9 |   .0009587   .00020294   .00269465  -.00267909    .0023964   .00164319
            _cons |  .00045357  -.03075328  -.45067156  -.18202858  -.22634698   .00191647   .48289456
```

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

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

RQs: Does the effect of age on cognition vary by grip strength? Does the effect of grip strength on cognition vary by age?

```
print("R Eq 2.9: GLM Add 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
```

Model-Estimated Fixed Effects

```
Coefficients:
              Estimate Std. Error  t value      Pr(>|t|)
(Intercept)  29.407803   0.694906  42.3191      < 2.2e-16  Beta0
age85        -0.333961   0.120357  -2.7748      0.0057145  Beta1
grip9         0.619419   0.148742   4.1644 0.00003630980  Beta2
sexMW        -3.455637   0.887275  -3.8947      0.0001106  Beta3
demNF        -5.922543   1.013632  -5.8429 0.00000000885  Beta4
demNC       -16.300405   1.512547 -10.7768      < 2.2e-16  Beta5
age85:grip9   0.123018   0.040536   3.0348      0.0025224  Beta6

Residual standard error: 9.3146 on 543 degrees of freedom
Multiple R-squared:  0.28938,     Adjusted R-squared:  0.28153
F-statistic: 36.854 on 6 and 543 DF,  p-value: < 2.22e-16
```

ANOVA Table—Printed Just to Get the Residual Variance (= Mean Square Error or Residual)

```
Analysis of Variance Table → Rest of Type I sequential SS omitted!
              Df  Sum Sq  Mean Sq   F value        Pr(>F)
Residuals    543 47111.5     86.76 → residual variance
```

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:

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

```
print("Get missing demgroup difference: Future vs Current = Beta5-Beta4")
summary(glht(model=ModelAgeGrip, linfct=rbind(c(0,0,0,0,-1,1,0))),test=adjusted("none"))
Linear Hypotheses:
       Estimate Std. Error t value        Pr(>|t|)
1 == 0 -10.3779     1.6998 -6.1052 0.000000001956

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
Global Test:
       F DF1 DF2      Pr(>F)
1 67.701   2 543 5.6176e-27

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
Global Test:
       F DF1 DF2           Pr(>F)
1 14.599   3 543 0.0000000037133
```

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 $(\boldsymbol{Age_i}-\mathbf{85})$

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 $(\boldsymbol{Grip_i}-\mathbf{9})$

```
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')))
```

GLHT Results:

```
Linear Hypotheses:
                              Estimate Std. Error t value    Pr(>|t|)
Age Slope at Grip = 6 == 0  -0.7030160  0.1533696 -4.5838 0.000005671
Age Slope at Grip = 9 == 0  -0.3339606  0.1203566 -2.7748    0.005715
Age Slope at Grip = 12 == 0  0.0350949  0.1871539  0.1875    0.851324
Grip Slope at Age = 80 == 0  0.0043262  0.2473351  0.0175    0.986051
Grip Slope at Age = 85 == 0  0.6194186  0.1487424  4.1644 0.000036310
Grip Slope at Age = 90 == 0  1.2345110  0.2554083  4.8335 0.000001749
(Adjusted p values reported -- none method)
```

Simple_slopes Results:

```
   age85 grip9 Test Estimate Std. Error  t value  df     Pr(>|t|)
1 sstest    -3      -0.70302    0.15337 -4.58380 543 0.0000056714
2 sstest     0      -0.33396    0.12036 -2.77476 543    0.0057145
3 sstest     3       0.03509    0.18715  0.18752 543    0.8513240
4     -5 sstest      0.00433    0.24734  0.01749 543    0.9860510
5      0 sstest      0.61942    0.14874  4.16437 543 0.0000363098
6      5 sstest      1.23451    0.25541  4.83348 543 0.0000017488
```

Regions of Significance for the Age*Grip Interaction

```
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 INTERVAL → [9.665, 18.521] uncentered
When grip9 is OUTSIDE the interval [0.665, 9.521], the slope of age85 is p < .05.
The range of observed values of grip9 is [-9.000, 10.000] = 0 to 19 uncentered
```

After adding 9 to uncenter grip strength, the age slope will be significantly negative below grip = 9.665 pounds, nonsignificant between grip = 9.665 and 18.521 pounds, and significantly positive after grip = 18.521 pounds.

```
johnson_neyman(model=ModelAgeGrip, pred="grip9", modx="age85", digits=3, plot=FALSE)
```

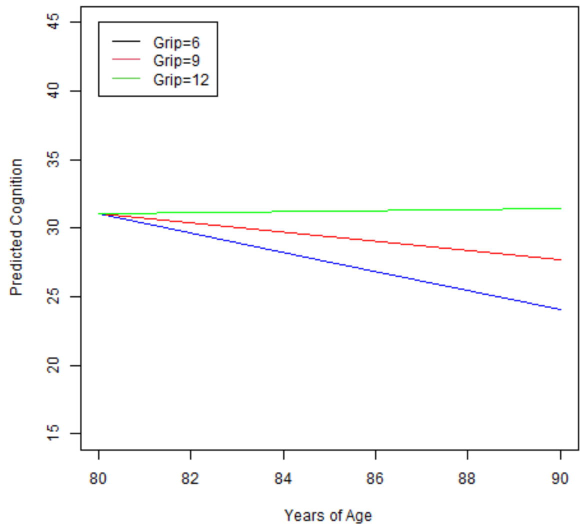
```
JOHNSON-NEYMAN INTERVAL → [70.127, 82.719] uncentered
When age85 is OUTSIDE the interval [-14.873, -2.281], the slope of grip9 is p < .05.
The range of observed values of age85 is [-4.984, 11.967] = 80.016 to 96.967 uncentered
```

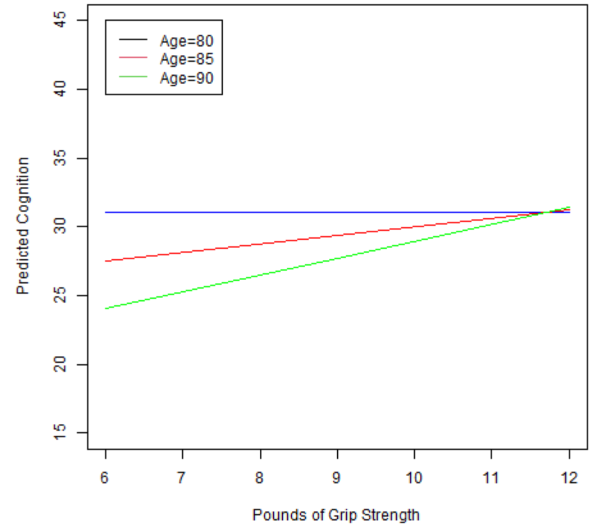
After adding 85 to uncenter age, the grip strength slope will be significantly negative below age = 70.127 years, nonsignificant between age = 70.127 and 82.719 years, and significantly positive after age = 82.719 years.

```
print("Pred cognition outcomes holding sexMW=men, demNF=none, and demNC=none")
print("Provides predicted outcomes from min,max,by=increment of predictors")
PredAgeGrip = summary(prediction(model=ModelAgeGrip, type="response",
              at=list(sexMW=0,demNF=0,demNC=0,age85=seq(-5,5,by=5),grip9=seq(-3,3,by=3))))
PredAgeGrip # print predicted outcomes, get warning that predictions go out of bounds
```

```
at(sexMW) at(demNF) at(demNC) at(age85) at(grip9) Prediction     SE     z          p lower upper
        0         0         0        -5        -3      31.06 1.2605 24.65 4.141e-134 28.59 33.54
        0         0         0         0        -3      27.55 0.9309 29.60 1.720e-192 25.73 29.37
        0         0         0         5        -3      24.03 1.1491 20.92  3.808e-97 21.78 26.29
        0         0         0        -5         0      31.08 0.9168 33.90 7.049e-252 29.28 32.87
        0         0         0         0         0      29.41 0.6949 42.32  0.000e+00 28.05 30.77
        0         0         0         5         0      27.74 0.9217 30.09 5.867e-199 25.93 29.54
        0         0         0        -5         3      31.09 1.0924 28.46 3.602e-178 28.95 33.23
        0         0         0         0         3      31.27 0.7053 44.33  0.000e+00 29.88 32.65
        0         0         0         5         3      31.44 1.2462 25.23 1.861e-140 29.00 33.88
```

```
# Create data frame with uncentered version of predictors for plotting")
PredAgeGrip = data.frame(PredAgeGrip) # first remove () from variable names
PredAgeGrip = data.frame(PredAgeGrip, grip=PredAgeGrip$at.grip9.+9,
                         age=PredAgeGrip$at.age85.+85)

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





Equation 2.13, add sex*dementia interaction:

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

RQs: Does the effect of sex on cognition vary by dementia group? Does the effect of dementia group on cognition vary by sex?

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 = $\boldsymbol{[\beta_5 + \beta_8(SexMW_i)] - [\beta_4 + \beta_7(SexMW_i)]}$

R Syntax and Output for Eq 2.13: GLM Adding Sex by Dementia Group Interaction

```
print("R Eq 2.13: GLM Add 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
```

Model-Estimated Fixed Effects

```
Coefficients:
              Estimate Std. Error t value     Pr(>|t|)
(Intercept)  29.070146   0.748499 38.8379    < 2.2e-16 Beta0
age85        -0.334799   0.119888 -2.7926    0.0054136 Beta1
grip9         0.617893   0.148079  4.1727 0.0000350646 Beta2
sexMW        -2.875594   1.011237 -2.8436    0.0046288 Beta3
demNF        -6.055901   1.635126 -3.7036    0.0002344 Beta4
demNC       -11.970731   2.244954 -5.3323 0.0000001427 Beta5
age85:grip9   0.122152   0.040353  3.0271    0.0025868 Beta6
sexMW:demNF   0.164270   2.070475  0.0793    0.9367921 Beta7
sexMW:demNC  -7.875100   3.024536 -2.6037    0.0094746 Beta8

Residual standard error: 9.2721 on 541 degrees of freedom
Multiple R-squared:  0.29844,     Adjusted R-squared:  0.28806
F-statistic: 28.767 on 8 and 541 DF,  p-value: < 2.22e-16
```

ANOVA Table—Printed Just to Get the Residual Variance (= Mean Square Error or Residual)

```
Analysis of Variance Table → Rest of Type I sequential SS omitted!
             Df  Sum Sq  Mean Sq   F value          Pr(>F)
Residuals   541 46511.1    85.97 → residual variance
```

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:

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

```
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

Linear Hypotheses:
                 Estimate
sexMW:demNF == 0  0.16427
sexMW:demNC == 0 -7.87510

Global Test:
       F DF1 DF2  Pr(>F)
1 3.4919   2 541 0.03113
```

```
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
```

```
Linear Hypotheses:
       Estimate
1 == 0  -6.0559
2 == 0 -11.9707

Global Test:
       F DF1 DF2          Pr(>F)
1 18.688   2 541 0.000000014193
```

```
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
```

```
Linear Hypotheses:
       Estimate
1 == 0  -5.8916
2 == 0 -19.8458

Global Test:
       F DF1 DF2      Pr(>F)
1 53.157   2 541 8.3779e-22
```

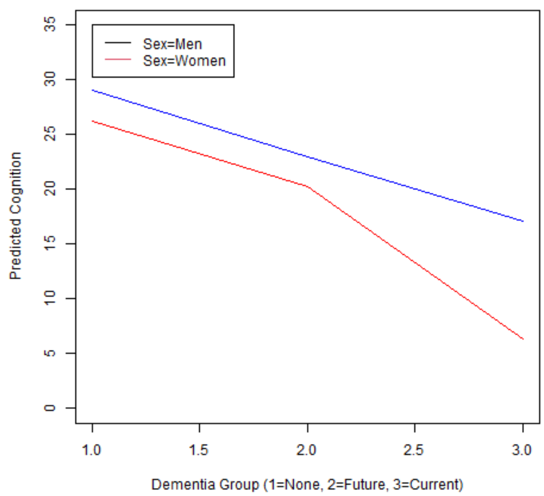
```
print("Pred cognition outcomes --adjusted cell means-- holding age=85 and grip=9")
print("Will need to ignore impossible combinations of demNF and demNC for min:max")
PredSexDem = summary(prediction(model=ModelSexDem, type="response",
                     at=list(sexMW=0:1, demNF=0:1, demNC=0:1, age85=0, grip9=0)))
PredSexDem # print predicted outcomes
```

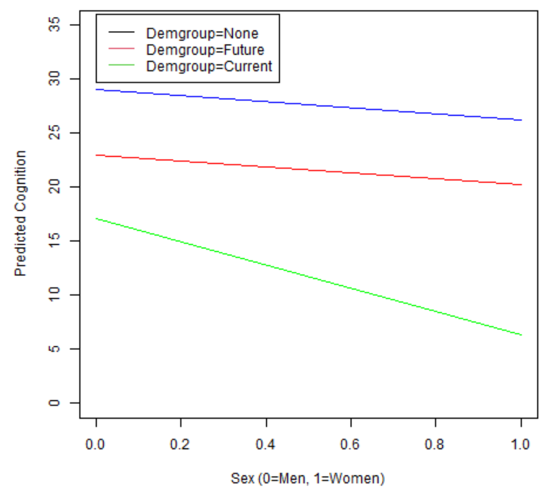
Adjusted cell means (for age=85 and grip=9) → red shows nonsense combinations to be removed below

at(sexMW)	at(demNF)	at(demNC)	at(age85)	at(grip9)	Prediction	SE	z	p	lower	upper
0	0	0	0	0	29.0701	0.7485	38.8379	0.000e+00	27.603	30.54
1	0	0	0	0	26.1946	0.6388	41.0037	0.000e+00	24.942	27.45
0	1	0	0	0	23.0142	1.4928	15.4172	1.253e-53	20.088	25.94
1	1	0	0	0	20.3029	1.1186	18.1498	1.290e-73	18.110	22.50
0	0	1	0	0	17.0994	2.1402	7.9896	1.354e-15	12.905	21.29
1	0	1	0	0	6.3487	1.9479	3.2593	1.117e-03	2.531	10.17
0	**1**	**1**	**0**	**0**	**11.0435**	**2.6964**	**4.0956**	**4.211e-05**	**5.759**	**16.33**
1	**1**	**1**	**0**	**0**	**0.4571**	**2.3179**	**0.1972**	**8.437e-01**	**-4.086**	**5.00**

```
print("Create data frame for plotting and remove unneeded rows")
PredSexDem = data.frame(PredSexDem) # first remove () from variable names
PredSexDem$sum = PredSexDem$at.demNF.+PredSexDem$at.demNC. # sum dummy codes
PredSexDem = subset(x=PredSexDem, PredSexDem$sum<2) # keep if sum<2
# Make demgroup combined variable for plot
PredSexDem$demgroup=NA # Make new empty variable to be recoded
PredSexDem$demgroup[which(PredSexDem$at.demNF.==0 & PredSexDem$at.demNC.==0)]=1
PredSexDem$demgroup[which(PredSexDem$at.demNF.==1 & PredSexDem$at.demNC.==0)]=2
PredSexDem$demgroup[which(PredSexDem$at.demNF.==0 & PredSexDem$at.demNC.==1)]=3

# Make and save plots
png(file = "R Sex by Demgroup=x GLM Plot.png")  # open file
plot(y=PredSexDem$Prediction, x=PredSexDem$demgroup, type="n", ylim=c(0,35), xlim=c(1,3),
     xlab="Dementia Group (1=None, 2=Future, 3=Current)", ylab="Predicted Cognition")
PredSexDem = sort_asc(data=PredSexDem,at.sexMW.) # 3 rows per sexMW now
lines(x=PredSexDem$demgroup[1:3], y=PredSexDem$Prediction[1:3], type="l", col="blue1")
lines(x=PredSexDem$demgroup[4:6], y=PredSexDem$Prediction[4:6], type="l", col="red1")
legend(x=1, y=35, legend = c("Sex=Men", "Sex=Women"), col=1:2, lty=1) #lty=linetype
dev.off()  # close file

png(file = "R Demgroup by Sex=x GLM Plot.png")  # open file
plot(y=PredSexDem$Prediction, x=PredSexDem$at.sexMW., type="n", ylim=c(0,35), xlim=c(0,1),
     xlab="Sex (0=Men, 1=Women)", ylab="Predicted Cognition")
```

```
PredSexDem = sort_asc(data=PredSexDem,demgroup) # 2 rows per demgroup now
lines(x=PredSexDem$sexMW[1:2], y=PredSexDem$Prediction[1:2], type="l", col="blue1")
lines(x=PredSexDem$sexMW[3:4], y=PredSexDem$Prediction[3:4], type="l", col="red1")
lines(x=PredSexDem$sexMW[5:6], y=PredSexDem$Prediction[5:6], type="l", col="green1")
legend(x=0, y=36, legend = c("Demgroup=None", "Demgroup=Future", "Demgroup=Current"),
       col=1:3, lty=1) #lty=linetype
dev.off()  # close file
```





Model syntax repeated to be able to understand the GLHT statements below:

```
ModelSexDem = lm(data=Example1, formula=cognition~1+age85+grip9+sexMW+demNF+demNC
                                     +age85:grip9 +sexMW:demNF +sexMW:demNC)

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"))
```

DF=1 simple effects of sex per dementia group

```
                                         Estimate Std. Error t value        Pr(>|t|)
Sex Diff for No Dementia == 0            -2.87559    1.01124 -2.8436       0.0046288
Sex Diff for Future Dementia == 0        -2.71132    1.87407 -1.4468       0.1485438
Sex Diff for Current Dementia == 0      -10.75069    2.89932 -3.7080       0.0002304
```

DF=1 simple effects of dementia group per sex

```
None-Future Diff for Men == 0            -6.05590    1.63513 -3.7036       0.0002344
None-Future Diff for Women == 0          -5.89163    1.27776 -4.6109 0.0000050083059
None-Current Diff for Men == 0          -11.97073    2.24495 -5.3323 0.0000001427086
None-Current Diff for Women == 0        -19.84583    2.02858 -9.7831        < 2.2e-16
Future-Current Diff for Men == 0         -5.91483    2.58676 -2.2866       0.0226061
Future-Current Diff for Women == 0      -13.95420    2.23892 -6.2326 0.0000000009239
```

DF=1 differences in simple effects = interactions

```
A: Sex effect differ btw None and Future? == 0           0.16427    2.07048  0.0793        0.9367921
A: None-Future effect differ btw Men and Women? == 0     0.16427    2.07048  0.0793        0.9367921

B: Sex effect differ btw None and Current? == 0         -7.87510    3.02454 -2.6037        0.0094746
B: None-Current effect differ btw Men and Women? == 0   -7.87510    3.02454 -2.6037        0.0094746

C: Sex effect differ btw Future and Current? == 0       -8.03937    3.41516 -2.3540        0.0189282
C: Future-Current effect differ btw Men and Women? == 0 -8.03937    3.41516 -2.3540        0.0189282
```

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

Dementia Group Adjusted 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)

STATA Syntax: GLM Adding Sex by Dementia Group Interaction (output is online only)

```
display "STATA Eq 2.13: GLM Add 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
```

<u>Example Results Section for Final Model [notes about what also to include]:</u>

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 purposes.

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 (0 = none vs. 1 = future; 0 = none vs. 1 = 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:

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

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 that the age slope predicting cognition became significantly less negative by 0.12 for each additional pound of grip strength (as shown by the difference in slope across 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 difference 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 distance between the lines, and the dementia group differences are shown by the difference 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 in 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