

432 Class 10 Slides

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Setup

```
library(rms) # note: also loads Hmisc  
library(skimr)  
library(simputation)  
library(broom)  
library(tidyverse)
```

Today's Materials

- Performing Linear Regression with `ols`
- Hormone Therapy and Baseline LDL in the HERS trial

The HERS trial is described in Vittinghoff et al., especially Chapter 4.

Hormone Therapy and Baseline LDL in the HERS Trial

```
hers <- read.csv("data/hersdata.csv") %>% tbl_df

hers1 <- hers %>%
  filter(diabetes == "no") %>%
  select(subject, LDL, HT, age, smoking, drinkany, SBP,
         physact, BMI, diabetes)
```

The Data

```
head(hers1)
```

```
# A tibble: 6 x 10
```

	subject	LDL	HT	age	smoking	drinkany	SBP	physact
	<int>	<dbl>	<fct>	<int>	<fct>	<fct>	<int>	<fct>
1	1	122	place~	70	no	no	138	much m~
2	2	242	place~	62	no	no	118	much l~
3	4	116	place~	64	yes	yes	152	much l~
4	5	151	place~	65	no	no	175	somewh~
5	6	138	hormo~	68	no	yes	174	about ~
6	8	121	hormo~	69	no	no	178	much m~

```
# ... with 2 more variables: BMI <dbl>, diabetes <fct>
```

The Codebook (n = 2,032 women without diabetes)

Variable	Description	Missing?
subject	subject code	0
LDL	LDL cholesterol in mg/dl	7
HT	factor: hormone therapy or placebo	0
age	age in years	0
smoking	yes or no	0
drinkany	yes or no	2
SBP	systolic BP in mm Hg	0
physact	5-level factor	0
BMI	body-mass index in kg/m ²	2
diabetes	yes or no (all of these are no)	0

Our Modeling Goal

Predict LDL using

- age
- smoking
- drinkany
- SBP
- physact
- BMI
- the interaction of smoking and BMI

Details on physact variable

```
hers1 %>% count(physact)
```

```
# A tibble: 5 x 2
```

	physact	n
	<fct>	<int>
1	about as active	674
2	much less active	107
3	much more active	252
4	somewhat less active	322
5	somewhat more active	677

Skim?

```
hers1 %>% select(-subject) %>% skim()
```

```
> hers1 %>% select(-subject) %>% skim()
```

Skim summary statistics



n obs: 2032

n variables: 9



Variable type: factor

variable	missing	complete	n	n_unique	top_counts	ordered
diabetes	0	2032	2032	1	no: 2032, yes: 0, NA: 0	FALSE
drinkany	2	2030	2032	2	no: 1135, yes: 895, NA: 2	FALSE
HT	0	2032	2032	2	pla: 1031, hor: 1001, NA: 0	FALSE
physact	0	2032	2032	5	som: 677, abo: 674, som: 322, muc: 252	FALSE
smoking	0	2032	2032	2	no: 1733, yes: 299, NA: 0	FALSE

Variable type: integer

variable	missing	complete	n	mean	sd	p0	p25	median	p75	p100	hist
age	0	2032	2032	66.89	6.75	44	62	67	72	79	
SBP	0	2032	2032	133.38	18.47	83	120	132	145	197	

Variable type: numeric

variable	missing	complete	n	mean	sd	p0	p25	median	p75	p100	hist
BMI	2	2030	2032	27.67	5.14	15.21	24.2	26.89	30.27	54.13	
LDL	7	2025	2032	145.65	37.07	36.8	120.6	141.4	166	351.2	

Missingness pattern?

```
na.pattern(hers1) # from Hmisc
```

```
pattern
```

```
0000000000 0000000010 0000010000 0100000000  
      2021          2          2          7
```

```
names(hers1)
```

```
[1] "subject"  "LDL"      "HT"       "age"      "smoking"  
[6] "drinkany" "SBP"     "physact"  "BMI"     "diabetes"
```

Simple Imputation into `hers2`

Simple Imputation for drinkany, BMI and LDL

Since drinkany is a factor, we have to do some extra work to impute.

```
set.seed(432092)

hers2 <- hers1 %>%
  mutate(drinkany_n =
    ifelse(drinkany == "yes", 1, 0)) %>%
  impute_pmm(drinkany_n ~ age + smoking) %>%
  mutate(drinkany =
    ifelse(drinkany_n == 1, "yes", "no")) %>%
  impute_rlm(BMI ~ age + smoking + SBP) %>%
  impute_rlm(LDL ~ age + smoking + SBP + BMI)
```

Now, check missingness...

```
na.pattern(hers2)
```

```
pattern
000000000000
      2032
```

```
names(hers2)
```

```
[1] "subject"      "LDL"          "HT"           "age"
[5] "smoking"      "drinkany"     "SBP"          "physact"
[9] "BMI"          "diabetes"     "drinkany_n"
```

Multiple Imputation with aregImpute

Multiple Imputation using aregImpute from Hmisc

Model to predict all missing values of any variables, using additive regression bootstrapping and predictive mean matching.

Steps are:

- 1 aregImpute draws a sample with replacement from the observations where the target variable is observed, not missing.
- 2 It then fits a flexible additive model to predict this target variable while finding the optimum transformation of it.
- 3 It then uses this fitted flexible model to predict the target variable in all of the original observations.
- 4 Finally, it imputes each missing value of the target variable with the observed value whose predicted transformed value is closest to the predicted transformed value of the missing value.

Fitting a Multiple Imputation Model

```
set.seed(4320132)
dd <- datadist(hers1)
options(datadist = "dd")
fit3 <- aregImpute(~ LDL + age + smoking + drinkany +
                  SBP + physact + BMI,
                  nk = c(0, 3:5), tlinear = FALSE,
                  data = hers1, B = 10, n.impute = 20)
```

Iteration 1

Iteration 2

Iteration 3

Iteration 4

Iteration 5

Iteration 6

Iteration 7

Iteration 8

Iteration 9

Multiple Imputation using `aregImpute` from `Hmisc`

`aregImpute` requires specifications of all variables, and several other details:

- `n.impute` = number of imputations, we'll run 20
- `nk` = number of knots to describe level of complexity, with our choice `nk = c(0, 3:5)` we'll fit both linear models and models with restricted cubic splines with 3, 4, and 5 knots
- `tlinear = FALSE` allows the target variable to have a non-linear transformation when `nk` is 3 or more
- `B = 10` specifies 10 bootstrap samples will be used
- `data` specifies the source of the variables

aregImpute Imputation Results (1 of 3)

```
fit3
```

```
> fit3
```

Multiple Imputation using Bootstrap and PMM

```
aregImpute(formula = ~LDL + age + smoking + drinkany + SBP +  
  physact + BMI, data = hers1, n.impute = 5, nk = c(0, 3:5),  
  tlinear = FALSE, B = 10)
```

```
n: 2032      p: 7      Imputations: 5      nk: 0
```

Number of NAs:

LDL	age	smoking	drinkany	SBP	physact	BMI
7	0	0	2	0	0	2

	type	d.f.
LDL	s	1
age	s	1
smoking	c	1
drinkany	c	1
SBP	s	1
physact	c	4
BMI	s	1

aregImpute Imputation Results (2 of 3)

R-squares for Predicting Non-Missing Values for Each Variable
Using Last Imputations of Predictors

	LDL	drinkany	BMI
	0.019	0.029	0.093

Resampling results for determining the complexity of imputation models

Variable being imputed: LDL

			nk=0	nk=3	nk=4	nk=5
Bootstrap bias-corrected	R ²		0.0151	0.0149	0.0101	0.00976
10-fold cross-validated	R ²		0.0154	0.0224	0.0129	0.01913
Bootstrap bias-corrected	mean	error	28.2956	42.5462	43.9458	39.56345
10-fold cross-validated	mean	error	145.8339	43.2577	44.8477	45.07517
Bootstrap bias-corrected	median	error	22.7110	35.0460	38.9420	32.95988
10-fold cross-validated	median	error	142.1896	35.3638	38.3446	38.08496

aregImpute Imputation Results (3 of 3)

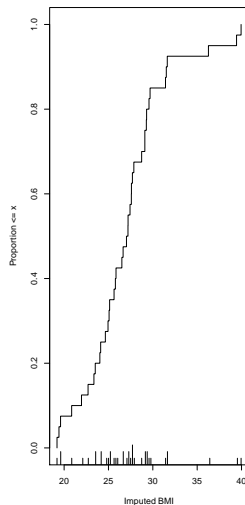
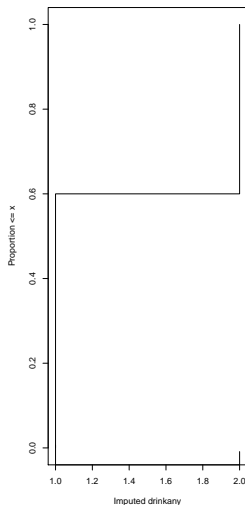
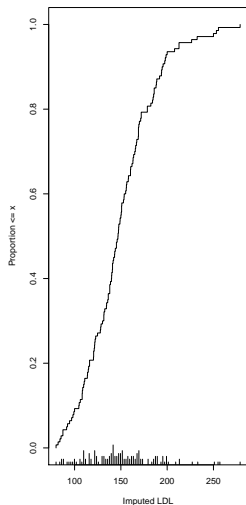
Variable being imputed: drinkany

		nk=0	nk=3	nk=4	nk=5
Bootstrap bias-corrected	R ²	0.0138	0.0110	0.0131	0.0104
10-fold cross-validated	R ²	0.0191	0.0184	0.0182	0.0122
Bootstrap bias-corrected	mean error	0.4535	0.4529	0.4551	0.4567
10-fold cross-validated	mean error	0.4482	0.4499	0.4382	0.4644
Bootstrap bias-corrected	median error	0.0000	0.0000	0.0000	0.0000
10-fold cross-validated	median error	0.2000	0.3000	0.0000	0.2000

Variable being imputed: BMI

		nk=0	nk=3	nk=4	nk=5
Bootstrap bias-corrected	R ²	0.0851	0.0878	0.0858	0.0892
10-fold cross-validated	R ²	0.0880	0.0940	0.0930	0.0923
Bootstrap bias-corrected	mean error	3.8316	4.8352	4.9466	5.1806
10-fold cross-validated	mean error	27.6718	4.8115	4.9504	4.9765
Bootstrap bias-corrected	median error	2.9944	4.0176	4.0021	4.2517
10-fold cross-validated	median error	27.0170	4.0261	3.9930	4.0836

A plot of the imputed values... (results)



A plot of the imputed values... (code)

```
par(mfrow = c(1,3))  
plot(fit3)  
par(mfrow = c(1,1))
```

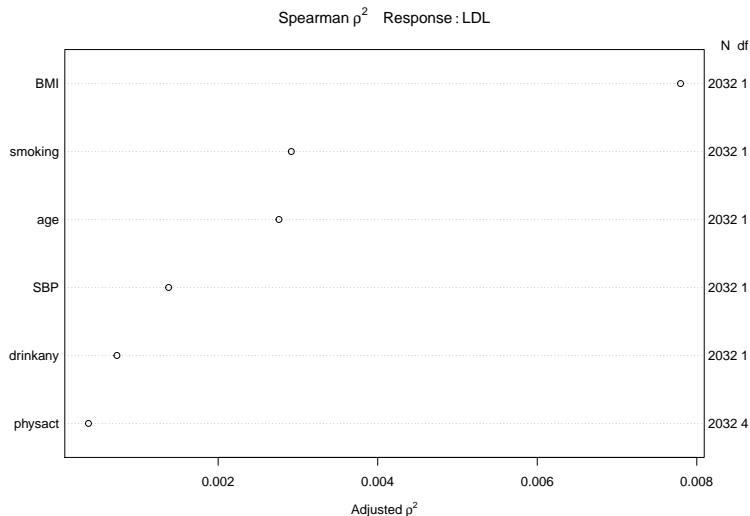
- For LDL, we imputed most of the 7 missing subjects in most of the 20 imputation runs to values within a range of around 120 through 200, but occasionally, we imputed values that were substantially lower than 100.
- For drinkany we imputed about 70% no and 30% yes.
- For BMI, we imputed values ranging from about 23 to 27 in many cases, and up near 40 in other cases.
- This method never imputes a value for a variable that doesn't already exist in the data.

Spearman ρ^2 Plot

We've already decided to include a BMI*smoking product term, but how should we prioritize the degrees of freedom we spend on non-linearity otherwise?

```
plot(spearman2(LDL ~ age + smoking + drinkany + SBP +  
              physact + BMI, data = hers2))
```

Spearman ρ^2 Plot Result



Fitting a Linear Regression with `ols`

Model we'll fit

Fitting a model to predict LDL using

- BMI with a restricted cubic spline, 5 knots
- age with a quadratic polynomial
- SBP as a linear term
- drinkany indicator
- physact factor
- smoking indicator and its interaction with BMI

We could fit this to the data

- restricted to complete cases (hers1, effectively)
- after simple imputation (hers2)
- after our multiple imputation (fit3)

Fitting the model after simple imputation

```
dd <- datadist(hers2)
options(datadist = "dd")

m2 <- ols(LDL ~ rcs(BMI, 5) + pol(age, 2) + SBP +
          drinkany + physact + smoking +
          smoking %ia% BMI, data = hers2,
          x = TRUE, y = TRUE)
```

where %ia% identifies the linear interaction alone.

m2 results (slide 1 of 2)

```
> m2
Linear Regression Model

ols(formula = LDL ~ rcs(BMI, 5) + pol(age, 2) + SBP + drinkany +
      physact + smoking + smoking %ia% BMI, data = hers2, x = TRUE,
      y = TRUE)
```

		Model Likelihood		Discrimination	
		Ratio Test		Indexes	
Obs	2032	LR chi2	53.14	R2	0.026
sigma	36.6503	d.f.	14	R2 adj	0.019
d.f.	2017	Pr(> chi2)	0.0000	g	6.631

Residuals

	Min	1Q	Median	3Q	Max
	-113.379	-24.326	-3.835	20.832	197.097

m2 results (slide 2 of 2)

	Coef	S.E.	t	Pr(> t)
Intercept	120.2662	67.6113	1.78	0.0754
BMI	1.5508	1.0071	1.54	0.1237
BMI'	-8.4486	9.0978	-0.93	0.3532
BMI''	39.6413	37.1378	1.07	0.2859
BMI'''	-54.8924	44.2677	-1.24	0.2151
age	-0.5249	1.9490	-0.27	0.7877
age^2	0.0014	0.0148	0.10	0.9233
SBP	0.1209	0.0451	2.68	0.0074
drinkany=yes	-3.7023	1.6544	-2.24	0.0253
physact=much less active	-4.7408	3.8621	-1.23	0.2198
physact=much more active	-0.2635	2.7391	-0.10	0.9234
physact=somewhat less active	0.0130	2.5101	0.01	0.9959
physact=somewhat more active	3.8031	2.0193	1.88	0.0598
smoking=yes	-6.8961	12.0196	-0.57	0.5662
smoking=yes * BMI	0.4892	0.4375	1.12	0.2636

Validation of summary statistics

```
validate(m2)
```

	index.orig	training	test	optimism
R-square	0.0258	0.0307	0.0188	0.0119
MSE	1333.3300	1320.0677	1342.9027	-22.8350
g	6.6306	7.1548	5.8726	1.2821
Intercept	0.0000	0.0000	26.2153	-26.2153
Slope	1.0000	1.0000	0.8208	0.1792

	index.corrected	n
R-square	0.0139	40
MSE	1356.1650	40
g	5.3485	40
Intercept	26.2153	40
Slope	0.8208	40

anova(m2) results

```
> anova(m2)
```

Analysis of Variance

Response: LDL

Factor	d.f.	Partial SS	MS	F	P
BMI (Factor+Higher Order Factors)	5	2.758824e+04	5517.64861	4.11	0.0010
All Interactions	1	1.679813e+03	1679.81344	1.25	0.2636
Nonlinear	3	9.735452e+03	3245.15068	2.42	0.0647
age	2	9.175762e+03	4587.88077	3.42	0.0330
Nonlinear	1	1.244351e+01	12.44351	0.01	0.9233
SBP	1	9.657476e+03	9657.47569	7.19	0.0074
drinkany	1	6.726918e+03	6726.91809	5.01	0.0253
physact	4	9.709992e+03	2427.49791	1.81	0.1247
smoking (Factor+Higher Order Factors)	2	1.085405e+04	5427.02463	4.04	0.0177
All Interactions	1	1.679813e+03	1679.81344	1.25	0.2636
smoking * BMI (Factor+Higher Order Factors)	1	1.679813e+03	1679.81344	1.25	0.2636
TOTAL NONLINEAR	4	9.738807e+03	2434.70175	1.81	0.1237
TOTAL NONLINEAR + INTERACTION	5	1.171134e+04	2342.26845	1.74	0.1214
REGRESSION	14	7.178905e+04	5127.78931	3.82	<.0001
ERROR	2017	2.709327e+06	1343.24569		

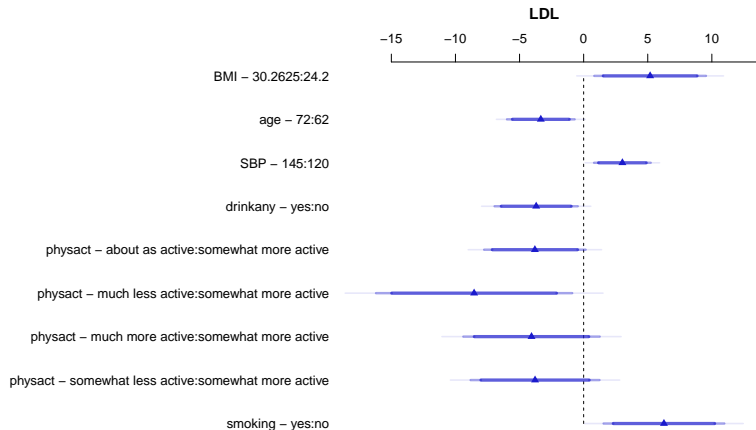
summary(m2) results

```
> summary(m2)
```

Effects	Response : LDL							
Factor	Low	High	Diff.	Effect	S.E.	Lower 0.95	Upper 0.95	
BMI	24.2	30.263	6.0625	5.1862	2.2217	0.82921	9.54330	
age	62.0	72.000	10.0000	-3.3412	1.3450	-5.97890	-0.70357	
SBP	120.0	145.000	25.0000	3.0218	1.1270	0.81165	5.23190	
drinkany - yes:no	1.0	2.000	NA	-3.7023	1.6544	-6.94690	-0.45779	
physact - about as active:somewhat more active	5.0	1.000	NA	-3.8031	2.0193	-7.76310	0.15695	
physact - much less active:somewhat more active	5.0	2.000	NA	-8.5439	3.9035	-16.19900	-0.88862	
physact - much more active:somewhat more active	5.0	3.000	NA	-4.0666	2.7125	-9.38630	1.25310	
physact - somewhat less active:somewhat more active	5.0	4.000	NA	-3.7901	2.5633	-8.81720	1.23690	
smoking - yes:no	1.0	2.000	NA	6.2635	2.4009	1.55500	10.97200	

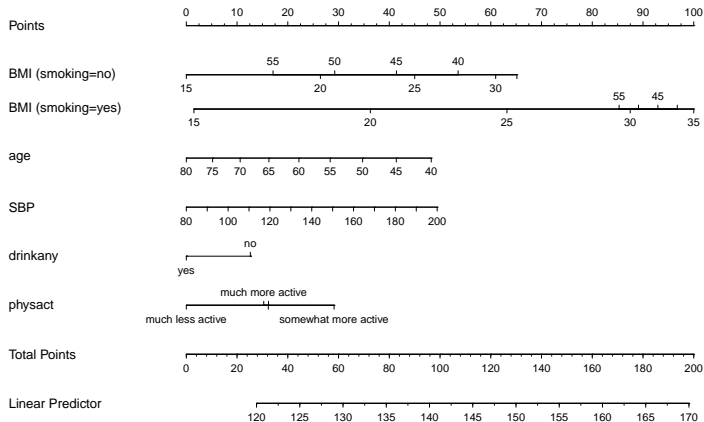
Adjusted to: BMI=26.9 smoking=no

plot(summary(m2)) results



Adjusted to: BMI=26.9 smoking=no

plot(nomogram(m2))



Making Predictions for an Individual

Suppose now that we want to use R to get a prediction for a new individual subject with BMI = 30, age = 50, smoking = yes and physact = about as active, drinkany= yes and SBP of 150.

```
predict(m2, expand.grid(BMI = 30, age = 50, smoking = "yes",  
                        physact = "about as active",  
                        drinkany = "yes", SBP = 150),  
        conf.int = 0.95, conf.type = "individual")
```

\$linear.predictors	\$lower	\$upper
160.9399	88.48615	233.3936

Making Predictions for a Long-Run Mean

The other kind of prediction we might wish to make is for the mean of a series of subjects whose BMI = 30, age = 50, smoking = yes and physact = about as active, drinkany= yes and SBP of 150.

```
predict(m2, expand.grid(BMI = 30, age = 50, smoking = "yes",  
                        physact = "about as active",  
                        drinkany = "yes", SBP = 150),  
        conf.int = 0.95, conf.type = "mean")
```

\$linear.predictors	\$lower	\$upper
160.9399	151.8119	170.0679

Of course, the confidence interval will always be narrower than the prediction interval given the same predictor values.

Influential Points?

```
which.influence(m2, cutoff = 0.4)
```

```
$Intercept
```

```
[1] 1135
```

```
$age
```

```
[1] 1135
```

```
$smoking
```

```
[1] 132
```

```
$`smoking * BMI`
```

```
[1] 132
```

Fitting the model to the complete cases

```
d <- datadist(hers1)
options(datadist = "d")

m1 <- ols(LDL ~ rcs(BMI, 5) + pol(age, 2) + SBP +
          drinkany + physact + smoking +
          smoking %ia% BMI, data = hers1,
          x = TRUE, y = TRUE)
```

where %ia% identifies the linear interaction alone.

Putting it Together

What have we got?

- An imputation model `fit3`

```
fit3 <- aregImpute(~ LDL + age + smoking + drinkany + SBP +  
  physact + BMI, nk = c(0, 3:5), tlinear = FALSE,  
  data = hers1, B = 10, n.impute = 20, x = TRUE)
```

- A prediction model

```
m1 <- ols(LDL ~ rcs(BMI, 5) + pol(age, 2) + SBP +  
  drinkany + physact + smoking + smoking %ia% BMI,  
  x = TRUE, y = TRUE)
```

Now we put them together

Linear Regression & Imputation Model

```
m3imp <-  
  fit.mult.impute(LDL ~ rcs(BMI, 5) + pol(age, 2) + SBP +  
    drinkany + physact + smoking +  
    smoking %ia% BMI,  
    fitter = ols, xtrans = fit3,  
    data = hers1)
```

Variance Inflation Factors Due to Imputation:

Intercept	BMI
1.00	1.00
BMI '	BMI ' '
1.00	1.00
BMI ' ' '	age
1.00	1.00
age^2	SBP

m3imp results (1 of 2)

```
> m3imp
```

```
Linear Regression Model
```

```
fit.mult.impute(formula = LDL ~ rcs(BMI, 5) + pol(age, 2) + SBP +  
  drinkany + physact + smoking + smoking %ia% BMI, fitter = ols,  
  xtrans = fit3, data = hers1)
```

		Model Likelihood		Discrimination	
		Ratio Test		Indexes	
Obs	2032	LR chi2	53.30	R2	0.026
sigma	36.7128	d.f.	14	R2 adj	0.019
d.f.	2017	Pr(> chi2)	0.0000	g	6.652

```
Residuals
```

Min	1Q	Median	3Q	Max
-113.10	-24.46	-3.81	20.92	197.42

m3imp results (2 of 2)

	Coef	S.E.	t	Pr(> t)
Intercept	121.1499	67.7998	1.79	0.0741
BMI	1.5445	1.0097	1.53	0.1263
BMI'	-8.2945	9.1027	-0.91	0.3623
BMI''	39.0890	37.3055	1.05	0.2949
BMI'''	-54.2119	44.4779	-1.22	0.2230
age	-0.5521	1.9547	-0.28	0.7776
age^2	0.0016	0.0148	0.11	0.9119
SBP	0.1216	0.0453	2.69	0.0073
drinkany=yes	-3.7404	1.6625	-2.25	0.0246
physact=much less active	-4.7426	3.8692	-1.23	0.2204
physact=much more active	-0.2665	2.7455	-0.10	0.9227
physact=somewhat less active	0.0313	2.5214	0.01	0.9901
physact=somewhat more active	3.8060	2.0257	1.88	0.0604
smoking=yes	-6.9198	12.0472	-0.57	0.5658
smoking=yes * BMI	0.4917	0.4388	1.12	0.2626

anova(m3imp)

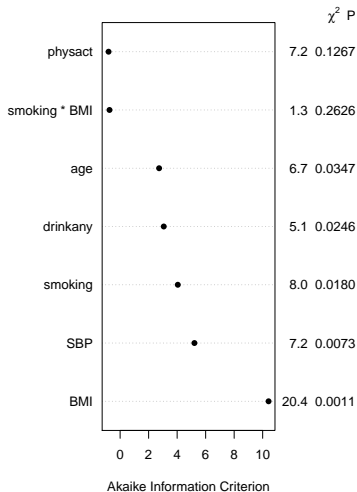
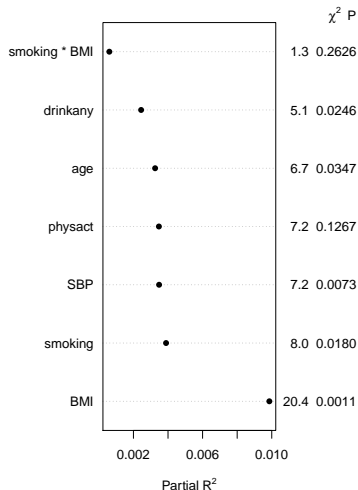
```
> anova(m3imp)
```

Analysis of Variance

Response: LDL

Factor	d.f.	Partial SS	MS	F	P
BMI (Factor+Higher Order Factors)	5	27514.6406	5502.9281	4.08	0.0011
All Interactions	1	1692.6044	1692.6044	1.26	0.2626
Nonlinear	3	9741.6194	3247.2065	2.41	0.0653
age	2	9078.9851	4539.4926	3.37	0.0347
Nonlinear	1	16.5032	16.5032	0.01	0.9119
SBP	1	9721.1667	9721.1667	7.21	0.0073
drinkany	1	6822.3861	6822.3861	5.06	0.0246
physact	4	9690.3632	2422.5908	1.80	0.1267
smoking (Factor+Higher Order Factors)	2	10845.6127	5422.8063	4.02	0.0180
All Interactions	1	1692.6044	1692.6044	1.26	0.2626
smoking * BMI (Factor+Higher Order Factors)	1	1692.6044	1692.6044	1.26	0.2626
TOTAL NONLINEAR	4	9747.0966	2436.7741	1.81	0.1246
TOTAL NONLINEAR + INTERACTION	5	11717.3715	2343.4743	1.74	0.1225
REGRESSION	14	71571.1297	5112.2236	3.79	<.0001
ERROR	2017	2718570.0412	1347.8285		

Evaluation via Partial R² and AIC (result)



Evaluation via Partial R^2 and AIC (code)

```
par(mfrow = c(1,2))  
plot(anova(m3imp), what="partial R2")  
plot(anova(m3imp), what="aic")  
par(mfrow = c(1,1))
```

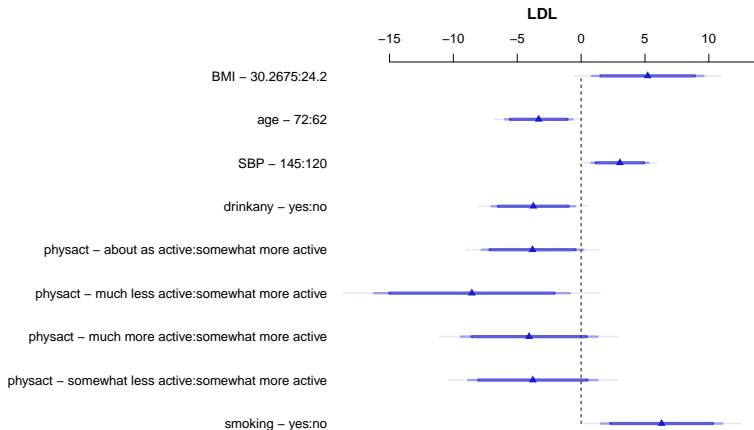
summary(m3imp)

```
> summary(m3imp)
```

Effects	Response : LDL						
Factor	Low	High	Diff.	Effect	S.E.	Lower 0.95	Upper 0.95
BMI	24.2	30.268	6.0675	5.2165	2.2287	0.84565	9.58730
age	62.0	72.000	10.0000	-3.3219	1.3498	-5.96910	-0.67463
SBP	120.0	145.000	25.0000	3.0394	1.1317	0.81989	5.25880
drinkany - yes:no	1.0	2.000	NA	-3.7404	1.6625	-7.00080	-0.47996
physact - about as active:somewhat more active	5.0	1.000	NA	-3.8060	2.0257	-7.77860	0.16663
physact - much less active:somewhat more active	5.0	2.000	NA	-8.5486	3.9114	-16.21900	-0.87779
physact - much more active:somewhat more active	5.0	3.000	NA	-4.0724	2.7198	-9.40640	1.26160
physact - somewhat less active:somewhat more active	5.0	4.000	NA	-3.7746	2.5773	-8.82900	1.27980
smoking - yes:no	1.0	2.000	NA	6.3043	2.4196	1.55900	11.05000

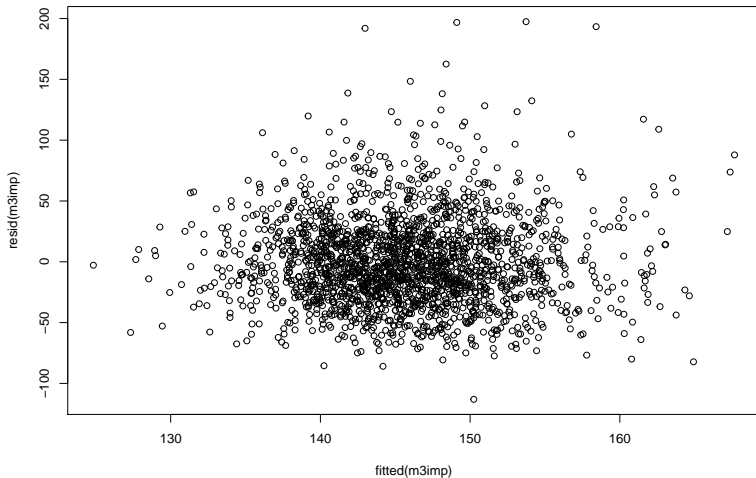
Adjusted to: BMI=26.895 smoking=no

```
plot(summary(m3imp))
```



Adjusted to: BMI=26.895 smoking=no


```
plot(resid(m1imp) ~ fitted(m1imp))
```



plot(nomogram(m3imp))

