ANLY 511 Final Project - MANOVA

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MANOVA

MANOVA stands for multivariate analysis of variance. It's basically used to evaluate mean differences on two or more dependent variables simultaneously. That's the main difference compared with ANOVA.

We try to answer below research questions by performing MANOVA. And CO2, CO, and THC are three dependent variables.

Research Questions

1. We want to know if there is statistically significant difference in CO2, CO, and THC between the different types of vehicle.
2. We want to know if there is statistically significant difference in CO2, CO, and THC between vehicle manufacturers.
3. We want to know if there is statistically significant difference in CO2, CO, and THC between the different vehicle transmission types.

Assumptions of MANOVA

There are additional assumptions of MANOVA:

1. Homogeneity of the variances across the range of predictors:

Our data should have equal variance-covariance matrics for each combination formed by each group in the independent variable.

2. Multicollinearity:

Our data should be no multicollinearity among dependent variables.

Loading packages

```
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.2 --
## v ggplot2 3.3.6     v purrr   0.3.4
## v tibble  3.1.7     v dplyr   1.0.9
## v tidyr   1.2.0     v stringr 1.4.0
```

```
## v readr   2.1.2     v forcats 0.5.1
## -- Conflicts ---------------------------------------- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(ggpubr)
library(rstatix)
```

```
##
## Attaching package: 'rstatix'
##
## The following object is masked from 'package:stats':
##
##     filter
```

```
library(car)
```

```
## Loading required package: carData
##
## Attaching package: 'car'
##
## The following object is masked from 'package:dplyr':
##
##     recode
##
## The following object is masked from 'package:purrr':
##
##     some
```

```
library(broom)
library(gplots)
```

```
##
## Attaching package: 'gplots'
##
## The following object is masked from 'package:stats':
##
##     lowess
```

```
library(mvnormalTest)
library(heplots)
```

Enter Data

```
# Read cleaned nonelectric data
nonelectric<-read.csv("/Users/linlinw/Desktop/ANLY511-Final-Project-main/data/cardata_nonelectric_clean
# Remove first column X
nonelectric<-nonelectric[,-1]
# View first couple rows of data
head(nonelectric)
```

```
##   Model.Year Vehicle.Manufacturer.Name Veh.Mfr.Code Represented.Test.Veh.Make
## 1       2018              aston martin          ASX              Aston Martin
## 2       2018              aston martin          ASX              Aston Martin
## 3       2018              aston martin          ASX              Aston Martin
## 4       2018              aston martin          ASX              Aston Martin
## 5       2018              aston martin          ASX              Aston Martin
## 6       2018              aston martin          ASX              Aston Martin
##   Represented.Test.Veh.Model Test.Veh.Displacement..L. Vehicle.Type
## 1                       DB11                       5.2          Car
## 2                       DB11                       5.2          Car
## 3                    DB11 V8                       4.0          Car
## 4                    DB11 V8                       4.0          Car
## 5                   Rapide S                       6.0          Car
## 6                   Rapide S                       6.0          Car
##   Rated.Horsepower X..of.Cylinders.and.Rotors Tested.Transmission.Type.Code
## 1              600                         12                            SA
## 2              600                         12                            SA
## 3              503                          8                            SA
## 4              503                          8                            SA
## 5              552                         12                            SA
## 6              552                         12                            SA
##   Tested.Transmission.Type X..of.Gears Transmission.Lockup. Drive.System.Code
## 1           Semi-Automatic           8                    Y                 R
## 2           Semi-Automatic           8                    Y                 R
## 3           Semi-Automatic           8                    Y                 R
## 4           Semi-Automatic           8                    Y                 R
## 5           Semi-Automatic           8                    Y                 R
## 6           Semi-Automatic           8                    Y                 R
##   Drive.System.Description Equivalent.Test.Weight..lbs.. Axle.Ratio N.V.Ratio
## 1      2-Wheel Drive, Rear                           4500       2.70      22.2
## 2      2-Wheel Drive, Rear                           4500       2.70      22.2
## 3      2-Wheel Drive, Rear                           4500       2.70      22.2
## 4      2-Wheel Drive, Rear                           4500       2.70      22.2
## 5      2-Wheel Drive, Rear                           4750       2.73      22.4
## 6      2-Wheel Drive, Rear                           4750       2.73      22.4
##   Test.Fuel.Type.Description THC..g.mi. CO..g.mi. CO2..g.mi. RND_ADJ_FE
## 1       Tier 2 Cert Gasoline   0.024700  0.418000     466.87       18.8
## 2       Tier 2 Cert Gasoline   0.001155  0.067334     285.00       30.9
## 3       Tier 2 Cert Gasoline   0.026500  0.070000     386.66       22.7
## 4       Tier 2 Cert Gasoline   0.000500  0.030000     259.74       33.8
## 5       Tier 2 Cert Gasoline   0.026900  0.500000     511.93       17.3
## 6       Tier 2 Cert Gasoline   0.000800  0.060000     296.63       29.9
##   DT.Inertia.Work.Ratio.Rating DT.Absolute.Speed.Change.Ratg
## 1                   -2.5300000                   -1.7300000
## 2                    1.3600000                    0.4400000
## 3                  -11.9900000                   -9.2600000
## 4                   -3.6400000                   -3.2100000
## 5                    0.5655838                    0.4420405
## 6                    0.5655838                    0.4420405
##   DT.Energy.Economy.Rating Target.Coef.A..lbf. Target.Coef.B..lbf.mph.
## 1               -1.7100000               40.94                  0.0169
## 2               -0.5900000               40.94                  0.0169
## 3               -7.7100000               40.94                  0.0169
## 4               -0.9600000               40.94                  0.0169
```

```
## 5               -0.2002973               32.66                  0.6085
## 6               -0.2002973               32.66                  0.6085
##   Target.Coef.C..lbf.mph..2. Set.Coef.A..lbf. Set.Coef.B..lbf.mph.
## 1                     0.0271           6.810               0.0807
## 2                     0.0271           6.810               0.0807
## 3                     0.0271          11.260               0.0919
## 4                     0.0271          11.260               0.0919
## 5                     0.0198           1.093               2.1980
## 6                     0.0198           1.093               2.1980
##   Set.Coef.C..lbf.mph..2. Aftertreatment.Device.Cd Aftertreatment.Device.Desc
## 1                  0.0245                      TWC         Three-way catalyst
## 2                  0.0245                      TWC         Three-way catalyst
## 3                  0.0251                      TWC         Three-way catalyst
## 4                  0.0251                      TWC         Three-way catalyst
## 5                  0.0280                      TWC         Three-way catalyst
## 6                  0.0280                      TWC         Three-way catalyst
##   Police...Emergency.Vehicle. Averaging.Method.Cd Averging.Method.Desc
## 1                           N                   N         No averaging
## 2                           N                   N         No averaging
## 3                           N                   N         No averaging
## 4                           N                   N         No averaging
## 5                           N                   N         No averaging
## 6                           N                   N         No averaging
```

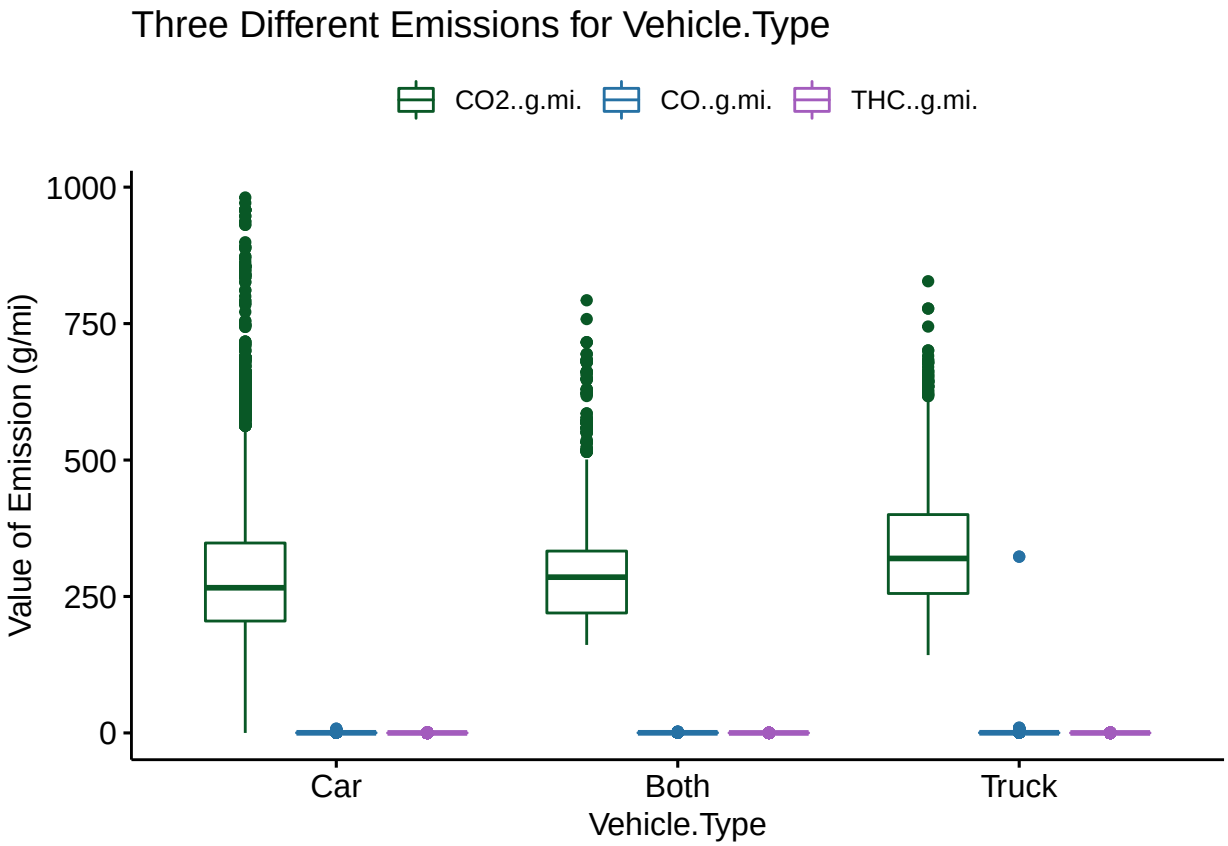
Research Question 1: Is there any important difference in CO2, CO, and THC between the different types of vehicle?

Exploratory Data Analysis:

```
# Create color palettes
Blues <- colorRampPalette(c("#0A146B", "#A9A3DA"))
Purples <- colorRampPalette(c("#3E1370", "#BDA3DA"))
GrBuPuPi <- c("#095826", "#0E7032", "#10913F", "#55A472", "#8CBF9E", "#8CBFB8",
              "#63B7AC", "#2D9A8B", "#137568", "#094E45", "#0B3C5C", "#17547C",
              "#2671A4", "#3C8CC1", "#72B1DB", "#96C3E1", "#B0CDE1", "#B0B3E1",
              "#858ACD", "#4F55AB", "#1923B3", "#0E1468", "#3C1075", "#5821A1",
              "#6B27C4", "#9455E5", "#A278D8", "#A990CA", "#ADA0BF", "#C1A5CB",
              "#B887CA", "#A35CBD", "#762594")
```

```
# Visaulize dataset
ggboxplot(
  nonelectric, x = "Vehicle.Type", y = c("CO2..g.mi.", "CO..g.mi.", "THC..g.mi."),
  merge = TRUE, palette = c("#095826",  "#2671A4","#A35CBD" ),
  title = "Three Different Emissions for Vehicle.Type",
  ylab = "Value of Emission (g/mi)"
  )
```

```
## Warning: `gather_()` was deprecated in tidyr 1.2.0.
## Please use `gather()` instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was generated.
```



From the above boxplot, we can see there is significant difference in CO2 and CO between vehicle type, and significant difference in CO2 and THC between vehicle type. However, the difference in CO and THC between vehicle type is not obvious.

Test assumption

1. Check for Homogeneity

```
boxM(Y = nonelectric[, c("CO2..g.mi.", "CO..g.mi.", "THC..g.mi.")], group = nonelectric$Vehicle.Type)
```

```
##
##  Box's M-test for Homogeneity of Covariance Matrices
##
## data:  nonelectric[, c("CO2..g.mi.", "CO..g.mi.", "THC..g.mi.")]
## Chi-Sq (approx.) = 58734, df = 12, p-value < 2.2e-16
```

Since the p-value is significant for Box's M test, we reject the null hypothesis at 5% significance level and conclude that variance-covariance matrices are not equal for each combination formed by each group in the independent variable. Thus, this assumption is satisfied.

2. Check Multicollinearity

```
cor_co2_co<-cor.test(x = nonelectric$CO2..g.mi., y = nonelectric$CO..g.mi., method = "pearson")$estimate
cor_co2_thc<-cor.test(x = nonelectric$CO2..g.mi., y = nonelectric$THC..g.mi., method = "pearson")$estima
cor_thc_co<-cor.test(x = nonelectric$THC..g.mi., y = nonelectric$CO..g.mi., method = "pearson")$estimate
result<-cbind(cor_co2_co, cor_co2_thc, cor_thc_co)
result
```

```
##     cor_co2_co cor_co2_thc cor_thc_co
## cor  0.0562401   0.3195182 0.07842236
```

As the correlation coefficient between each dependent variable is smaller than 0.9, there is no multicollinearity. So this assumption is hold.

Perform MANOVA

Hypotheses

H_0 : There is no significant difference in CO2, CO, and THC between the different types of vehicle.

H_a : There is significant difference in CO2, CO, and THC between the different types of vehicle.

```
# Fit the MANOVA model
fit1 = manova(cbind(CO2..g.mi., CO..g.mi., THC..g.mi.) ~ Vehicle.Type, data = nonelectric)
summary(fit1, intercept = TRUE)
```

```
##                 Df  Pillai approx F num Df den Df    Pr(>F)
## (Intercept)      1 0.88848    57714      3  21733 < 2.2e-16 ***
## Vehicle.Type     2 0.04618      171      6  43468 < 2.2e-16 ***
## Residuals    21735
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Since the p-value for Vehicle.Type variable is smaller than the significance level 0.05, we can reject the null hypotheses at 5% significance level, and conclude that there is statistically significant difference in CO2, CO, and THC between the different types of vehicle.

However, we are unclear about which emissions are affected by vehicle type. We perform univariate ANOVAs to figure it out.

```
summary.aov(fit1)
```

```
##  Response CO2..g.mi. :
##                 Df    Sum Sq Mean Sq F value    Pr(>F)
## Vehicle.Type     2  10263186 5131593  421.74 < 2.2e-16 ***
## Residuals    21735 264465545   12168
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##  Response CO..g.mi. :
##                 Df Sum Sq Mean Sq F value  Pr(>F)
## Vehicle.Type     2    126  62.795  6.4026 0.00166 **
## Residuals    21735 213170   9.808
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##  Response THC..g.mi. :
##                 Df Sum Sq  Mean Sq F value    Pr(>F)
## Vehicle.Type     2  0.147 0.073417  35.578 3.751e-16 ***
## Residuals    21735 44.852 0.002064
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

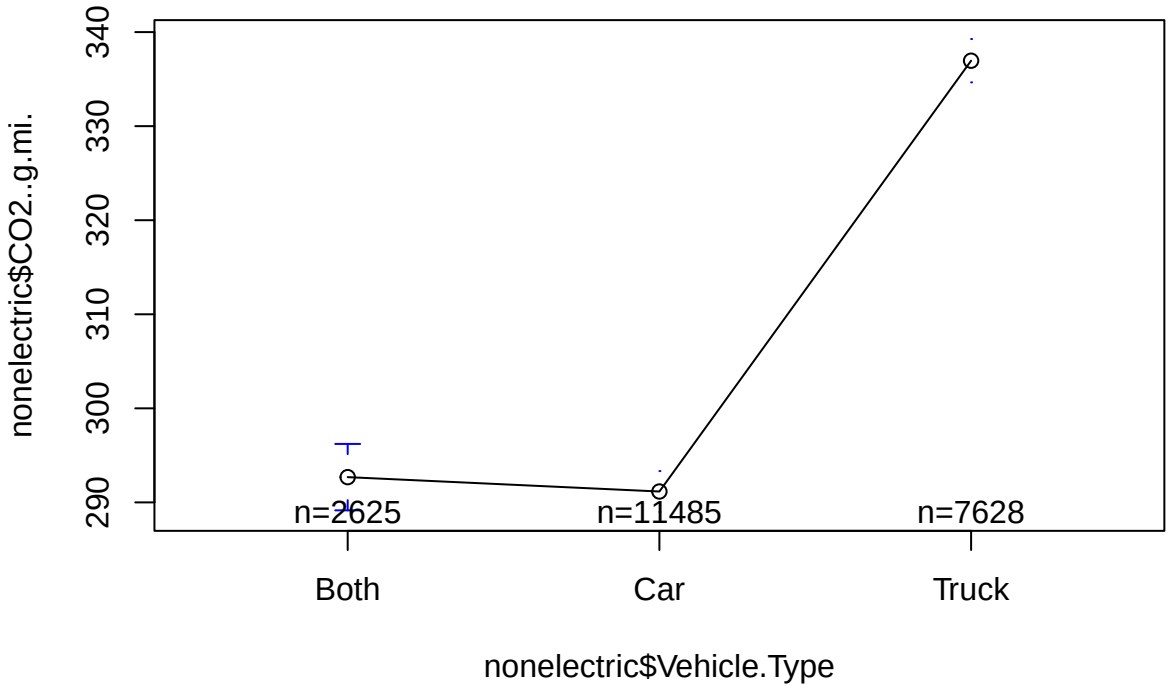
We can see from the output that the p-value for all univariate ANOVAs are smaller than significance level 0.05, which indicates that vehicle type has a statistically significant effect on CO2, CO, and THC emissions.

Visualizing Group Means

Visualizing the Group means for each level of our independent variable vehicle type is helpful to get a better understanding of our results.

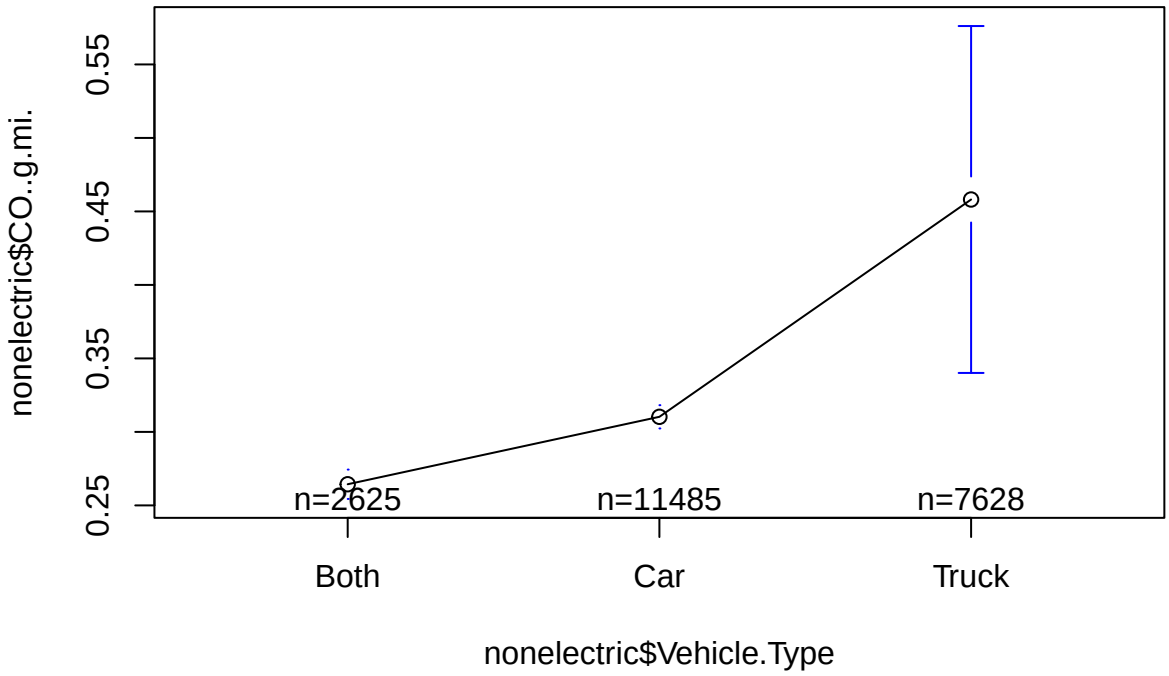
```
#visualize mean CO2 by vehicle type
plotmeans(nonelectric$CO2..g.mi. ~ nonelectric$Vehicle.Type)
```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```

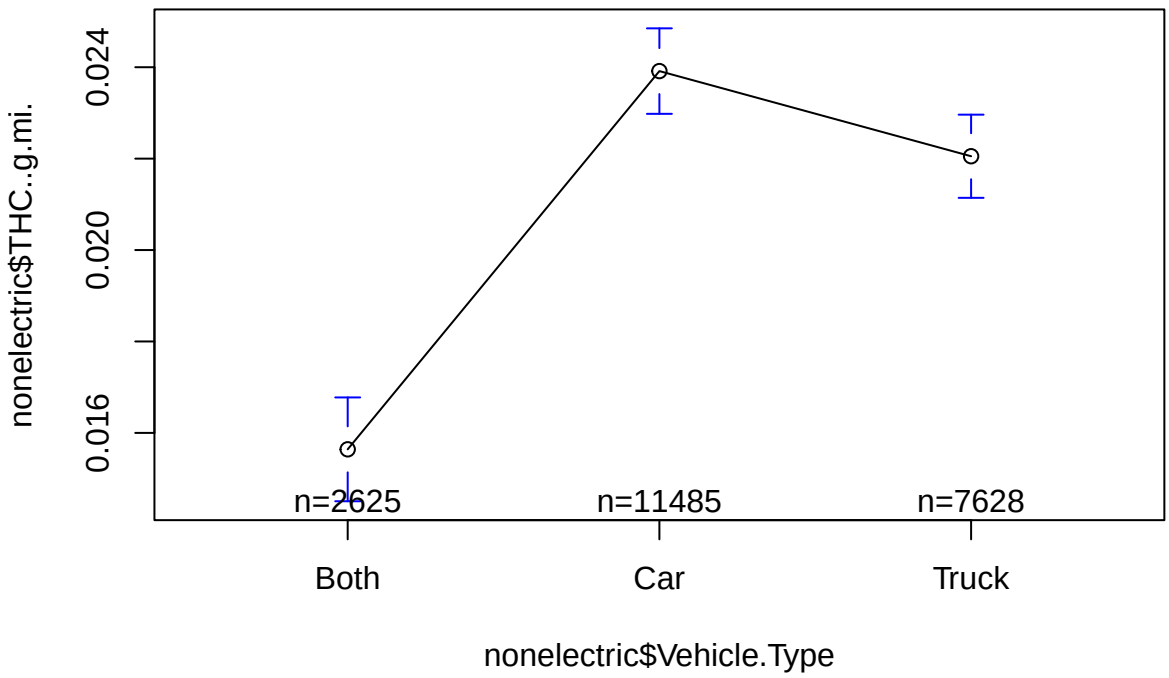



```
#visualize mean CO by vehicle type
plotmeans(nonelectric$CO..g.mi. ~ nonelectric$Vehicle.Type)
```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```



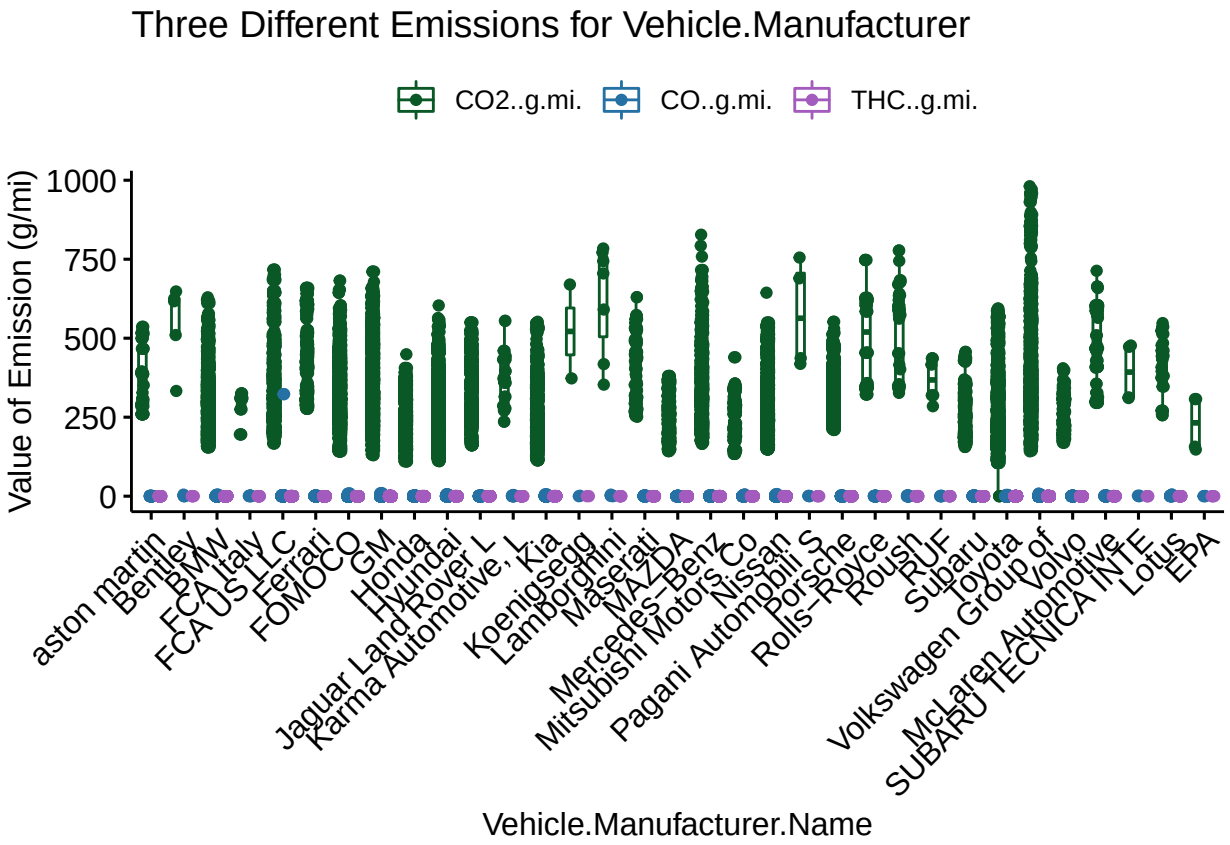

```
#visualize mean THC by vehicle type
plotmeans(nonelectric$THC..g.mi. ~ nonelectric$Vehicle.Type)
```



From the above three plots, we can see that the mean CO2, CO, and THC varies quite a bit by vehicle types. This matches the results from our MANOVA, which indicates that there is statistically significant difference in three emissions based on vehicle types.

Research Question 2: Is there any important difference in CO2, CO, and THC between the different vehicle manufacturers?

```
# Visaulize dataset
p2<-ggboxplot(
  nonelectric, x = "Vehicle.Manufacturer.Name", y = c("CO2..g.mi.", "CO..g.mi.", "THC..g.mi."),
  merge = TRUE, palette = c("#095826",  "#2671A4","#A35CBD" ),
  title = "Three Different Emissions for Vehicle.Manufacturer",
  ylab = "Value of Emission (g/mi)",
  add = "jitter"
)
p2 + rotate_x_text(45)
```



From this boxplot, we can get same conclusion with first plot. There is no important difference in CO and THC between vehicle manufacturer.

Hypotheses2

H_0 : There is no significant difference in CO2, CO, and THC between vehicle manufacturer.

H_a : There is significant difference in CO2, CO, and THC between vehicle manufacturer.

```
# Fit the MANOVA model
fit2 = manova(cbind(CO2..g.mi., CO..g.mi., THC..g.mi.) ~ Vehicle.Manufacturer.Name, data = nonelectric)
summary(fit2, intercept = TRUE)
```

```
##                              Df  Pillai approx F num Df den Df    Pr(>F)
## (Intercept)                   1 0.90421    68286      3  21703 < 2.2e-16 ***
## Vehicle.Manufacturer.Name    32 0.22328       55     96  65115 < 2.2e-16 ***
## Residuals                 21705
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Since the p-value for vehicle manufacturer variable is smaller than the significance level 0.05, we can reject the null hypotheses at 5% significance level, and conclude that there is statistically significant difference in CO2, CO, and THC between the different types of vehicle.

Then we perform univariate ANOVAs to figure it out which emissions are affected by vehicle manufacturer

```r
summary.aov(fit2)
```

```
##  Response CO2..g.mi. :
##                               Df    Sum Sq Mean Sq F value    Pr(>F)
## Vehicle.Manufacturer.Name    32  51944440 1623264  158.15 < 2.2e-16 ***
## Residuals                 21705 222784291   10264
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##  Response CO..g.mi. :
##                               Df Sum Sq Mean Sq F value    Pr(>F)
## Vehicle.Manufacturer.Name    32    701 21.8911   2.235 7.695e-05 ***
## Residuals                 21705 212595  9.7947
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##  Response THC..g.mi. :
##                               Df Sum Sq  Mean Sq F value    Pr(>F)
## Vehicle.Manufacturer.Name    32  1.726 0.053943  27.057 < 2.2e-16 ***
## Residuals                 21705 43.273 0.001994
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We can see from the output that the p-value for all univariate ANOVAs are smaller than significance level 0.05, which indicates that Vehicle Manufacturer has a statistically significant effect on CO2, CO, and THC emissions.

Visualizing Group Means

Visualizing the Group means for each level of our independent variable Vehicle.Manufacturer.Name is helpful to get a better understanding of our results.

```r
#visualize mean CO2 by vehicle type
plotmeans(nonelectric$CO2..g.mi. ~ nonelectric$Vehicle.Manufacturer.Name) +rotate_x_text(45)
```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```

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## length arrow is of indeterminate angle and so skipped

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## length arrow is of indeterminate angle and so skipped

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## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

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## length arrow is of indeterminate angle and so skipped

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## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```

```
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## length arrow is of indeterminate angle and so skipped

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## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

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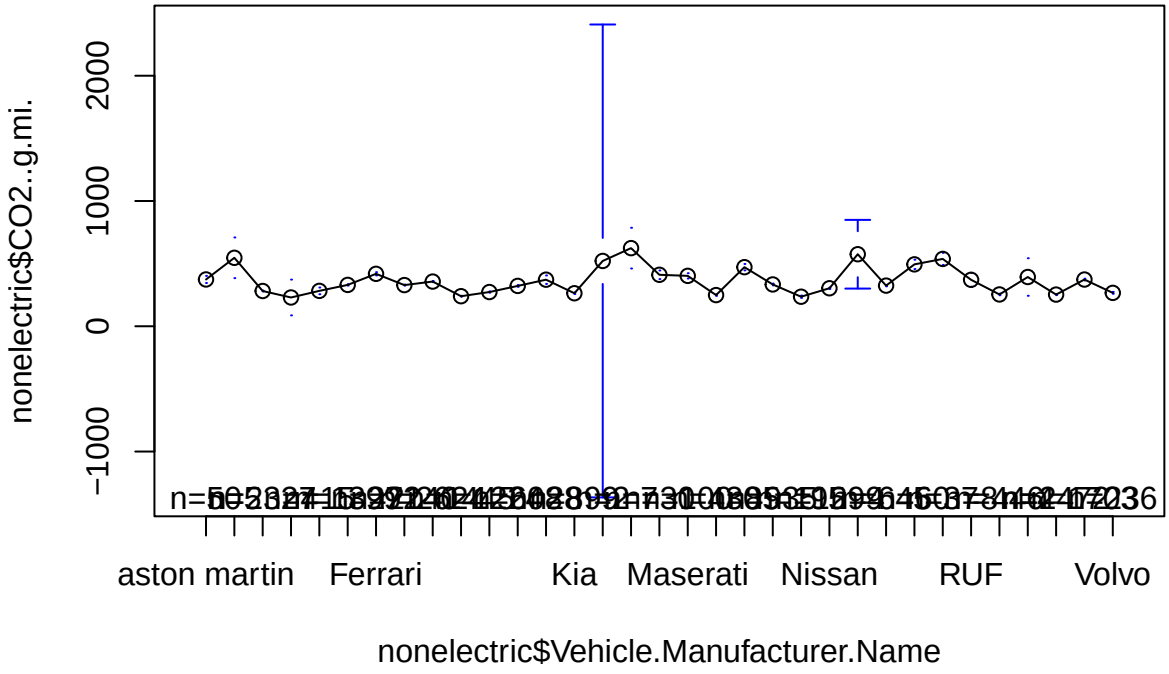


```
## NULL
```

```
#visualize mean CO by vehicle type
plotmeans(nonelectric$CO..g.mi. ~ nonelectric$Vehicle.Manufacturer.Name)
```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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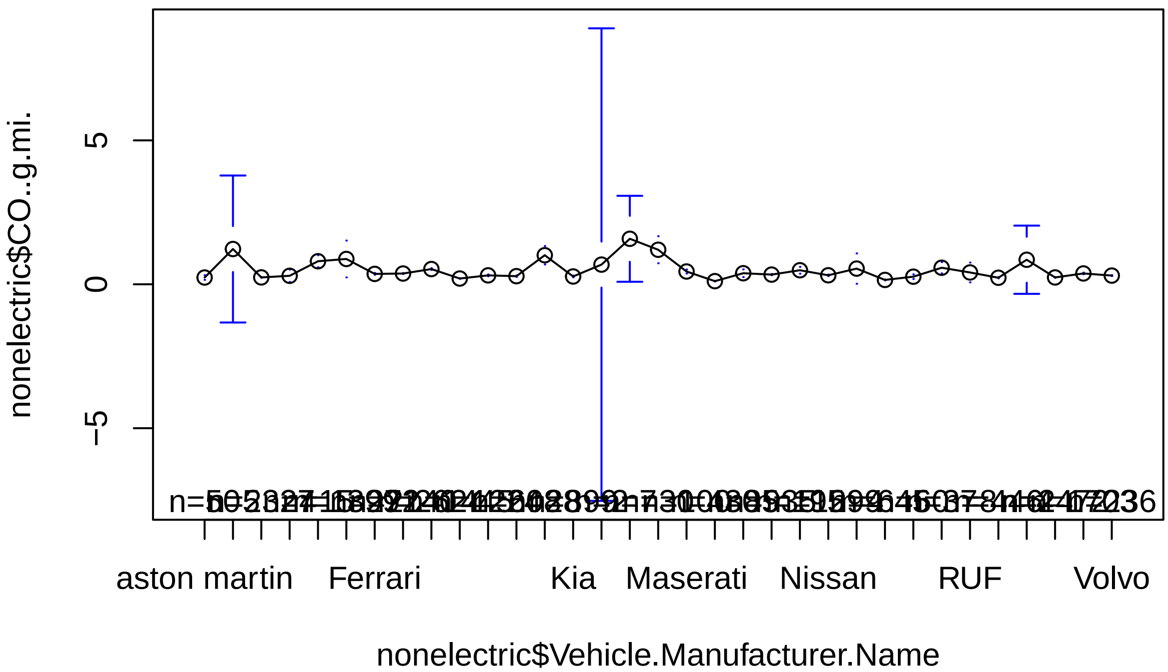


```
#visualize mean THC by vehicle type
plotmeans(nonelectric$THC..g.mi. ~ nonelectric$Vehicle.Manufacturer.Name)
```

```
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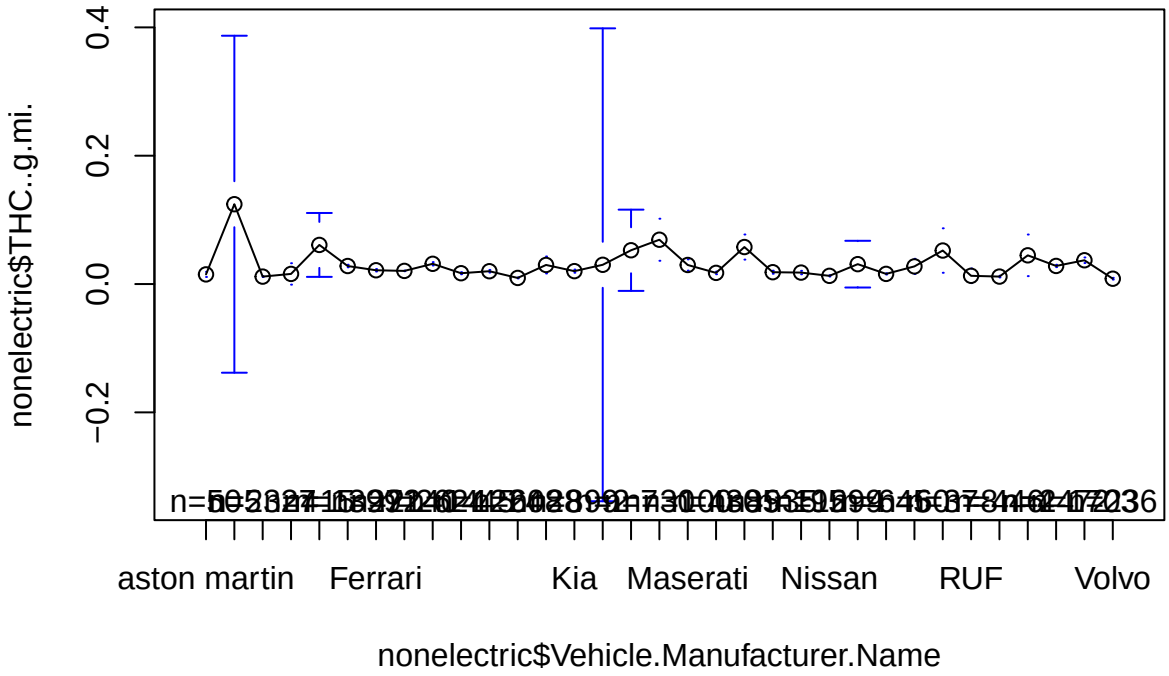
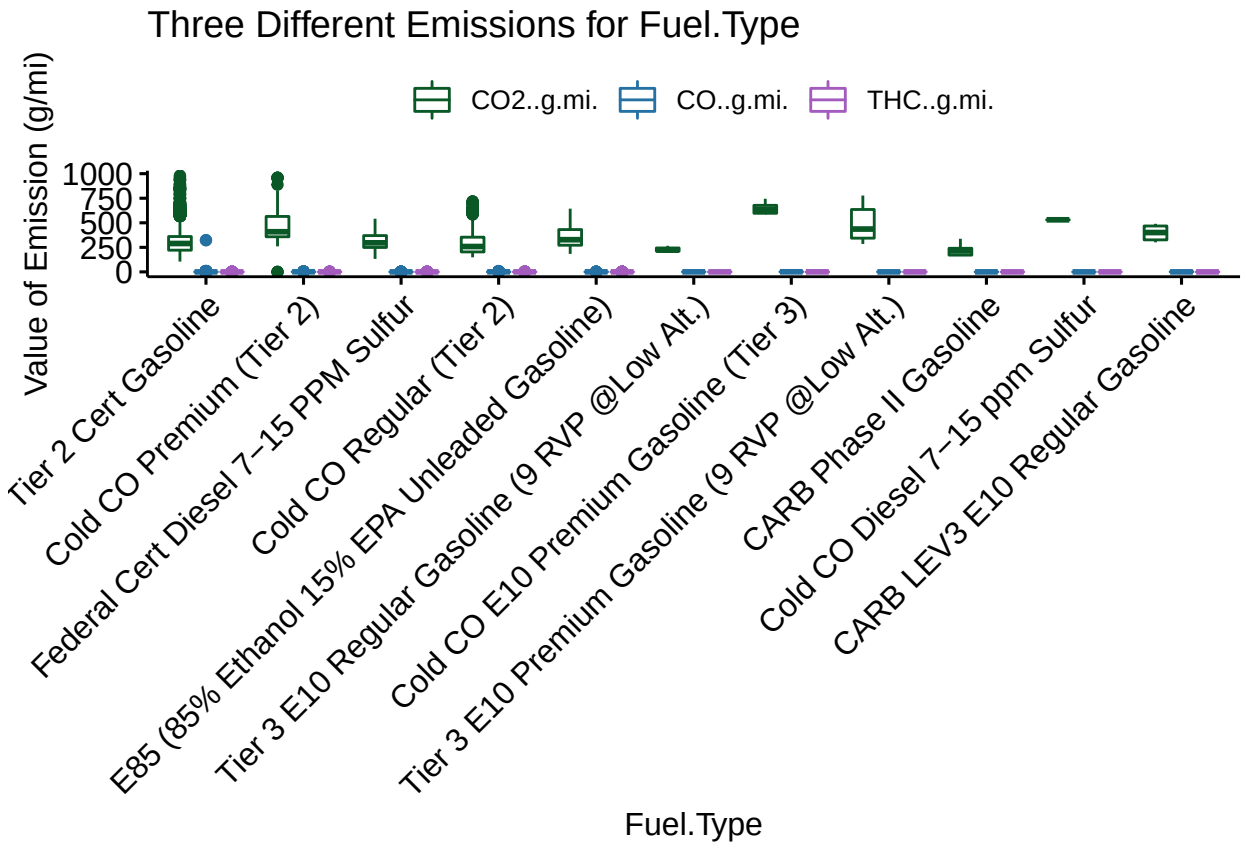


From the above three plots, we can see that the mean CO2, CO, and THC do not vary a lot by vehicle manufacturer. This doesn't matches the results from our MANOVA.

Research Question 3: Is there any important difference in CO2, CO, and THC between the different vehicle transmission types?

```
# Visaulize dataset
p3<-ggboxplot(
  nonelectric, x = "Test.Fuel.Type.Description", y = c("CO2..g.mi.", "CO..g.mi.", "THC..g.mi."),
  merge = TRUE, palette = c("#095826",  "#2671A4","#A35CBD" ),
  title = "Three Different Emissions for Fuel.Type",
  ylab = "Value of Emission (g/mi)",
  xlab = "Fuel.Type"
)
p3 + rotate_x_text(45)
```



Hypotheses 3

H_0 : There is no significant difference in CO2, CO, and THC between the different types of fuel

H_a : There is significant difference in CO2, CO, and THC between the different types of fuel

```
# Fit the MANOVA model
fit3 = manova(cbind(CO2..g.mi., CO..g.mi., THC..g.mi.) ~ Test.Fuel.Type.Description, data = nonelectric
summary(fit3, intercept = TRUE)
```

```
##                               Df  Pillai approx F num Df den Df    Pr(>F)
## (Intercept)                    1 0.88787    57342      3  21725 < 2.2e-16 ***
## Test.Fuel.Type.Description    10 0.52439      460     30  65181 < 2.2e-16 ***
## Residuals                  21727
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Since the p-value for Fuel.Type variable is smaller than the significance level 0.05, we can reject the null hypotheses at 5% significance level, and conclude that there is statistically significant difference in CO2, CO, and THC between the different types of fuel.

However, we are unclear about which emissions are affected by fuel type. We perform univariate ANOVAs to figure it out.

```
summary.aov(fit3)
```

```
##  Response CO2..g.mi. :
```

```
##                               Df    Sum Sq Mean Sq F value    Pr(>F)
## Test.Fuel.Type.Description    10  11752782 1175278  97.101 < 2.2e-16 ***
## Residuals                  21727 262975949   12104
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##  Response CO..g.mi. :
##                               Df Sum Sq Mean Sq F value    Pr(>F)
## Test.Fuel.Type.Description    10    439  43.911  4.4822 2.379e-06 ***
## Residuals                  21727 212856   9.797
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##  Response THC..g.mi. :
##                               Df Sum Sq Mean Sq F value    Pr(>F)
## Test.Fuel.Type.Description    10 21.274 2.12738  1948.2 < 2.2e-16 ***
## Residuals                  21727 23.725 0.00109
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We can see from the output that the p-value for all univariate ANOVAs are smaller than significance level 0.05, which indicates that fuel type has a statistically significant effect on CO2, CO, and THC emissions.

Visualizing Group Means

Visualizing the Group means for each level of our independent variable vehicle type is helpful to get a better understanding of our results.

```
#visualize mean CO2 by vehicle type
plotmeans(nonelectric$CO2..g.mi. ~ nonelectric$Test.Fuel.Type.Description)
```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```

```
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## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```

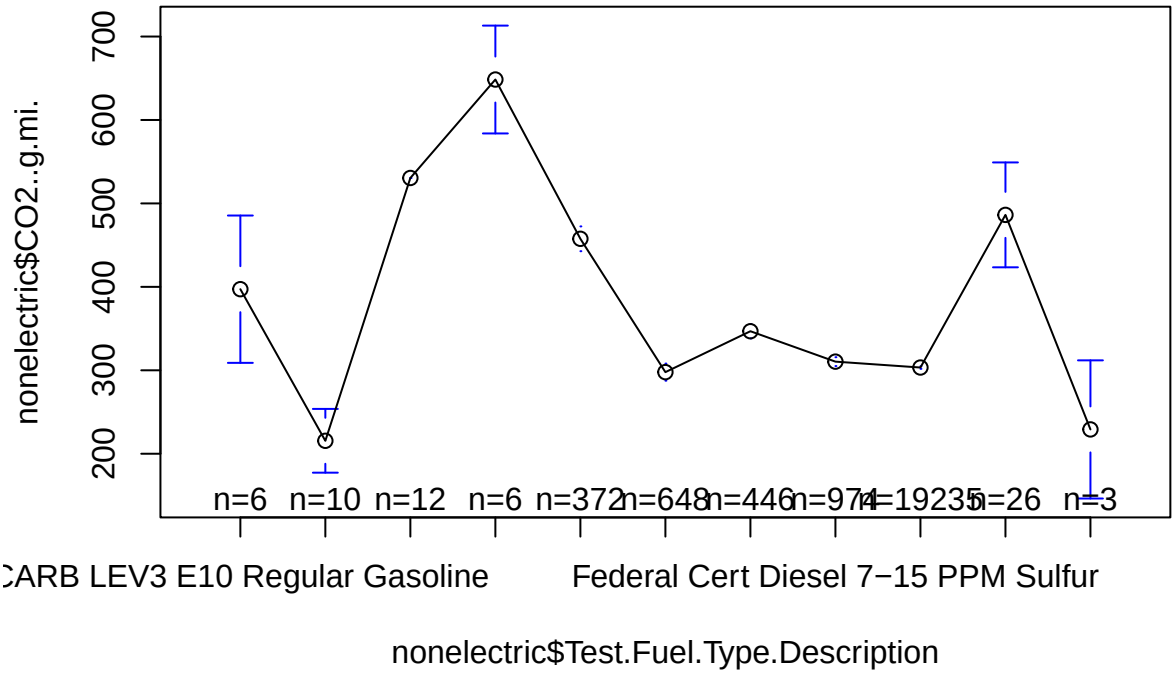


```
#visualize mean CO by vehicle type
plotmeans(nonelectric$CO..g.mi. ~ nonelectric$Test.Fuel.Type.Description)
```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```

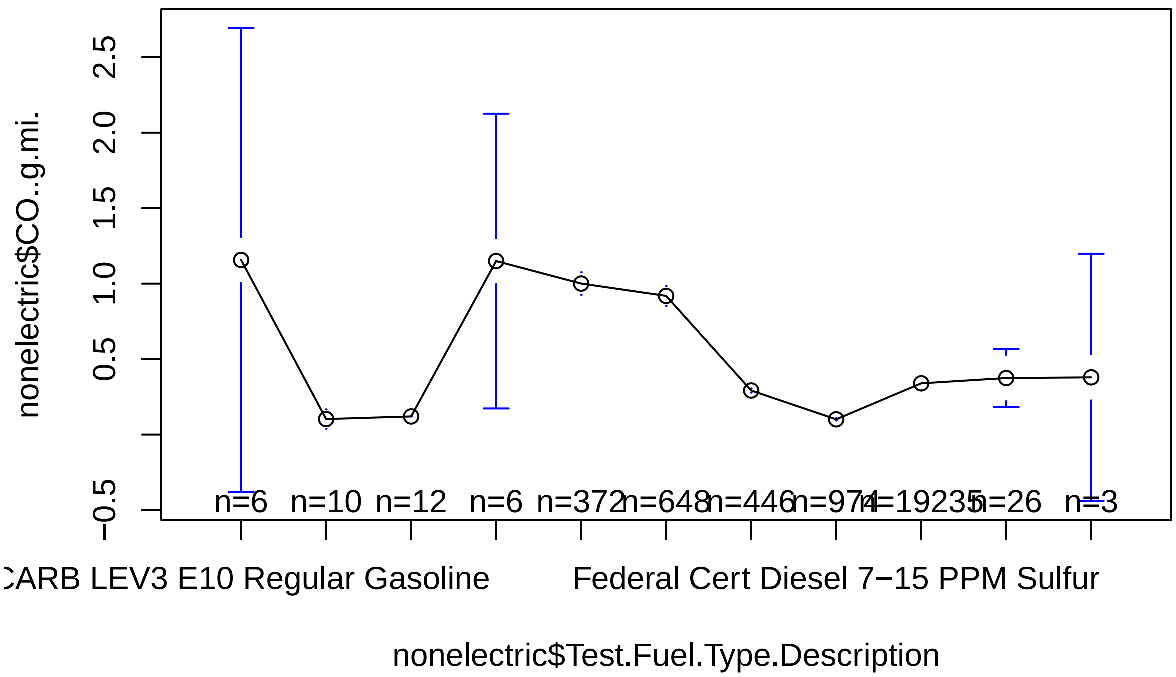


```r
#visualize mean THC by vehicle type
plotmeans(nonelectric$THC..g.mi. ~ nonelectric$Test.Fuel.Type.Description)
```

```
## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
```

```
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, li, x, pmax(y - gap, li), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped

## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
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## Warning in arrows(x, ui, x, pmin(y + gap, ui), col = barcol, lwd = lwd, : zero-
## length arrow is of indeterminate angle and so skipped
```

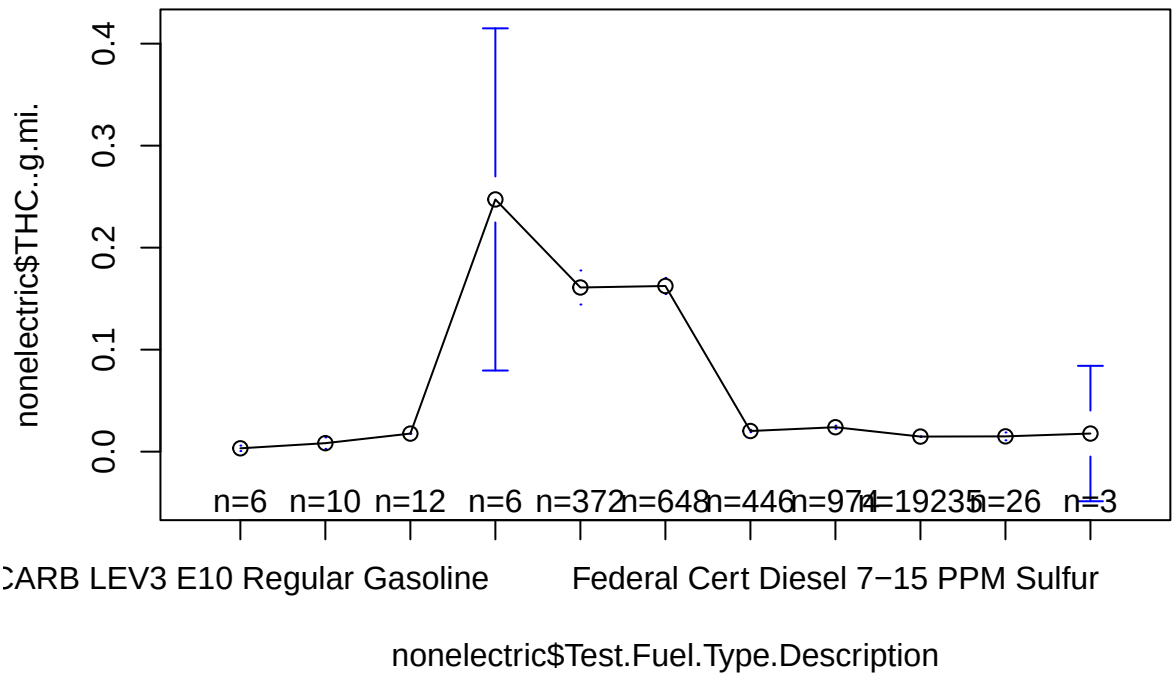

From the above three plots, we can see that the mean CO2, CO, and THC varies quite a bit by fuel types. This matches the results from our MANOVA, which indicates that there is statistically significant difference in three emissions based on fuel types.