Exploratory analysis and Hyphotesis testing on the ToothGrowth R dataset - *Elena Civati*

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Overview

The ToothGrowth dataset contains data from this study on the effect of Vitamin C intake on Tooth Growth in 60 guinea pigs. Each animal received one of three dose levels of vitamin C (0.5, 1, and 2 mg/day) by one of two delivery methods, orange juice or ascorbic acid, and the length of odontoblasts was measured. In this analysis, after a brief exploration of the dataset, we'll try to answer two questions:
1. Is there statistical evidence of a difference in tooth growth among animals receveing Ascorbic acid and Orange juice, for all measurements and for measurements differentiated by dose?
2. Is there statistical evidence of a difference in tooth growth among animals receveing different doses of vitC, for all measurements and for measurements differentiated by delivery method?

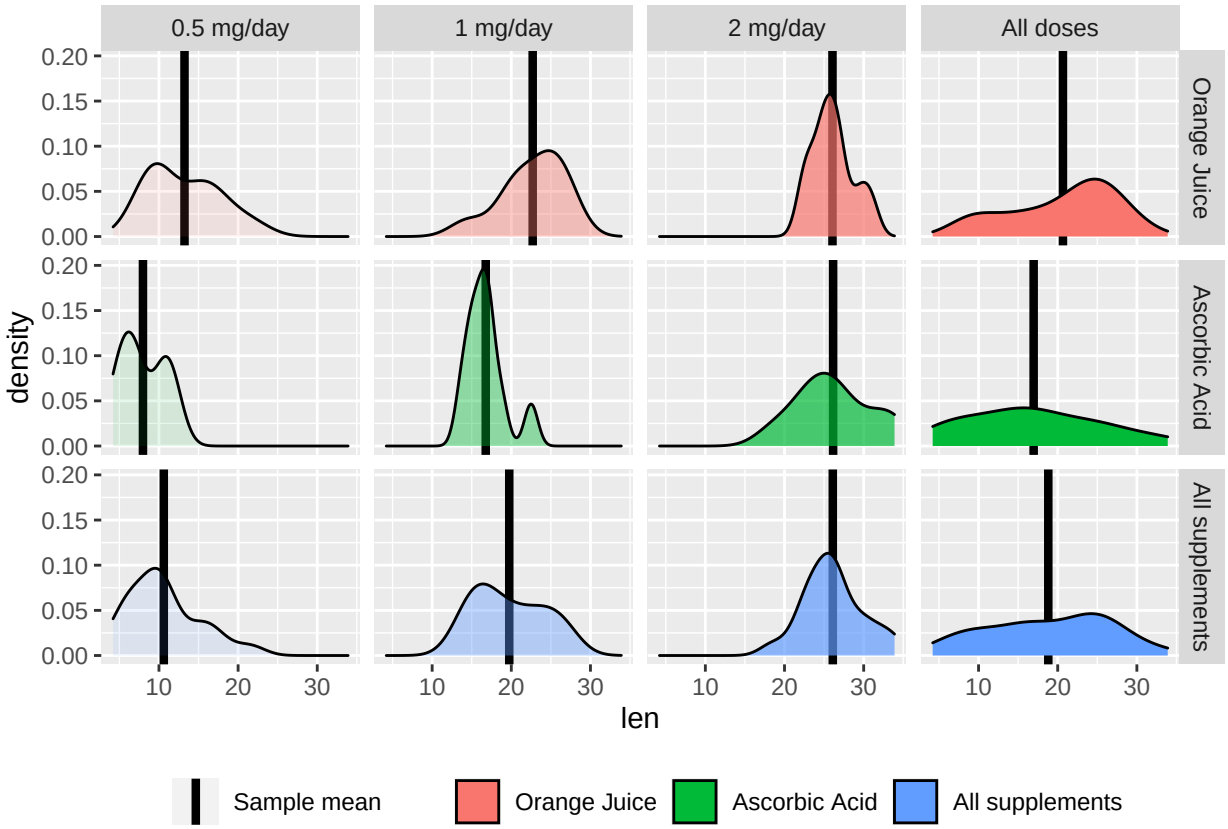
Exploratory analysis

First, as shown in Table 1 (*see Appendix for code*), we calculated mean odontoblasts length for the group receiving orange juice (20.66) and ascorbic acid (16.96). The data were also divided by dose of Vitamin C (means equal to 10.61, 19.74 and 26.10 as dose was increased) and by both factors.
This summary suggests that:
- Mean tooth growth could be greater in animals receiving orange juice than in animals receiving ascorbic acid, in particular with the 0.5 mg/day and the 1 mg/day doses.
- Mean odontoblasts length seems to increase in parallel with the dose administered; this effect is larger than the effect of delivery method.

Table 1: Average odontoblasts length by delivery method and dose

Supplement	0.5 mg/day	1 mg/day	2 mg/day	All doses
Orange Juice	13.23	22.70	26.06	20.66
Ascorbic Acid	7.98	16.77	26.14	16.96
All supplements	10.61	19.74	26.10	18.81

In Plot 1 (*see Appendix for code*) data were once again divided by each of the factors. The position of vertical lines, representing mean values, confirms our previous observations. Furthermore, the densities look quite mound-shaped; as to variability, it seems to be quite constant in the last two columns, while among the first two columns and among rows it shows more changes.



Inferential analysis

As data are normally distributed (or at least their distribution is roughly symmetric and mound-shaped) it's possible to use a t test. In contrast, the population variance is unknown and the sample are nor very large, so a z test is not advisable.
The variances will be assumed to be unequal, because we are not provided enough information about randomisation and study design; data points are unpaired; the significance level will be α=0.05. I choose tests for inequality because they are more strict than one-sided tests, so there is less risk of a false discovery. We'll report p-values and confidence intervals.
(NOTE: there is no need to adjust the p-values because test are performed on different subsets).

Delivery method effect

Null hypothesis: **H0: Mean odontoblasts length IS EQUAL between guinea pigs receiving Orange juice and Ascorbic acid, both at each dose level and regardless of the dose**

Alternative hypothesis: **Ha: Mean odontoblasts length IS DIFFERENT between guinea pigs receiving Orange juice and Ascorbic acid, both at each dose level and regardless of the dose**

So, we're performing 4 two-groups, two-sided t tests, dividing data by supplement type: one for the entire dataset and one for each of the doses.
The results are summarized in Table 2 (*see Appendix for code*), with significant ones highlighted in red.

Dose effect

Null hypothesis: **H0: Mean odontoblasts length IS EQUAL between guinea pigs receiving 0.5mg/day and 1mg/day of vitC, both for each delivery method and regardless of the method**

Table 2:

Orange juice vs Ascorbic acid		95% Confidence Interval	
	pValue	Lower limit	Upper limit
0.5 mg/day	**0.006**	**1.719**	**8.781**
1 mg/day	**0.001**	**2.802**	**9.058**
2 mg/day	0.964	-3.798	3.638
All doses	0.061	-0.171	7.571

Table 3:

	DOSE: 0.5mg/day vs 1mg/day	95% Confidence Interval			DOSE: 1mg/day vs 2mg/day	95% Confidence Interval	
	pValue	Lower limit	Upper limit		pValue	Lower limit	Upper limit
Orange Juice	**8.8e-05**	**-13.416**	**-5.524**		**0.039195**	**-6.531**	**-0.189**
Ascorbic Acid	**1e-06**	**-11.266**	**-6.314**		**9.2e-05**	**-13.054**	**-5.686**
All supplements	**0**	**-11.984**	**-6.276**		**1.9e-05**	**-8.996**	**-3.734**

Alternative hypothesis:**Ha: Mean odontoblasts length IS DIFFERENT between guinea pigs receiving 0.5mg/day and 1mg/day of vitC, both for each delivery method and regardless of the method**

Analogous hyphotesis are made for comparison between 1mg/day and 2mg/day dose.
As we'll see, it is redundant to test the difference between the lowest and the highest dose. Therefore, we'll perform 6 two-sided tests and summarize results in Table 3 (*see Appendix for code*).

Conclusions

As shown in Table 2, mean odontoblasts length is different between orange juice and ascorbic acid treated animals only for the vitC doses of 0.5 mg/day and 1 mg/day. We reject H0 with a significance level, respectively, of 0.06% and 0.01%.
Table 3 shows that all results are significant with very low p-values: we reject all null hypothesis, so the mean tooth growth is different in each group of animals receiving different doses of vitC. Even if we didn't test 0.5mg/day dose vs 2mg/day dose, the difference would be equal to the sum of the other differences and it would be significant too.

Based on those results I would suggest to do another experiment involving 3 groups: Orange Juice, Ascorbic Acid and a Control group with no extra vitC intake, to assess the baseline tooth growth in Guinea pigs.
Depending on the desired power, the sample size could be proposed as shown in Table 4 (*see Appendix for code*). For the computing, I assumed a variance equal to the variance of all measurements in the ToothGrowth dataset and a difference in means equal to 5 (a reasonable number if we look at the confidence intervals we found).

Table 4: Proposed sample size

Power	Sample_Size
60 %	24
70 %	30
80 %	38
90 %	51
95 %	62

Appendix

Loading libraries and data in R:

```
library(dplyr)
library(ggplot2)
library(reshape2)
library(datasets)
library(kableExtra)
denti<-ToothGrowth
```

R Code for Table 1

Please, note that this code works in R Markdown with the chunk option "results='asis' "

```
denti<-mutate(denti, dose=as.character(dose))
only_supp<-mutate(denti, dose="All doses")
only_dose<-mutate(denti, supp="All supplements")
nothing<-mutate(denti, supp="All supplements", dose="All doses")
df<-rbind(denti, only_dose, only_supp, nothing)
levels(df$supp)<-c("Orange Juice", "Ascorbic Acid", "All supplements")
df<-mutate(df, dose=ifelse(dose!="All doses",paste(dose, "mg/day"),dose))
names(df)<-c("len", "Supplement", "dose")
means<-df %>% group_by(Supplement, dose) %>% summarize(mn=round(mean(len),2))
t<-dcast(means, Supplement ~ dose, margins="mn")
knitr::kable(t, caption="Average odontoblasts length by delivery method and dose")
```

R Code for Plot 1

```
means<-mutate(means, line="Sample mean")
g<-ggplot(data=df, aes(len, fill=Supplement, alpha=dose))
g<-g +facet_grid(Supplement~dose)
g<-g+geom_vline(aes(xintercept=mn, col=line),data=means, lwd=1.5)
g<-g + geom_density()
g<-g+scale_color_manual(values="black")
g<-g+ theme(legend.position = "bottom", legend.title = element_blank())
g<-g+guides(alpha=F)
g
```

R Code for Table 2

```
library(kableExtra)
sets<-list(which(denti$dose==0.5), which(denti$dose==1),
           which(denti$dose==2), NULL)
results<-lapply(sets, function(x) t.test(len ~ supp, denti, subset=x))
tb<-matrix(0,4,3)
for (i in 1:4) {
tb[i,]<-unlist(results[[i]][c(3,4)],3)
}
tb<-round(tb,3)
row.names(tb)<-colnames(t)[2:5]
colnames(tb)<-c("pValue", "Lower limit", "Upper limit")
sig<-which(tb[,1]<.05)
kbl(tb, caption="Hypothesis testing results") %>% kable_classic() %>%
```

```
    add_header_above(c(" "=2, "95% Confidence Interval"=2)) %>%
    row_spec(sig, bold=T, color="white", background="red")
```

Code for Table 3

```
dose12<-subset(denti, dose==0.5 | dose==1)
dose23<-subset(denti, dose==1 | dose==2)
doselist<-list(dose12, dose23)
tablelist<-list()
resultlist<-list()
for (i in 1:2) {
    sets<-list(which(doselist[[i]]$supp=="OJ"), which(doselist[[i]]$supp=="VC"), NULL)
    resultlist[[i]]<-lapply(sets, function(x) t.test(len ~ dose, doselist[[i]], subset=x))
    tablelist[[i]]<-matrix(0,3,3)
    for (j in 1:3) {
        tablelist[[i]][j,]<-unlist(resultlist[[i]][[j]][c(3,4)])
    }
    tablelist[[i]][,1:3]<-round(tablelist[[i]][,c(1,2,3)],c(rep.int(6,3),rep.int(3,6)))
    row.names(tablelist[[i]])<-t[,1]
    colnames(tablelist[[i]])<-c("pValue", "Lower limit", "Upper limit")
}
kbl(cbind(tablelist[[1]], matrix(" ",3,1), tablelist[[2]]), caption="") %>% kable_classic() %>%
    add_header_above(c(" "=1,"DOSE: 0.5mg/day \nvs 1mg/day"=1,
                       "95% Confidence Interval"=2,"","DOSE: 1mg/day \nvs 2mg/day"=1,
                       "95% Confidence Interval"=2 )) %>%
    row_spec(1:3, bold=T, color="white", background="red") %>
    column_spec(c(1,5), color="black", background = "white")
```

Code for Table 4

Displays correctly in PDF with results='asis' R Markdown chunck option

```
pows<-c(0.6, 0.7, 0.8, 0.9, 0.95)
std<-sd(denti$len)
n<-sapply(pows, function(x) ceiling(power.t.test(delta=5, sd=std, power=x)$n))
tbl<-data.frame(Power=paste(pows*100,"%"), Sample_Size=n)
knitr::kable(tbl, caption="Proposed sample size")
```