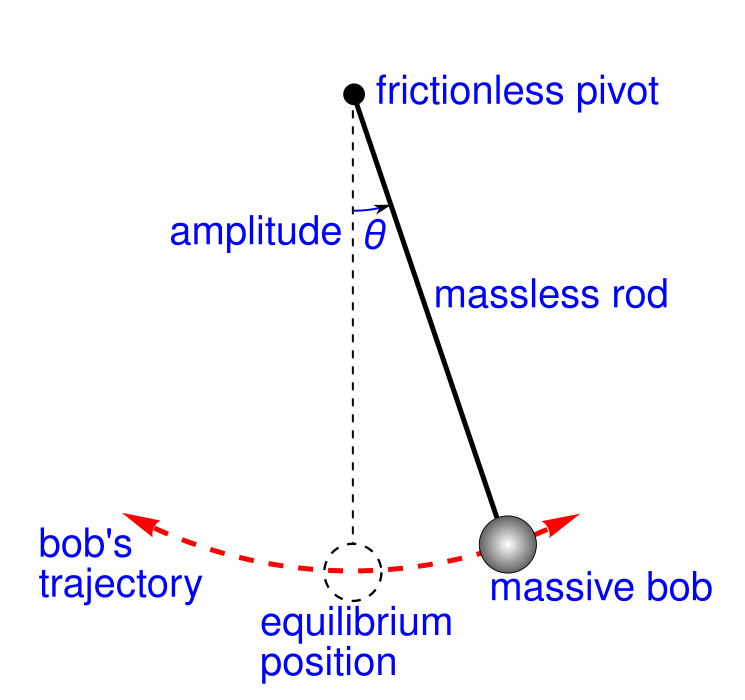
How does a pendulum’s length affect its time period?

Heather Wang, Qihan Liu, Runxi Yu, Vincent Bae

## Introduction



Simple gravity pendulum

A pendulum

## Experiment design

## Hypotheses

Null hypothesis: Changes in the string’s length do not affect the time period.

Alternate hypothesis: Changes in the string’s length do affect the time period.

## Analysis

### Data overview

data <- read.csv("data.csv")  
data

## length\_cm time\_10\_periods  
## 1 25 11.01  
## 2 25 10.93  
## 3 25 11.01  
## 4 25 10.94  
## 5 20 10.60  
## 6 20 10.26  
## 7 20 10.16  
## 8 20 10.28  
## 9 15 9.28  
## 10 15 9.18  
## 11 15 9.41  
## 12 15 9.61  
## 13 10 8.40  
## 14 10 8.35  
## 15 10 8.70  
## 16 10 8.76

summary(data)

## length\_cm time\_10\_periods   
## Min. :10.00 Min. : 8.350   
## 1st Qu.:13.75 1st Qu.: 9.075   
## Median :17.50 Median : 9.885   
## Mean :17.50 Mean : 9.805   
## 3rd Qu.:21.25 3rd Qu.:10.682   
## Max. :25.00 Max. :11.010

Treating the length as discrete groups, let us estimate the mean and standard deviation of each group.

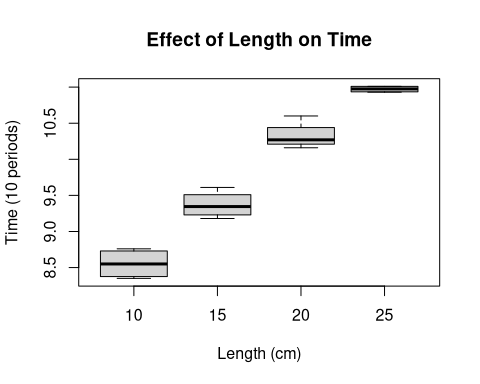
aggregate(time\_10\_periods ~ length\_cm, data = data, function(x) c(mean = mean(x), sd = sd(x), n = length(x)))

## length\_cm time\_10\_periods.mean time\_10\_periods.sd time\_10\_periods.n  
## 1 10 8.55250000 0.20742469 4.00000000  
## 2 15 9.37000000 0.18565200 4.00000000  
## 3 20 10.32500000 0.19070046 4.00000000  
## 4 25 10.97250000 0.04349329 4.00000000

This allows us to see that there is a significant Difference in Means betwen groups, of approximately 0.6 between neighbouring groups, where the standard deviation is roughly around 0.1 to 0.2.

In order to gain a general sense of the data we have obtained, let us plot the data. A box plot is used, to present the information aggregated by group above.

boxplot(time\_10\_periods ~ length\_cm, data = data,  
 main = "Effect of Length on Time",  
 xlab = "Length (cm)",  
 ylab = "Time (10 periods)")



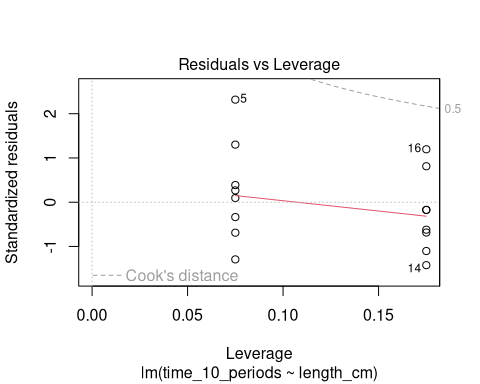
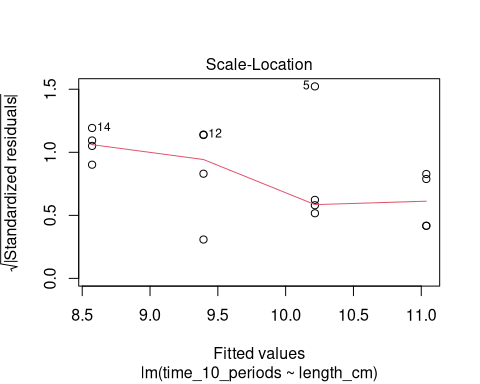
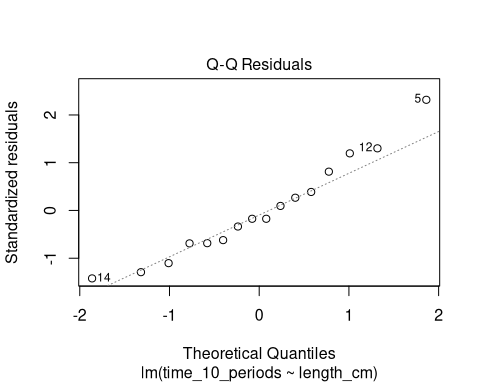
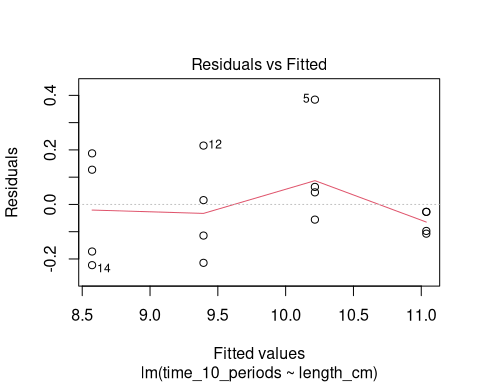
### Linear regression

model <- lm(time\_10\_periods ~ length\_cm, data = data)  
summary(model)

##   
## Call:  
## lm(formula = time\_10\_periods ~ length\_cm, data = data)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.22275 -0.10900 -0.02725 0.08000 0.38425   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 6.929750 0.141582 48.95 < 2e-16 \*\*\*  
## length\_cm 0.164300 0.007707 21.32 4.52e-12 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.1723 on 14 degrees of freedom  
## Multiple R-squared: 0.9701, Adjusted R-squared: 0.968   
## F-statistic: 454.5 on 1 and 14 DF, p-value: 4.516e-12

We shall run various diagnostic plots of this linear regression model to confirm whether it is truly a linear regression:

plot(model)



There are insufficient sample points for the diagnostic plots to be accurate, but they seem to be acceptable for this sample size. It is however somewhat unclear what causes the enlarged residues for large theoretical quantities.

Given that a linear regression is mostly appropriate as suggested by the diagnostic tests, its -value suggests that it is extremely unlikely to obtain our result (or more extreme results) given that the null hypothesis is true, therefore suggesting with high confidence that the null hypothesis is false and that the alternate hypothesis is true. Therefore: changes in the string’s length do affect the time period.

## T-tests

## Informal bibliography

I’m not really sure how to get BibLaTeX working with R Markdown yet, so here’s just an itemized list of references without any particular bibliography format.

* Simple Gravity pendulum, by Chetvorno, public domain, <https://commons.wikimedia.org/w/index.php?curid=5276335>