# SLT_paper

AC

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### History:

- 2020-08-05 final first version

### Read data in

```
#read demo data created by AC from info in paper
demo_data=read.csv("demo-data.tsv",sep="\t")

# read dataset composed with python
data_all <- read.csv("final_classifications_PU_zoon.csv")

#remove the word mixed that takes up space and is unnecessary
data_all$Zoon_classif=factor(gsub("Mixed_","",as.character(data_all$Zoon_classif),fixed=T))

#relevel the factor so that it's easier to read
data_all$Zoon_classif=factor(data_all$Zoon_classif, levels=c("Canonical","Non-Canonical",
                                                             "Crying","Laughing","Junk",levels(data_all$


# create lab column with easier to read correspondance
data_all$lab<-as.character(data_all$Major_Choice)
data_all$lab[data_all$lab=="Non-canonical syllables"]<-"Non-Canonical"
data_all$lab[data_all$lab=="Canonical syllables"]<-"Canonical"
data_all$lab[data_all$lab %in% c("Don't mark","None")]<-"Junk"
data_all$lab=factor(data_all$lab,levels=levels(data_all$Zoon_classif))
#apply same factor levels as zooniverse so that we can do symmetrical confusion matrices
```

## Correspondence between lab & zooniverse annotation at the level of segments

Here we look at to what extent zooniverse and lab annotations match at the level of individual segments. Each data point is one segment (one "vocalization").

```
table(data_all$lab)
```

```
##
##                       Canonical                   Non-Canonical
##                             258                            2532
##                          Crying                        Laughing
##                              51                              49
##                            Junk              Laughing_Canonical
##                             904                               0
##                  Laughing_Crying          Laughing_Non-Canonical
##                               0                               0
## Laughing_Non-Canonical_Crying            Non-Canonical_Crying
##                               0                               0
## Non-Canonical_Laughing_Crying
##                               0
```

```
table(data_all$Zoon_classif)
```

```
##
##                       Canonical                   Non-Canonical
##                             226                            2535
##                          Crying                        Laughing
##                              94                             130
##                            Junk              Laughing_Canonical
##                             625                               2
##                  Laughing_Crying          Laughing_Non-Canonical
##                               3                              76
## Laughing_Non-Canonical_Crying            Non-Canonical_Crying
##                               3                              99
## Non-Canonical_Laughing_Crying
##                               1
```

```
mycf=confusionMatrix(data_all$lab, data_all$Zoon_classif, dnn = c("Lab","Zooniverse"))

conf_tab=mycf$table

# this package uses sensitivity & specificity
#Sensitivity=recall
#Specificity=precision

mycf
```

```
## Confusion Matrix and Statistics
##
##                               Zooniverse
## Lab                            Canonical Non-Canonical Crying Laughing Junk
##   Canonical                           93           122      3        8   22
##   Non-Canonical                       51          2057     60       49  193
##   Crying                               0            17     13        2    4
##   Laughing                             0             5      2       26    6
##   Junk                                82           334     16       45  400
```

```
##   Laughing_Canonical                    0             0      0        0    0
##   Laughing_Crying                       0             0      0        0    0
##   Laughing_Non-Canonical                0             0      0        0    0
##   Laughing_Non-Canonical_Crying         0             0      0        0    0
##   Non-Canonical_Crying                  0             0      0        0    0
##   Non-Canonical_Laughing_Crying         0             0      0        0    0
##                               Zooniverse
## Lab                            Laughing_Canonical Laughing_Crying
##   Canonical                                     0               1
##   Non-Canonical                                 0               1
##   Crying                                        0               1
##   Laughing                                      1               0
##   Junk                                          1               0
##   Laughing_Canonical                            0               0
##   Laughing_Crying                               0               0
##   Laughing_Non-Canonical                        0               0
##   Laughing_Non-Canonical_Crying                 0               0
##   Non-Canonical_Crying                          0               0
##   Non-Canonical_Laughing_Crying                 0               0
##                               Zooniverse
## Lab                            Laughing_Non-Canonical
##   Canonical                                     6
##   Non-Canonical                                51
##   Crying                                        0
##   Laughing                                      8
##   Junk                                         11
##   Laughing_Canonical                            0
##   Laughing_Crying                               0
##   Laughing_Non-Canonical                        0
##   Laughing_Non-Canonical_Crying                 0
##   Non-Canonical_Crying                          0
##   Non-Canonical_Laughing_Crying                 0
##                               Zooniverse
## Lab                            Laughing_Non-Canonical_Crying
##   Canonical                                                0
##   Non-Canonical                                            1
##   Crying                                                   1
##   Laughing                                                 0
##   Junk                                                     1
##   Laughing_Canonical                                       0
##   Laughing_Crying                                          0
##   Laughing_Non-Canonical                                   0
##   Laughing_Non-Canonical_Crying                            0
##   Non-Canonical_Crying                                     0
##   Non-Canonical_Laughing_Crying                            0
##                               Zooniverse
## Lab                            Non-Canonical_Crying
##   Canonical                                     3
##   Non-Canonical                                69
##   Crying                                       13
##   Laughing                                      0
##   Junk                                         14
##   Laughing_Canonical                            0
##   Laughing_Crying                               0
```

```
##   Laughing_Non-Canonical                          0
##   Laughing_Non-Canonical_Crying                   0
##   Non-Canonical_Crying                            0
##   Non-Canonical_Laughing_Crying                   0
##                               Zooniverse
## Lab                            Non-Canonical_Laughing_Crying
##   Canonical                                                0
##   Non-Canonical                                            0
##   Crying                                                   0
##   Laughing                                                 1
##   Junk                                                     0
##   Laughing_Canonical                                       0
##   Laughing_Crying                                          0
##   Laughing_Non-Canonical                                   0
##   Laughing_Non-Canonical_Crying                            0
##   Non-Canonical_Crying                                     0
##   Non-Canonical_Laughing_Crying                            0
##
## Overall Statistics
##
##                Accuracy : 0.6824
##                  95% CI : (0.6673, 0.6972)
##     No Information Rate : 0.6682
##     P-Value [Acc > NIR] : 0.0322
##
##                   Kappa : 0.3773
##
##  Mcnemar's Test P-Value : NA
##
## Statistics by Class:
##
##                      Class: Canonical Class: Non-Canonical Class: Crying
## Sensitivity                   0.41150               0.8114      0.138298
## Specificity                   0.95376               0.6227      0.989730
## Pos Pred Value                0.36047               0.8124      0.254902
## Neg Pred Value                0.96239               0.6212      0.978360
## Prevalence                    0.05957               0.6682      0.024776
## Detection Rate                0.02451               0.5422      0.003426
## Detection Prevalence          0.06800               0.6674      0.013442
## Balanced Accuracy             0.68263               0.7171      0.564014
##                      Class: Laughing Class: Junk Class: Laughing_Canonical
## Sensitivity                 0.200000      0.6400                 0.0000000
## Specificity                 0.993723      0.8410                 1.0000000
## Pos Pred Value              0.530612      0.4425                       NaN
## Neg Pred Value              0.972230      0.9221                 0.9994729
## Prevalence                  0.034265      0.1647                 0.0005271
## Detection Rate              0.006853      0.1054                 0.0000000
## Detection Prevalence        0.012915      0.2383                 0.0000000
## Balanced Accuracy           0.596861      0.7405                 0.5000000
##                      Class: Laughing_Crying Class: Laughing_Non-Canonical
## Sensitivity                       0.0000000                        0.00000
## Specificity                       1.0000000                        1.00000
## Pos Pred Value                          NaN                            NaN
## Neg Pred Value                    0.9992093                        0.97997
```

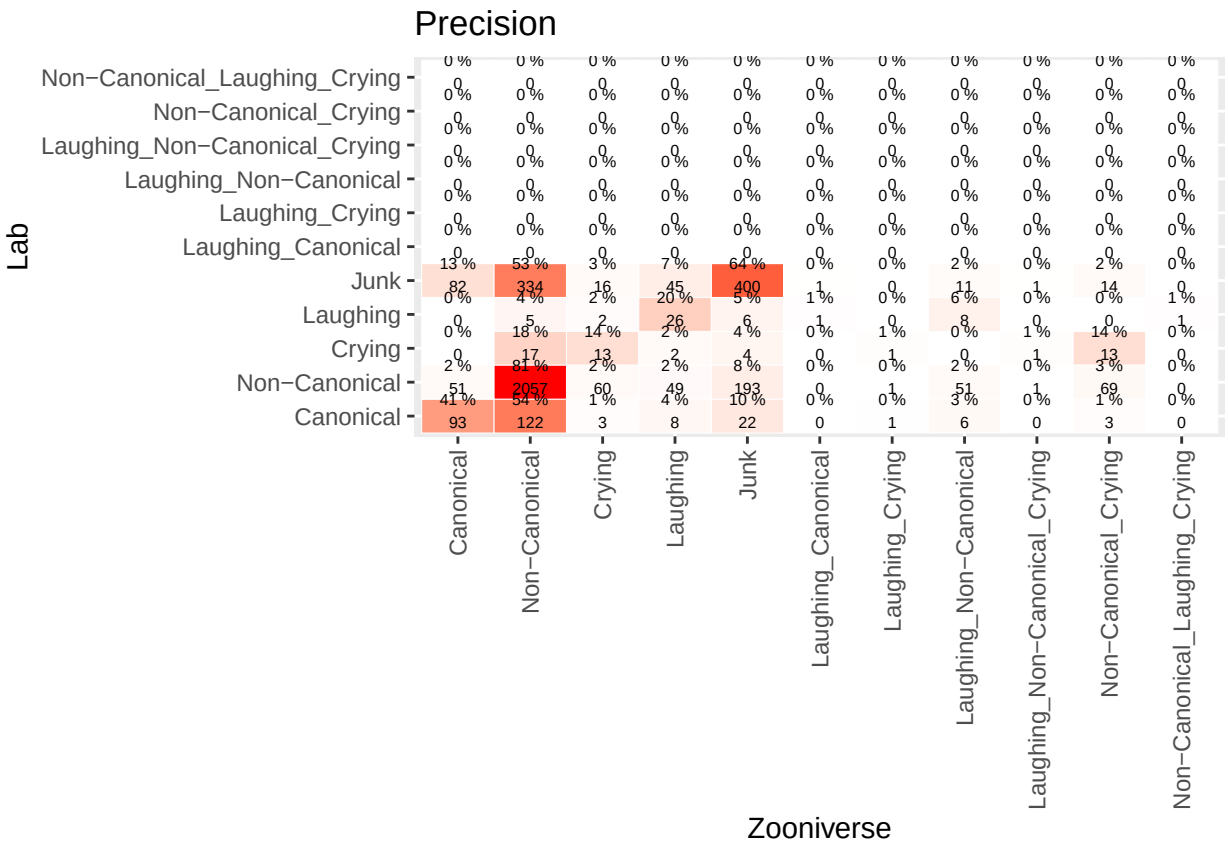
```
## Prevalence                          0.0007907                          0.02003
## Detection Rate                      0.0000000                          0.00000
## Detection Prevalence                0.0000000                          0.00000
## Balanced Accuracy                   0.5000000                          0.50000
##                       Class: Laughing_Non-Canonical_Crying
## Sensitivity                                      0.0000000
## Specificity                                      1.0000000
## Pos Pred Value                                         NaN
## Neg Pred Value                                   0.9992093
## Prevalence                                       0.0007907
## Detection Rate                                   0.0000000
## Detection Prevalence                             0.0000000
## Balanced Accuracy                                0.5000000
##                       Class: Non-Canonical_Crying
## Sensitivity                               0.00000
## Specificity                               1.00000
## Pos Pred Value                                NaN
## Neg Pred Value                            0.97391
## Prevalence                                0.02609
## Detection Rate                            0.00000
## Detection Prevalence                      0.00000
## Balanced Accuracy                         0.50000
##                       Class: Non-Canonical_Laughing_Crying
## Sensitivity                                      0.0000000
## Specificity                                      1.0000000
## Pos Pred Value                                         NaN
## Neg Pred Value                                   0.9997364
## Prevalence                                       0.0002636
## Detection Rate                                   0.0000000
## Detection Prevalence                             0.0000000
## Balanced Accuracy                                0.5000000
```

### Precision

Precision means: If a segment was called X by zooniverse coders, what proportion of the time was it called X by lab coders?

```
prop_cat=data.frame(conf_tab/colSums(conf_tab)*100) #generates precision because columns
prop_cat$id=paste(prop_cat$Lab,prop_cat$Zooniverse)
colnames(prop_cat)[3]<-"pr"

data.frame(conf_tab)->stall
stall$id=paste(stall$Lab,stall$Zooniverse)
stall=merge(stall,prop_cat[c("id","pr")])



ggplot(data = stall, mapping = aes(y = Lab, x=Zooniverse)) +
 geom_tile(aes(fill= rescale(pr)), colour = "white") +
  geom_text(aes(label = paste(round(pr),"%")), vjust = -1,size=2) +
  geom_text(aes(label = Freq), vjust = 1,size=2) +
  scale_fill_gradient(low = "white", high = "red", name = "Percentage") +
     theme(legend.position = "none") +
  xlab("Zooniverse") + ylab("Lab") +
```

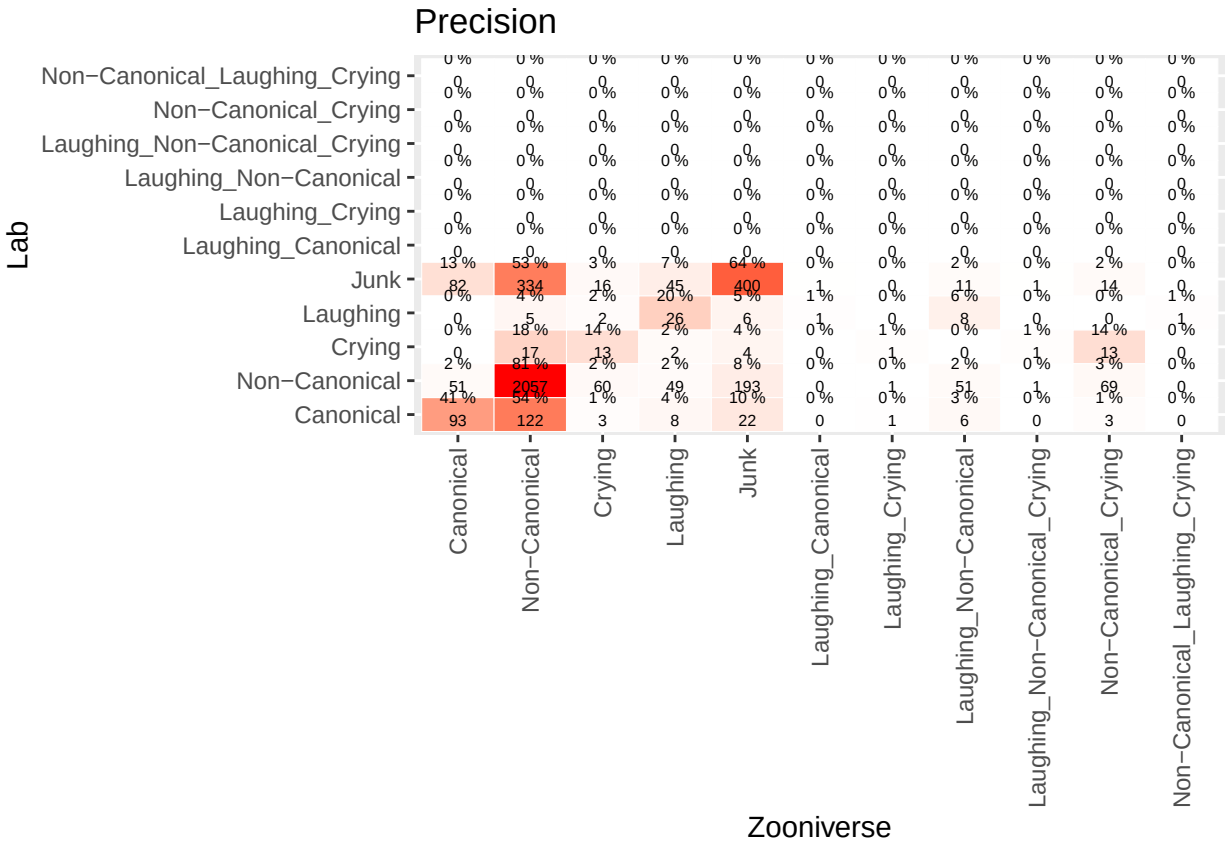
```
  ggtitle("Precision")+ theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))
```




**Recall**

Recall means: If a segment was called X by lab coders, what proportion of the time was it called X by zooniverse coders?

```
prop_cat=data.frame(conf_tab/colSums(conf_tab)*100) #generates precision because columns
prop_cat$id=paste(prop_cat$Lab,prop_cat$Zooniverse)
colnames(prop_cat)[3]<-"pr"

data.frame(conf_tab)->stall
stall$id=paste(stall$Lab,stall$Zooniverse)
stall=merge(stall,prop_cat[c("id","pr")])



ggplot(data = stall, mapping = aes(y = Lab, x=Zooniverse)) +
 geom_tile(aes(fill= rescale(pr)), colour = "white") +
  geom_text(aes(label = paste(round(pr),"%")), vjust = -1,size=2) +
  geom_text(aes(label = Freq), vjust = 1,size=2) +
  scale_fill_gradient(low = "white", high = "red", name = "Percentage") +
     theme(legend.position = "none") +
  xlab("Zooniverse") + ylab("Lab") +
  ggtitle("Precision")+ theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))
```




### repeat collapsing

```
#given results above, we map the mixed
data_all$Zoon_classif[data_all$Zoon_classif=="Laughing_Canonical"]<-"Canonical"
data_all$Zoon_classif[data_all$Zoon_classif=="Laughing_Non-Canonical"]<-"Non-Canonical"
data_all$Zoon_classif[data_all$Zoon_classif=="Laughing_Non-Canonical_Crying"]<-"Non-Canonical"
data_all$Zoon_classif[data_all$Zoon_classif=="Laughing_Crying"]<-"Crying"
data_all$Zoon_classif[data_all$Zoon_classif=="Non-Canonical_Crying"]<-"Non-Canonical"
data_all$Zoon_classif[data_all$Zoon_classif=="Non-Canonical_Laughing_Crying"]<-"Non-Canonical"

#and reset the factors for cleanliness
data_all$Zoon_classif=factor(data_all$Zoon_classif)
data_all$lab=factor(data_all$lab)

mycf=confusionMatrix(data_all$lab, data_all$Zoon_classif, dnn = c("Lab","Zooniverse"))
conf_tab=mycf$table

# this package uses sensitivity & specificity
#Sensitivity=recall
#Specificity=precision

mycf
```

```
## Confusion Matrix and Statistics
##
##                Zooniverse
```

```
## Lab             Canonical Non-Canonical Crying Laughing Junk
##   Canonical            93           131      4        8   22
##   Non-Canonical        51          2178     61       49  193
##   Crying                0            31     14        2    4
##   Laughing              1            14      2       26    6
##   Junk                 83           360     16       45  400
##
## Overall Statistics
##
##                Accuracy : 0.7145
##                  95% CI : (0.6999, 0.7289)
##     No Information Rate : 0.7153
##     P-Value [Acc > NIR] : 0.5511
##
##                   Kappa : 0.4034
##
##  Mcnemar's Test P-Value : <2e-16
##
## Statistics by Class:
##
##                      Class: Canonical Class: Non-Canonical Class: Crying
## Sensitivity                   0.40789               0.8025       0.14433
## Specificity                   0.95373               0.6722       0.98999
## Pos Pred Value                0.36047               0.8602       0.27451
## Neg Pred Value                0.96182               0.5753       0.97783
## Prevalence                    0.06009               0.7153       0.02557
## Detection Rate                0.02451               0.5741       0.00369
## Detection Prevalence          0.06800               0.6674       0.01344
## Balanced Accuracy             0.68081               0.7374       0.56716
##                      Class: Laughing Class: Junk
## Sensitivity                 0.200000      0.6400
## Specificity                 0.993723      0.8410
## Pos Pred Value              0.530612      0.4425
## Neg Pred Value              0.972230      0.9221
## Prevalence                  0.034265      0.1647
## Detection Rate              0.006853      0.1054
## Detection Prevalence        0.012915      0.2383
## Balanced Accuracy           0.596861      0.7405
```

```
pdf("precision.pdf",height=10,width=10)
prop_cat=data.frame(conf_tab/colSums(conf_tab)*100) #generates precision because columns
prop_cat$id=paste(prop_cat$Lab,prop_cat$Zooniverse)
colnames(prop_cat)[3]<-"pr"

data.frame(conf_tab)->stall
stall$id=paste(stall$Lab,stall$Zooniverse)
stall=merge(stall,prop_cat[c("id","pr")])



ggplot(data = stall, mapping = aes(y = Lab, x=Zooniverse)) +
 geom_tile(aes(fill= rescale(pr)), colour = "white") +
  geom_text(aes(label = paste(round(pr),"%")), vjust = -1,size=8) +
  geom_text(aes(label = Freq), vjust = 1,size=8) +
```

```
  scale_fill_gradient(low = "white", high = "red", name = "Proportion") +
     theme(legend.position = "none") +
  xlab("Zooniverse") + ylab("Lab") +
  ggtitle("Precision")+theme(text = element_text(size=20),
        axis.text.x = element_text(angle=90, hjust=1))
dev.off()
```

```
## pdf
##   2
```

```
pdf("recall.pdf",height=10,width=10)
prop_cat=data.frame(conf_tab/rowSums(conf_tab)*100)  #generates recall because rows
prop_cat$id=paste(prop_cat$Lab,prop_cat$Zooniverse)
colnames(prop_cat)[3]<-"rec"

data.frame(conf_tab)->stall
stall$id=paste(stall$Lab,stall$Zooniverse)
stall=merge(stall,prop_cat[c("id","rec")])

ggplot(data = stall, mapping = aes(y = Lab, x=Zooniverse)) +
 geom_tile(aes(fill= rescale(rec)), colour = "white") +
  geom_text(aes(label = paste(round(rec),"%")), vjust = -1,size=8) +
  geom_text(aes(label = Freq), vjust = 1,size=8) +
  scale_fill_gradient(low = "white", high = "red", name = "Proportion") +
     theme(legend.position = "none") +
  xlab("Zooniverse") + ylab("Lab") +
  ggtitle("Recall")+theme(text = element_text(size=20),
        axis.text.x = element_text(angle=90, hjust=1))


dev.off()
```

```
## pdf
##   2
```

## Child level descriptors

Although there may be errors at the level of the segment, what we really care about is whether Zooniverse annotations give a reliable image of the child's individual development. This is what we look at in this section. In all of these graphs, red points correspond to children diagnosed with Angelman Syndrome, black for low-risk control.

```
#get the ns by child, then calculate the linguistic ratio & canonical ratio, separately for zooniverse
ztab=table(data_all$ChildID,data_all$Zoon_classif)
z_lr=rowSums(ztab[,c("Canonical","Non-Canonical")])/rowSums(ztab[,-which(colnames(ztab) %in% c("Junk"))]
z_cr=ztab[,c("Canonical")]/rowSums(ztab[,c("Canonical","Non-Canonical")])

ltab=table(data_all$ChildID,data_all$lab)
l_lr=rowSums(ltab[,c("Canonical","Non-Canonical")])/rowSums(ltab[,-which(colnames(ztab) %in% c("Junk"))]
l_cr=ltab[,c("Canonical")]/rowSums(ltab[,c("Canonical","Non-Canonical")])

#put all the ratios together
if(sum(rownames(ztab)==rownames(ltab))==dim(ztab)[1]) ratios=cbind(rownames(ztab),z_lr,z_cr,l_lr,l_cr)
colnames(ratios)[1]<-"ChildID"
```

```
#add age
#ages=aggregate(data_all$Age,by=list(data_all$ChildID),mean) #this is a weird way of adding ages, since
#improvement: now we merge with a demo data tab, but note this is merged with child id, so the problem


merge(ratios,demo_data,by="ChildID")->ratios
colnames(ratios)[dim(ratios)[2]]<-"Age"

#cbinding results in text, so we numerize the ratios
for(thisvar in c("z_lr","z_cr","l_lr","l_cr")) ratios[,thisvar]=as.numeric(as.character(ratios[,thisvar]
summary(ratios)
```

```
##     ChildID       z_lr             z_cr              l_lr
##  1111_1 :1   Min.   :0.7625   Min.   :0.02473   Min.   :0.8219
##  1151_1 :1   1st Qu.:0.8976   1st Qu.:0.03569   1st Qu.:0.9387
##  1801_1 :1   Median :0.9303   Median :0.06496   Median :0.9659
##  2881_1 :1   Mean   :0.9120   Mean   :0.09207   Mean   :0.9523
##  3021_1 :1   3rd Qu.:0.9535   3rd Qu.:0.12083   3rd Qu.:0.9833
##  3041_1 :1   Max.   :0.9678   Max.   :0.23267   Max.   :1.0000
##  (Other):4
##       l_cr                    Diagnosis Sex        Age
##  Min.   :0.01429   AngelmanSyndrome:9   F:3   Min.   :11.83
##  1st Qu.:0.06697   Low-RiskControl :1   M:7   1st Qu.:23.11
##  Median :0.07990                              Median :43.78
##  Mean   :0.10326                              Mean   :35.49
##  3rd Qu.:0.11944                              3rd Qu.:46.27
##  Max.   :0.23944                              Max.   :53.26
##
```

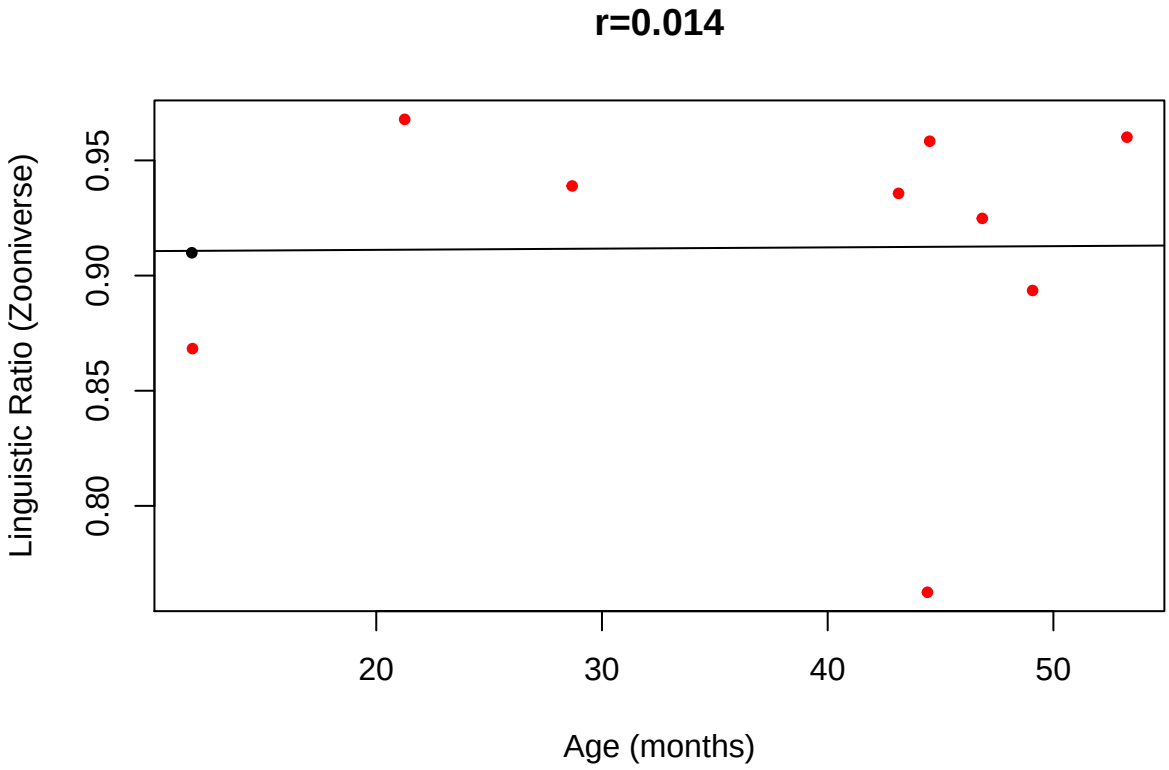
We first look generally at two measures that have been found to relate to age:

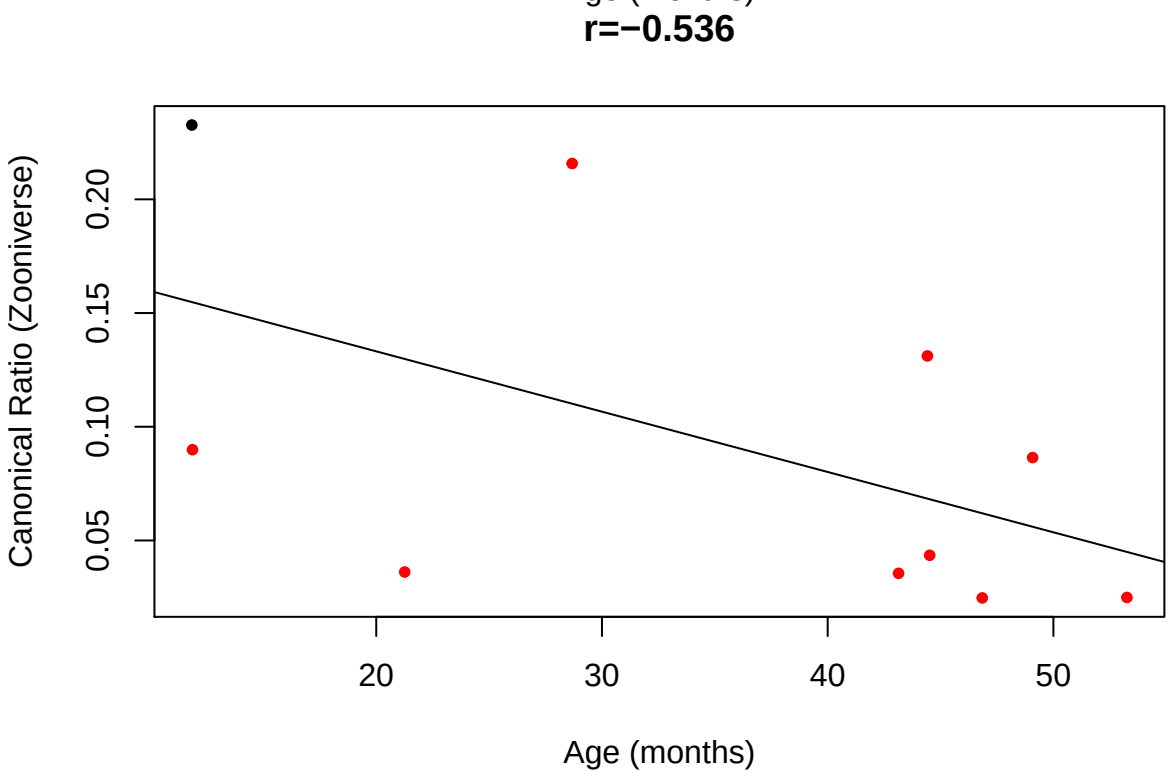
- linguistic ratio = ("Canonical"+"Non-Canonical")/"All vocalizations" (i.e. we remove junk)
- canonical ratio = "Canonical"/("Canonical"+"Non-Canonical") (i.e. we remove junk + non-linguistic vocalizations)

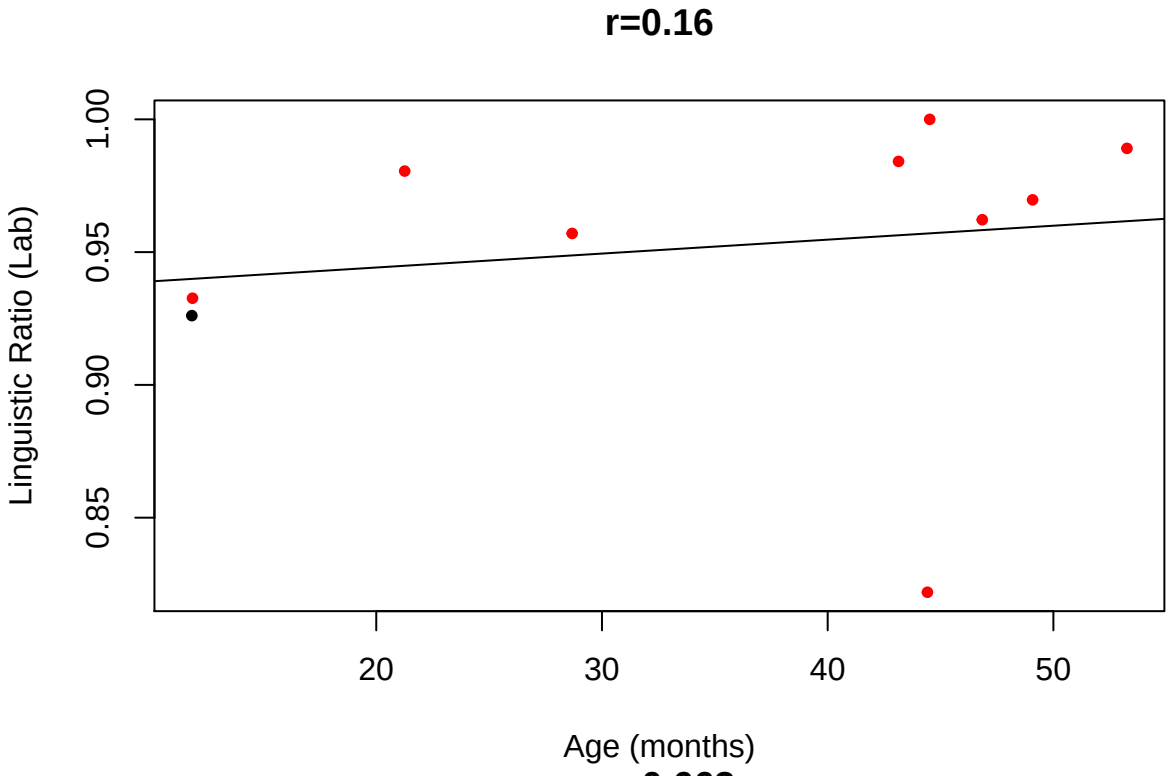
As expected, linguistic ratio goes up with age.

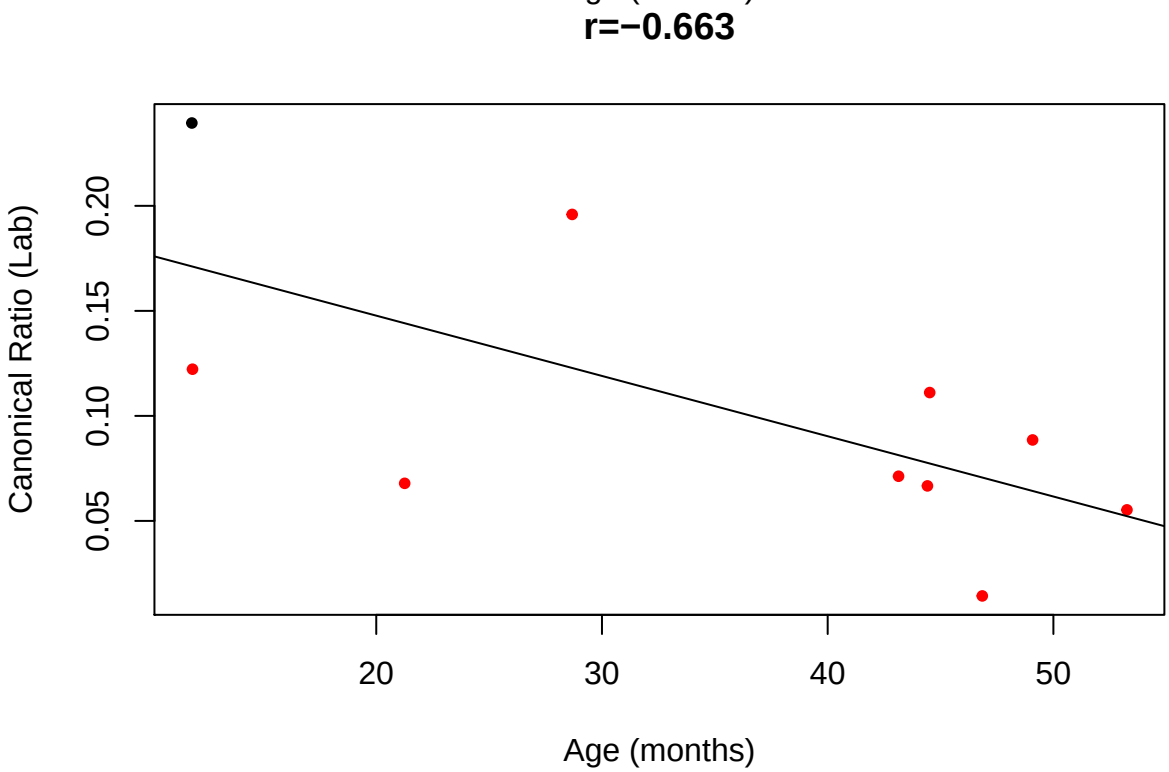
Surprisingly, canonical ratio goes DOWN with age.

```
prettynames=c("Linguistic Ratio (Zooniverse)","Canonical Ratio (Zooniverse)",
              "Linguistic Ratio (Lab)","Canonical Ratio (Lab)" )
names(prettynames)<-c("z_lr","z_cr","l_lr","l_cr")

#!!! this is working the opposite than it should! but note that to get angsynd kids to come out in red,
mycols=c("red","black")
names(mycols)<-c("Low-RiskControl","AngelmanSyndrome")

for(thisvar in c("z_lr","z_cr","l_lr","l_cr")) {
  myr=round(cor.test(ratios[,thisvar],ratios$Age)$estimate,3)
  plot(ratios[,thisvar]~ratios$Age, pch=20,xlab="Age (months)",ylab=prettynames[thisvar],main=paste0("r
       col=mycols[ratios$Diagnosis])
  abline(lm(ratios[,thisvar]~ratios$Age))
  }
```


r=0.014
Linguistic Ratio (Zooniverse)
0.80
0.85
0.90
0.95
20
30
40
50
Age (months)


r=−0.536
Canonical Ratio (Zooniverse)
0.05
0.10
0.15
0.20
20
30
40
50
Age (months)




But the key thing for us: Are Zooniverse annotations describing children similar to lab annotations? The answer is clearly yes.

```
#Ling ratio
pdf("ling_rat_z_vs_l.pdf",height=5,width=5)
lims=range(c(ratios[,"z_lr"],ratios[,"l_lr"]))
```

```
  myr=round(cor.test(ratios[,"z_lr"],ratios[,"l_lr"])$estimate,3)
  plot(ratios[,"z_lr"]~ratios[,"l_lr"], pch=20,xlab=prettynames["l_lr"],ylab=prettynames["z_lr"],main=pa
       xlim=lims,ylim=lims,
       col=mycols[ratios$Diagnosis])
  abline(lm(ratios[,"z_lr"]~ratios[,"l_lr"]))
  lines(c(0,1),c(0,1),lty=2,col="darkgray")
dev.off()
```

```
## pdf
##   2
```

```
  #CR
pdf("can_rat_z_vs_l.pdf",height=5,width=5)
lims=range(c(ratios[,"z_cr"],ratios[,"l_cr"]))
    myr=round(cor.test(ratios[,"z_cr"],ratios[,"l_cr"])$estimate,3)
  plot(ratios[,"z_cr"]~ratios[,"l_cr"], pch=20,xlab=prettynames["l_cr"],ylab=prettynames["z_cr"],main=pa
       xlim=lims,ylim=lims,
       col=mycols[ratios$Diagnosis])
  abline(lm(ratios[,"z_cr"]~ratios[,"l_cr"]),col="darkgray")
    lines(c(0,1),c(0,1),lty=2,col="darkgray")
dev.off()
```

```
## pdf
##   2
```

```
#COMBINED to save space
pdf("combined.pdf",height=5,width=5)
lims=range(c(ratios[,"z_lr"],ratios[,"l_lr"]),c(ratios[,"z_cr"],ratios[,"l_cr"]))
  #myr=round(cor.test(ratios[,"z_lr"],ratios[,"l_lr"])$estimate,3)

  plot(ratios[,"z_lr"]~ratios[,"l_lr"],xlab="Laboratory annotations",ylab="Zooniverse annotations",
       xlim=lims,ylim=lims,
       pch=20,col=mycols[ratios$Diagnosis])
    points(ratios[,"z_cr"]~ratios[,"l_cr"], pch=2, col=mycols[ratios$Diagnosis])
  abline(lm(ratios[,"z_cr"]~ratios[,"l_cr"]))
  abline(lm(ratios[,"z_lr"]~ratios[,"l_lr"]),lty=3)
 # lines(c(0,1),c(0,1),lty=2,col="darkgray")
dev.off()
```

```
## pdf
##   2
```