Data Supplement S2

R code

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######## FUNCTIONS

# 1 # Coefficients function:

## indicates which logistic reg. model coefficients correspond to the group of view selected
### cofficients are used to predict image quality depending on age and bmi
### groups are:
#### xiphoid (for subxyphoid view)
#### pleuras (for right and left pleura views)
#### kidneys (for right and left kidney views)
#### biliary (for gallbladder, portal hilum and portal veins views)
#### bladder (for bladder view)
#### vessels (for aorta and inferior vena cava views)

func.coef<-function(group){
  VEC.COEF<-c(NA,NA,NA)
  if(group=="xiphoid"){VEC.COEF<-c(8.696048,-0.1997064,-0.05700030)}
  if(group=="pleuras"){VEC.COEF<-c(8.771463,-0.2088377,-0.05162462)}
  if(group=="kidneys"){VEC.COEF<-c(9.206422,-0.1986911,-0.06590426)}
  if(group=="biliary"){VEC.COEF<-c(8.441660,-0.2080407,-0.05203970)}
  if(group=="bladder"){VEC.COEF<-c(7.265297,-0.1301629,-0.05978479)}
  if(group=="vessels"){VEC.COEF<-c(7.744625,-0.1951335,-0.05104990)}
  return(VEC.COEF)}


# 2 # RLC function:

## computes RLC score (Wt) over the number of exams realized by the student
### depends on:
#### the group of view
#### the serie of exams realized by the student : series of successes (0) and failures (1)
#### the odds-ratio of failure Rd: generally 1.5 or 2 (Biau et al. (2010) Stat Med 29: 1900-9)
#### proficiency limit
#### p_echo indicates the probability of good image quality depending on age and bmi
#### p0t is the probability of poor image quality (surrogate of the probability of failure)

RA.LC.cus <- function(group,serie, Rd, limit){
  coef<-func.coef(group)
  p_echo <- exp(coef[1]+coef[2]*bmi+coef[3]*age)/(1+exp((coef[1]+coef[2]*bmi+coef[3]*age)))
  p0t <- 1-p_echo
  Wt<-rep(0,length(serie)+1)
  cus <- rep(0, length(serie)+1)
  for(i in 1:length(serie)){
    Wt[i] <- ifelse(serie[i]==0 ,log(1-p0t[i]+Rd*p0t[i]) , log(1-p0t[i]+Rd*p0t[i]) - log(Rd))
    ifelse(cus[i]>=limit, cus[i+1]<- limit, cus[i+1]<-max(cus[i]+Wt[i],0))  }
  cbind.data.frame(Wt=Wt,cus=cus)}


# 3 # RLC limit function:

## computes the number of exams needed to reach the proficiency limit
### returns "Inf" if the student do not reach the limit

limit.RA.LC.cus<-function(group,serie, Rd,limit){
  coef<-func.coef(group)
  p_echo <- exp(coef[1]+coef[2]*bmi+coef[3]*age)/(1+exp((coef[1]+coef[2]*bmi+coef[3]*age)))
  p0t <- 1-p_echo
  Wt<-seq(0,length(serie))
  cus <- rep(0, length(serie)+1)
  for(i in 1:length(serie)){
    Wt[i] <- ifelse(serie[i]==0,log(1-p0t[i]+Rd*p0t[i]) , log(1-p0t[i]+Rd*p0t[i]) - log(Rd))
    cus[i+1] <-  max(cus[i]+Wt[i],0)
    if(cus[i+1]>= limit)
      return(i)}
  return(Inf)}


# 4 # Plot function:
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## plot the learning curve for a student with the RLC score
### lserie is the length of the serie of exams performed by the student
### X is the highest value of x axis (number of exams)
### Y is the highest value of y axis (RLC score)

plot.RA.LC.CUSUM.OR<-function(group,lserie,Rd,limit,X,Y){

  coef<-func.coef(group)
  p_echo <- exp(coef[1]+coef[2]*bmi+coef[3]*age)/(1+exp((coef[1]+coef[2]*bmi+coef[3]*age)))
  p0t <- 1-p_echo

  par(mar=c(6, 4, 4, 2) +0.1)
  plot(c(0,X), c(0,Y), type='n', xlab="",ylab='RLC score', axes=F)
  axis(1, at=seq(0, X, 5), labels=seq(0, X, 5), line=1)
  axis(2, at=seq(0, Y, 1), labels=seq(0, Y, 1),las=1)
  mtext('Number of Exams', side=1, line=3.2)

  lines(RA.LC.cus(group,serie,Rd,limit)$cus[RA.LC.cus(group,serie,Rd,limit)$cus!=limit],
col="blue")

  lines(c(0, X), c(0, 0),lty=2)
  lines(c(0, X), c(limit, limit), col="purple",lty=2)

  obs<-c(1:lserie)
  TAB<-data.frame(obs,serie)
  TAB
  points(TAB$obs[serie==1],TAB$serie[serie==1],pch=4, col="darkred")

  legend("topleft", legend=c("Limit (proficiency)","Failures"),col=c("purple","darkred"),
lty=c(2,0),pch=c(NA_integer_,4),bty="n", cex=0.8, y.intersp=1.5,x.intersp=1.5)}


######## DATA

# dataset:

## each data line correspond to one patient ultrasound exam including the 11 views of interest

## data rows:

### student (student1, student2...)
### exam_number (for each student)
### age (years)
### weight (kg)
### height (m)
### body mass index (bmi)
### aorta (for aorta view): 0 if succes, 1 if failure
### ivc (for inferior vena cava view): 0 if succes, 1 if failure
### pveins (for portal veins view): 0 if succes, 1 if failure
### philum (for portal hilum view): 0 if succes, 1 if failure
### gb (for gallbladder view): 0 if succes, 1 if failure, abs if absent
### rkid (for right kidney view): 0 if succes, 1 if failure, abs if absent
### rpleura (for right pleura view): 0 if succes, 1 if failure
### lkid (for left kidney view): 0 if succes, 1 if failure, abs if absent
### rpleura (for right pleura view): 0 if succes, 1 if failure
### bladder (for bladder view): 0 if succes, 1 if failure, abs if empty
### xiph (for subxiphoid view): 0 if succes, 1 if failure

d<-data
d$bmi<-d$weight/((d$height/100)^2) # to compute bmi

# set the odds ratio of failure (Rd): 1.5 or 2
# set the proficiency limit
# set X depending on the number of exams performed by students
# set Y depending on RLC scores


######## EXAMPLES OF INDIVIDUAL LEARNING CURVES

Rd<-1.5
limit<-5
X<-50
Y<-10

# Aorta view for student 1:
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group<-"vessels"
serie<-d$aorta[d$student=="student1"]
lserie<-length(serie)
bmi<-d$bmi[d$student=="student1"]
age<-d$age[d$student=="student1"]

plot.RA.LC.CUSUM.OR(group,lserie,Rd,limit,X,Y)


# for series with "absent" views:

## need to exclude exams where organ may be absent (gallbladder, kidneys) or empty (bladder)
## example of Gallbladder view for student 3:

group<-"biliary"
serie<-as.numeric(as.character(d$gb[d$student=="student3" & d$gb!="abs"]))
lserie<-length(serie)
bmi<-d$bmi[d$student=="student3" & d$gb!="abs"]
age<-d$age[d$student=="student3" & d$gb!="abs"]

plot.RA.LC.CUSUM.OR(group,lserie,Rd,limit,X,Y)


######## PLOTTING STUDENTS LEARNING CURVES FOR A SPECIFIC VIEW (ex: aorta view)

# set parameters Rd, limit, X and Y

Rd<-1.5
limit<-1
X<-50
Y<-1.5

# select the group of view

group<-"vessels"

# set graphic parameters for all the learning curves

par(mar=c(6, 4, 4, 2) +0.1)
plot(c(0,X), c(0,Y), type='n', xlab="",ylab='RLC score', axes=F, cex.lab=1.2)
axis(1, at=seq(0, X, 5), labels=seq(0, X, 5), line=1, cex.axis=1.2)
axis(2, at=seq(0, Y, 0.5), labels=seq(0, Y, 0.5),las=1, cex.axis=1.2)
mtext('Number of Exams', side=1, line=3.2)
lines(c(0, X), c(0, 0),lty=2)
lines(c(3, X), c(limit, limit), col="purple")
legend("topleft",bty="n",legend="Student n", col=1,lty=1,lwd="2")
text(x=X-10,y=limit+0.05,"limit (proficiency)", col="purple")

# plot the curve for each student on the same graph :

## student 1:

serie<-d$aorta[d$student=="student1"]
lserie<-length(serie)
bmi<-d$bmi[d$student=="student1"]
age<-d$age[d$student=="student1"]

lines(RA.LC.cus(group,serie,Rd,limit)$cus[RA.LC.cus(group,serie,Rd,limit)$cus!=limit],
col="1",lwd="2",lty=1)
limit.RA.LC.cus(group,serie, Rd,limit) # number of exams needed to reach proficiency

## student 2: etc...

# for series with "absent" views:

## need to exclude exams where organ may be absent (gallbladder, kidneys) or empty (bladder)
## example of right kidney view for student 4:

serie<-as.numeric(as.character(d$rkid[d$student=="student4" & d$rkid!="abs"]))
lserie<-length(serie)
bmi<-d$bmi[d$student=="student4" & d$rkid!="abs"]
age<-d$age[d$student=="student4" & d$rkid!="abs"]

lines(RA.LC.cus(group,serie,Rd,limit)$cus[RA.LC.cus(group,serie,Rd,limit)$cus!=limit],
col="4",lwd="2",lty=1)
limit.RA.LC.cus(group,serie, Rd,limit) # number of exams needed to reach proficiency
```