Introduction

Virtual Reality is something I use on a weekly basis, either recreationally or in my research. Until taking DfHV, I never thought about how VR masks may be designed to fit a population. I frequently use the HTC Vive and it fits my face fairly well, but what about others? How did HTC decide how to shape their mask? Do the shape and adjustment features allow the HTC Vive to fit to the *majority* of its target users? Who is being left out if the virtual reality experience? Is there a better way to design this mask to fit a larger population?

Overview

The purpose of the following report is to evaluate the accommodation of the HTC Vive Virtual Reality headset for men and women ages 12 to 62 years old. Depending on the results, a new Virtual Reality head mount design may be suggested to better accommodate the population. The minimum age was selected because popular VR headsets like the Gear VR and Oculus Rift have a 13+ and 12+ age limit respectively. Although the HTC Vive does not specify a specific age restriction, it warns against allowing *children* to use the HTC Vive. [1] It is assumed if the HTC Vive *were* to have an age restriction it would be similar to that of the Oculus or Gear VR. Maximum age limit was chosen as virtual reality relates to industry. Virtual Reality is becoming more prevalent in industry, it is commonly used to enable innovation and help with decision making. [2] Since Virtual Reality is being seen more and more frequently in industry, the maximum age limit was chosen to be 62, the average retirement age for Americans. [3] It's assumed that the majority those over 62 years of age are not using Virtual Reality.

Benchmarking

The measurements for the more popular Virtual Reality head mounts are not readily available online. I had to take my own measurements of the HTC Vive as they relate to Anthropometric Measurements.

Measurements

The measurements for accommodation were taken from an Anthropometric survey of army personnel conducted in 1987-1988 (ANSUR). These measurements were used to predict the measurements of a much larger population (NHANES 2011-2014) using a regression model with residual variance, discussed later in the paper. The anthropometric measurements assed for the Virtual Reality Headset were Head Circumference, Interpupillary Breadth, and Bizygomatic breadth. The maximum and minimum measurements related to Head Circumference, Interpupillary Breadth, and Bizygomatic Breadth were measured with tape and calipers on the HTC Vive head mount.

1. <u>Head Circumference (ANSUR Measurement 61)</u>

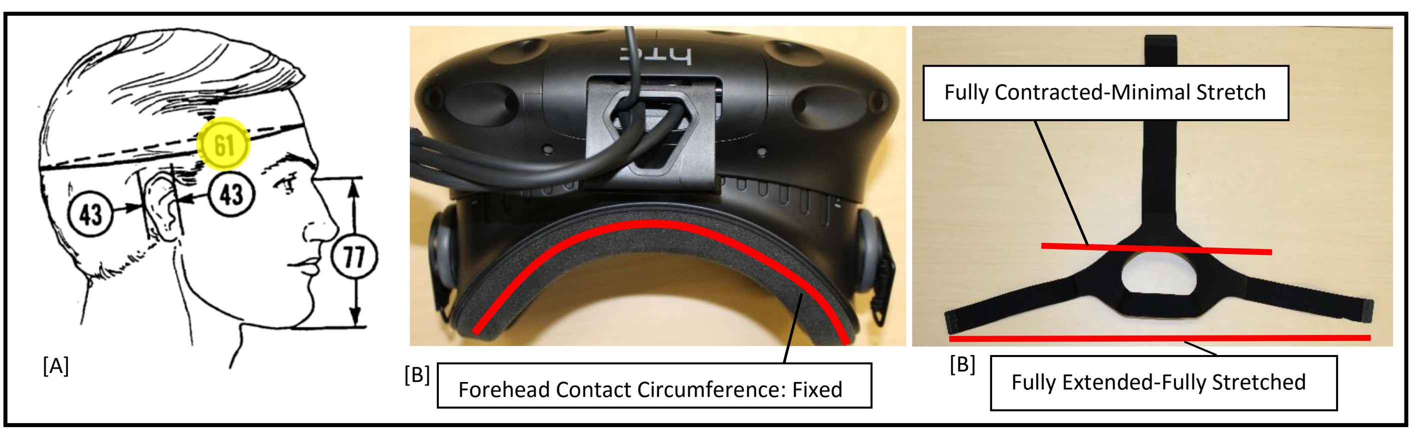


Figure 1: Measurements related to head circumference

Measurements of the HTC Vive that adjust to accommodate head circumference were made using measuring tape. (see Fig.1) The fixed forehead contact circumference (padding removed) was found to be 19cm in length. The elastic that wraps around the side and back of the head was adjusted to full extension and the elastic was stretched as far as possible without risking tearing it to simulate the largest head circumference possible. The elastic wrap in the fully extended-fully stretched position was 68.5cm. The elastic wrap was then fully contracted with minimal stretch to simulate the smallest accommodation possible. The wrap in the fully contracted-minimal stretch position was found to be 36.25cm. Given the fully extended, fully contracted and fixed contact circumference lengths, the maximum and minimum head circumference measurements were found for the HTC Vive.

Max Fit = Fully Extended + Forehead Contact Circumference = 68.5cm+19cm = 875mm

Min fit = Fully Contracted + Forehead Contact Circumference = 36.25 + 19 = 552.5mm

2. <u>Interpupillary Breadth (ANSUR Measurement 68)</u>

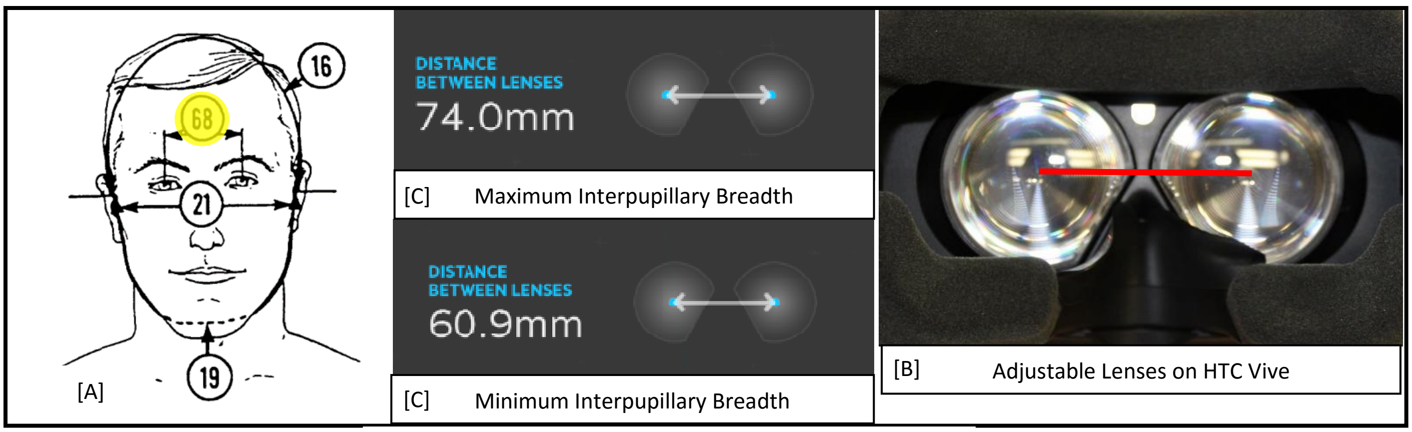


Figure 2: Measurements related to Interpupillary Breadth

The measurements for minimum and maximum interpupillary breadth for the HTC Vive were determined in-game. With the Vive headset on, one can adjust the lens distance to their liking. Figure 2 shows the range of lens adjustments available, the Minimum Interpupillary Breath and Maximum Interpupillary Breadth images in figure 2 were screenshots taken in-game. The measurements were verified with a set of calipers. The minimum interpupillary breadth for the HTC Vive was found to be 60.9mm and the maximum interpupillary breadth was found to be 74.0mm.

3. <u>Bizygomatic Breadth (ANSUR Measurement 21)</u>

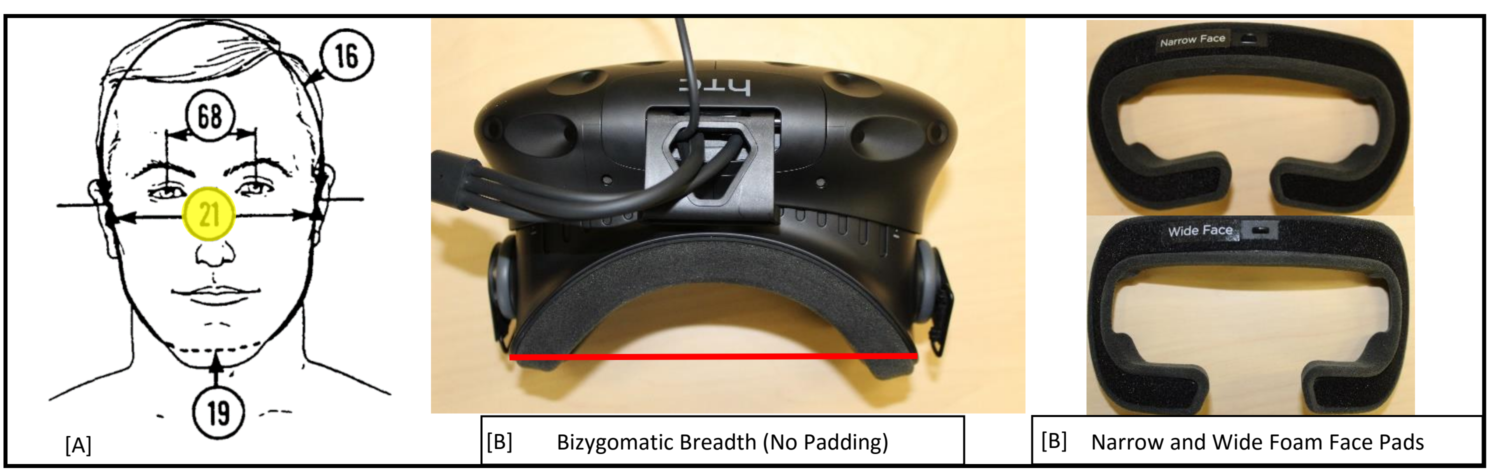


Figure 3: Position of the HTC Vive in relation to the zygomatic arches

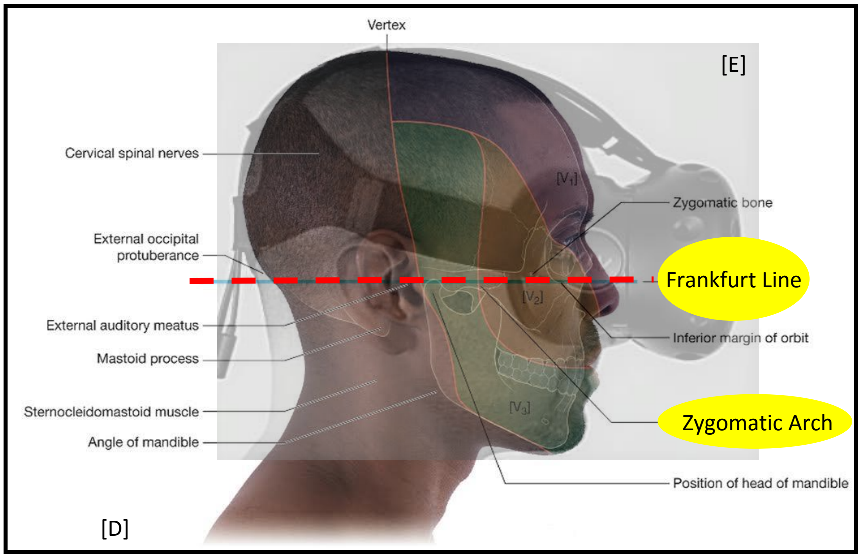


Figure 4: Position of the HTC Vive in relation to the zygomatic arches

According to the ANSUR study conducted in 1987-1988, Bizygomatic Breadth is measured as the maximum horizontal distance between the zygomatic arches. [5] A profile of the human head (figure 4) shows the position of the zygomatic arch, and what is known as the Frankfurt line, a horizontal line that runs through the zygomatic arch. [4] The Frankfort line meets the HTC Vive just below the head band. The distance between these intersection points on either side of the HTC Vive were measured. This measurement was made without the foam facemask inserts. This measurement was fixed as it was a measurement from rigid plastic to rigid plastic (see figure 3: Bizygomatic Breadth (No Padding)). This measurement was found to be 155mm. The measurement used to find the range of accommodation was the narrow and wide foam face pad thickness measurements (see figure 3: Narrow and wide foam face pads). The wide face pad thickness was measured at full compression, to simulate the widest face fit possible. This measurement was found to be 4.7mm. The narrow face pad was measured uncompressed to simulate the slimmest face fit possible. This measurement was found to be 19.4mm. Subtracting the flexible measurements (Wide face mask fully compressed/Narrow face mask uncompressed) from the rigid measurement (Bizygomatic Breadth (No Padding)) yields the accommodation bounds for Bizygomatic Breadth for the HTC Vive.

Widest Face Accommodated= Bizygomatic Breadth (no padding) - 2*Wide Face Pad Thickness (fully compressed) = 155mm-2*4.7mm = 146.6mm

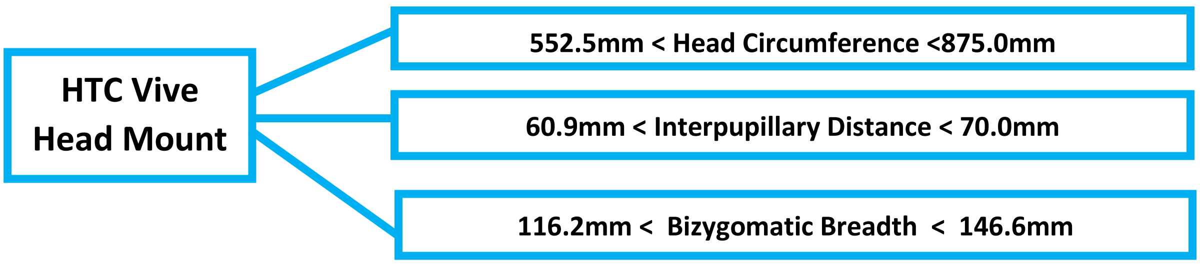
Most Narrow Face Accommodated= Bizygomatic Breadth (no padding) - 2*Narrow Face Pad Thickness (uncompressed) = 155mm - 2*19.4mm = 116.2mm

Methods and Analysis

Assuming the HTC Vive is designed for the US civilian population, the Nhanes 2011-2014 data were used to calculate accommodation (men and women ages 12 to 62). Unfortunately, Nhanes does not have the measurements of Head Circumference, Interpupillary Breadth, or Bizygomatic Breadth. ANSUR has these measurements, but since these are measurements of men and women in the US Army they are not a good representation of the US civilian population. A regression model with residual variance was needed to simulate Head Circumference, Interpupillary Breadth, and Bizygomatic Breadth data for the Nhanes 2011-2014 population using given ANSUR Stature, calculated ANSUR BMI, given Nhanes Stature, and Nhanes BMI, as well as other anthropometric measurements available in ANSUR. See Appendix A1 for the process in R.

HTC Vive Accommodation

After simulating data points for Head Circumference, Interpupillary Breadth, and Bizygomatic Breadth in the Nhanes 2011-2014 data, an accommodation model for the HTC Vive had to be created. This accommodation model was created as a subset of the Nhanes population with limitations on the measurements discussed earlier.



After defining these limitations in the HTC Vive Data set, the points were plotted along with points from the entire Nhanes 2011-2014 (age 12-62) data set.

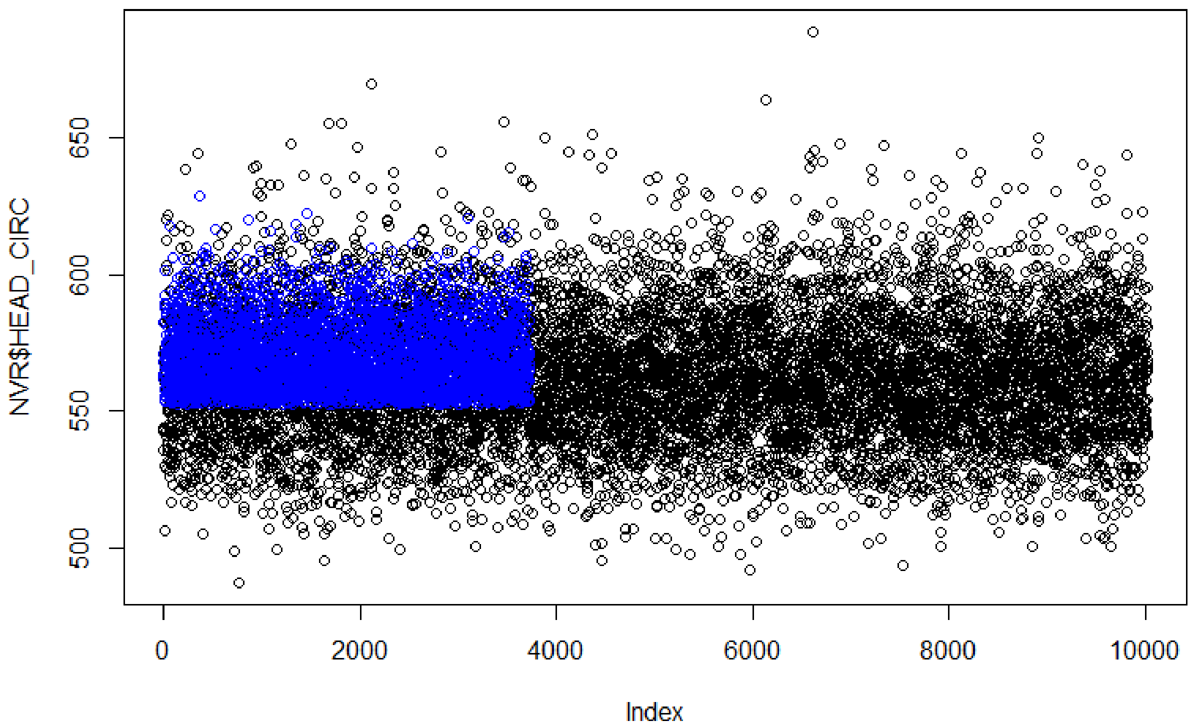


Figure 5: HTC Vive Accomodation for Nhanes Population 2011-2014 (Ages 12 to 62)

The black points in figure 5 show the entire Nhanes 2012-2014 population ages 12 to 62. The Blue points in the figure show the population that fits into the anthropometric limitations of Head Circumference, Pupillary Distance and Bizygomatic breadth set by the HTC Vive head mount. It is clear from the graph that HTC is not accommodating enough of its target age range for the US civilian population. The Vive accommodates 3726 out of 10022 people in the data set. In other words, the HTC Vive accommodates approximately 37.2% of its target users. It is clear that a few changes need to be made to this design to accommodate a larger population.

New Virtual Reality Head Mount

Calculating the 5th to 95th percentile for Head Circumference, Interpupillary Distance, and Bizygomatic Breadth and then adjusting the design to fit those percentiles will accommodate 90% of users if each measurement is evaluated individually. However, when these limitations are combined into a single set of data, this design only accommodates 8048 out of 10022 people, or 80.3%. (See Figure 6)

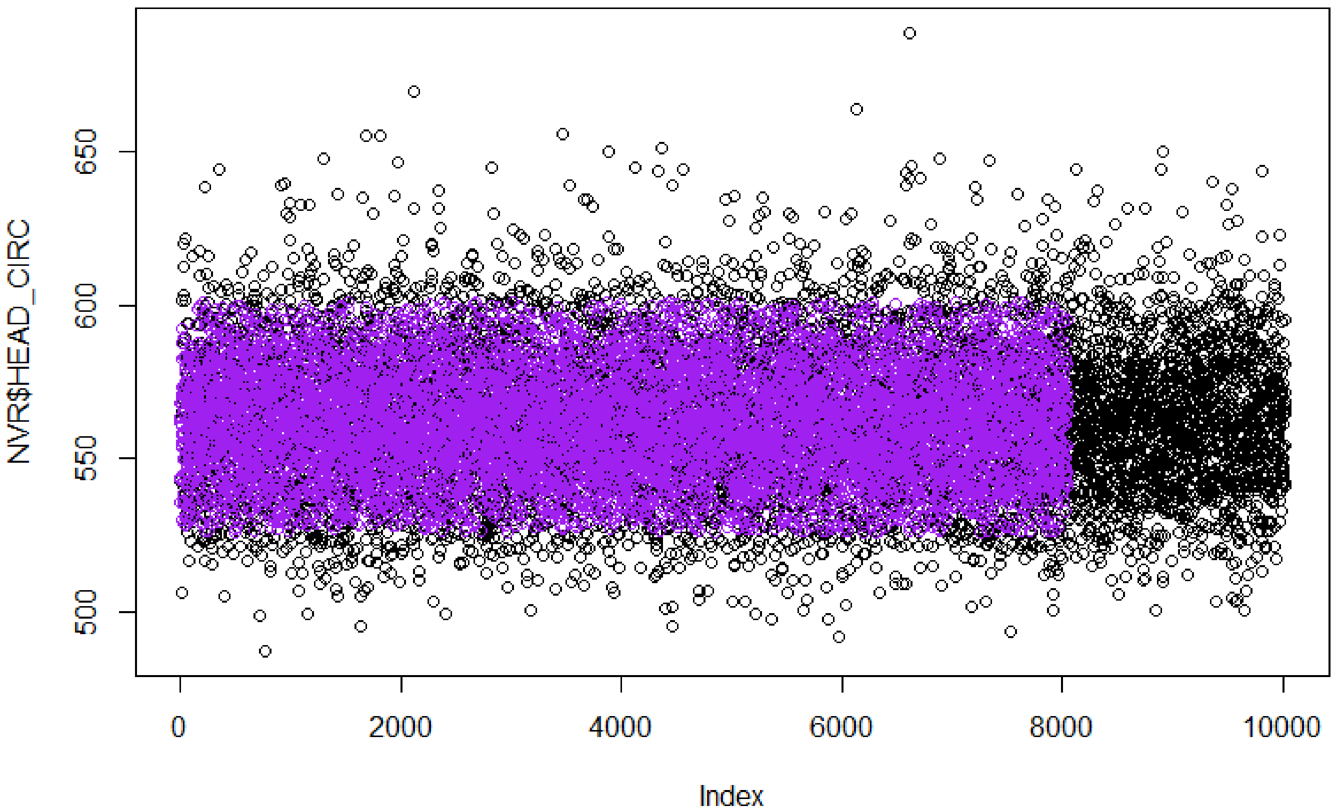


Figure 6: VR Head Mount (Design 1) Accommodation for Nhanes Population 2011-2014 (Ages 12 to 62)

Although this accommodation is significantly greater than that of the HTC Vive, it is still not enough. The design will have to accommodate *more* than 90% for each measurement individually, to allow for 90% accommodation as a whole. To achieve this, the 2.5th and 97.5th percentiles were calculated for each measurement and applied as new constraints for the improved VR Head Mount design. Yet this still wasn't enough, this accommodated roughly 88% of the target population. From this point it was decided that it would be easier to tweak one variable instead of 3 variables at a time. The easiest (and cheapest) variable to change within the product would be the head band, the dimension that adjusts for head circumference. The head band was changed to accommodate 100% of the head circumference measurements.

New Head Mount Design

- **513.6mm < Head Circumference <619.9mm**
- **56.2mm < Interpupillary Distance < 73.2mm**
- **122.2mm < Bizygomatic Breadth < 158.8mm**

Adjusting the head band to accommodate 100% of head circumference measurements allowed the New Head Mount Design to accommodate 9100 out of 10022 people, or 90.8% of the target population (see figure 7 below).

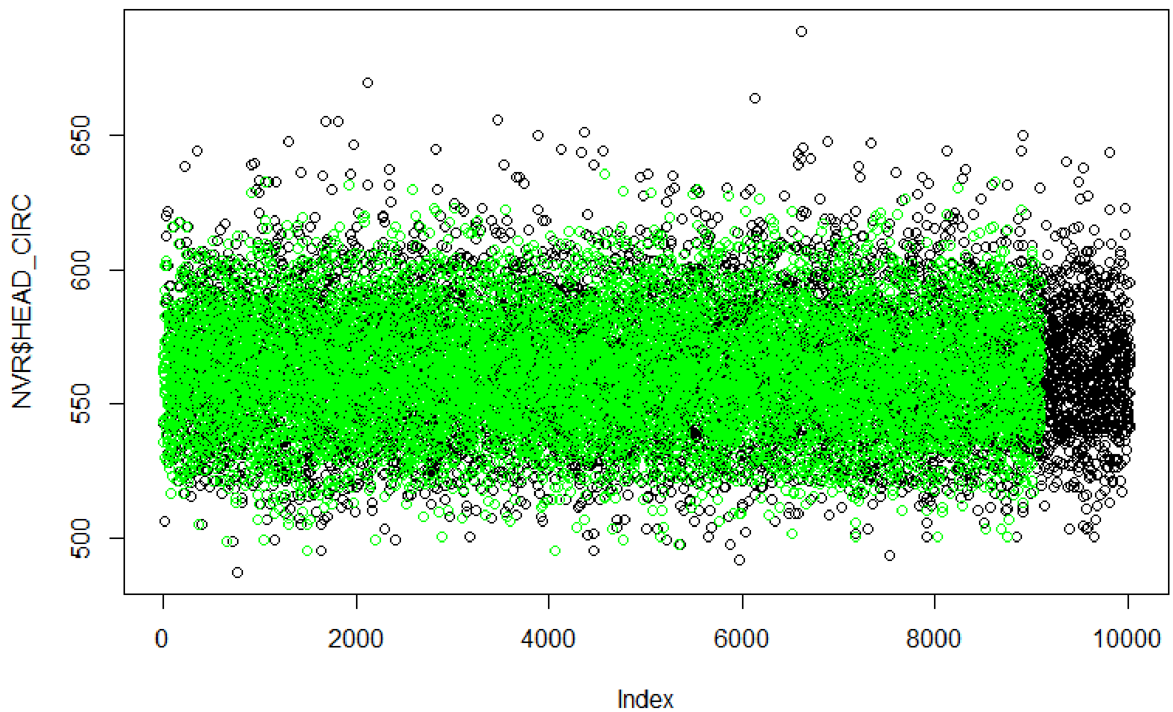


Figure 7: VR Head Mount (Design 2) 90.8% Accomodation for Nhanes Population 2011-2014 (Ages 12 to 62)

Conclusion: Comparing the New Design to the HTC Vive Design

1. Head Circumference: The new design for the head circumference band (plus fixed forehead contact circumference) has a fully contracted minimal stretch length of 513.6mm; 38.9mm shorter than the HTC Vives length. The band at full extension and stretch is 619.9mm, which is actually 255.1mm *shorter* than the HTC Vive band at full extension and stretch. The *difference* between min and max measurements for the new design is 106.3mm, compared to the difference between min and max of the HTC Vive which is 322.5mm. The new design for head circumference has a smaller range of adjustment, uses less material, *and* accommodates more of the target population compared to the HTC Vive.
2. Interpupillary Distance: The new design has a larger range of interpupillary distances. The difference between the max and min measurements of the new design is 17mm. The difference between the min and max measurements for the HTC Vive is 9.1mm. The interpupillary distance adjustment for the new design is nearly twice that of the existing design, this level of variability may be difficult to implement, but if possible, it would accommodate a much larger population of users.
3. The minimum bizygomatic breadth was actually increased in the new design. Target users do not need a minimum breadth as small as 116.2 mm, a minimum breadth of 122.2mm will do just fine. However, the difference between these two measurements is a mere 6mm, so changing the minimum breadth may not really be necessary at all. The maximum breadth for the new design turned out to be roughly 11mm larger than that of the HTC vive. The difference between min and max of the New Design was 36.6mm compared to the difference in the HTC Vive design which was 30.4. These ranges are fairly close to each other, it seems that the New Design accommodates for wider faces. It does not need to be designed to be narrower, only wider. (Perhaps an option for thinner face cushions?)

APPENDIX

A1

```
men<-read.csv(file.choose(), header=TRUE)
women<-read.csv(file.choose(), header=TRUE)
#pick which ansur data  I want
ANSURmenVR<- subset(men, select = c('BIZYGOMATIC_BRTH','INTERPUPILLARY_DIST', 'HEAD_CIRC', 'WEIGHT','STATURE'))
ANSURwomenVR<- subset(women, select = c('BIZYGOMATIC_BRTH','INTERPUPILLARY_DIST', 'HEAD_CIRC','WEIGHT','STATURE'))
#combine ansur data
ANSURvr<-rbind(ANSURmenVR,ANSURwomenVR)
#Calculate BMI
ANSURvr$BMI <-((ANSURvr$WEIGHT*.1)/(ANSURvr$STATURE*.001)^2)
#Get rid of -999 values in ANSURvr$INTERPUPILLARY_DIST
ANSURvr<-subset(ANSURvr,INTERPUPILLARY_DIST>0)
ANSURvr$INTERPUPILLARY_DIST


#Load Nhanes data, select age group
N11_12<- subset(Nhanes1112, select = c('BMXBMI', 'BMXHT', 'RIAGENDR', 'RIDAGEYR', 'WTMEC2YR'))
N13_14<- subset(Nhanes1314, select = c('BMXBMI', 'BMXHT', 'RIAGENDR', 'RIDAGEYR', 'WTMEC2YR'))
Nhanes<-rbind(N11_12,N13_14)
#get rid of NA values in NHANES data
N<-Nhanes[complete.cases(Nhanes),]
#filter out subjects older than 62 and younger than 12
NVR<-subset(N, RIDAGEYR< 62 & RIDAGEYR>12)
#change BMX height to mm
NVR$BMXHT = NVR$BMXHT*10;

#Combine Nhanes with ANSUR using regression with residual variance
RegressionResidualVar<-function(x1,x2, y, x1out,x2out){
  #lm = linear model
  reg<- lm(y~x1+x2)
  #coefficients function looks for the coefficients of the linear model

  c=coefficients(reg);
  #intercept is the
  intercept<-c[1];
  x1mult<-c[2]
  x2mult<-c[3]
  #find residuals: summaryreg$sigma = residual variance,  this is the standard deviation of the gaussian distribution (individual shift for each point)
  sd = summary(reg)$sigma;

  yout =  x1out*x1mult + x2out*x2mult + intercept + rnorm(length(x1out),0,sd);
  return(yout)

}
#create NHANES data for Head Circumference)
NVR$HEAD_CIRC<-RegressionResidualVar(ANSURvr$STATURE,ANSURvr$BMI, ANSURvr$HEAD_CIRC,  NVR$BMXHT, NVR$BMXBMI)
#create NHANES data for Interpupillary Distance
NVR$INTERPUPILLARY_DIST<-RegressionResidualVar(ANSURvr$STATURE,ANSURvr$BMI, ANSURvr$INTERPUPILLARY_DIST,  NVR$BMXHT, NVR$BMXBMI)
#create NHANES data for Bizgomatic Breadth
NVR$BIZYGOMATIC_BRTH<-RegressionResidualVar(ANSURvr$STATURE,ANSURvr$BMI, ANSURvr$BIZYGOMATIC_BRTH,  NVR$BMXHT, NVR$BMXBMI)

#plot new values vs stature and BMI just to check!(not shown)

plot(NVR$HEAD_CIRC)

HTC_Vive<-subset(NVR,INTERPUPILLARY_DIST>60.9 & INTERPUPILLARY_DIST<74 )
HTC_Vive2<-subset(NVR,INTERPUPILLARY_DIST>60.9 & INTERPUPILLARY_DIST<74 & HEAD_CIRC>552.5 & HEAD_CIRC<875)
HTC_Vive3<-subset(NVR,INTERPUPILLARY_DIST>60.9 & INTERPUPILLARY_DIST<74 & HEAD_CIRC>552.5 & HEAD_CIRC<875 & BIZYGOMATIC_BRTH>116.2 & BIZYGOMATIC_BRTH<145.6 )

points(HTC_Vive$INTERPUPILLARY_DIST, col='green')
points(HTC_Vive2$INTERPUPILLARY_DIST, col='red')
points(HTC_Vive3$HEAD_CIRC, col='blue')

quantile(NVR$HEAD_CIRC, c(0,1))


JOHN_VR90<-subset(NVR, INTERPUPILLARY_DIST>56 & INTERPUPILLARY_DIST<72 & HEAD_CIRC>526 & HEAD_CIRC<601 & BIZYGOMATIC_BRTH>124 & BIZYGOMATIC_BRTH<155)
points(JOHN_VR90$HEAD_CIRC, col = 'purple')

JOHN_VR95<-subset(NVR, INTERPUPILLARY_DIST>56.2 & INTERPUPILLARY_DIST<73.2 & HEAD_CIRC>487.4 & HEAD_CIRC<688.6 & BIZYGOMATIC_BRTH>122.2 & BIZYGOMATIC_BRTH<158.8)
points(JOHN_VR95$HEAD_CIRC, col = 'green')
```

WORKS CITED

[1] https://www.digitaltrends.com/virtual-reality/is-vr-safe-for-kids-we-asked-the-experts/

[2]https://link.springer.com/article/10.1007/s10055-016-0293-9

[3] https://money.usnews.com/money/retirement/articles/2014/05/12/the-ideal-retirement-age-and-why-you-wont-retire-then

[4] https://web.duke.edu/anatomy/

[5] 1987-1988 Anthropometric Survey of US Army Personnel: Summary Statistics Interim Report

IMAGES

[A] 1987-1988 Anthropometric Survey of US Army Personnel: Summary Statistics Interim Report

[B] My images

[C] In-game Screen Shot HTC Vive

[D] https://web.duke.edu/anatomy/Lab17/prelab19_Fig1.jpg

[E] https://cdn3.recombu.com/media/technology/Devices/HTC/Vive/Product/SideOn_w720_h405.jpg