No evidence for correlations between handgrip strength and sexually dimorphic acoustic properties of voices

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Data and analysis files are publicly available at https://osf.io/na6be/

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Abstract

Recent research on the signal value of masculine physical characteristics in men has focused on the possibility that such characteristics are valid cues of physical strength. However, evidence that sexually dimorphic vocal characteristics are correlated with physical strength is equivocal. Consequently, we undertook a further test for possible relationships between physical strength and masculine vocal characteristics. We tested the putative relationships between White UK (N=115) and Chinese (N=106) participants' handgrip strength (a widely used proxy for general upper-body strength) and five sexually dimorphic acoustic properties of voices: fundamental frequency (F0), fundamental frequency's standard deviation (F0-SD), formant dispersion (Df), formant position (Pf), and estimated vocal-tract length (VTL). Analyses revealed no evidence that stronger individuals had more masculine voices. Our results do not support the hypothesis that masculine vocal characteristics are a valid cue of physical strength in humans.

Introduction

Early research on the signal value of masculine physical characteristics in men focused on the possibility that masculine physical characteristics were valid cues of men's immunocompetence (Penton-Voak et al., 1999; Thornhill & Gangestad, 1999). More recent research has focused on the possibility that masculine physical characteristics may, instead, be valid cues of men's physical strength (reviewed in Puts, 2010 and Scott et al., 2013). Evidence supporting this latter hypothesis has come from studies reporting positive correlations between men's facial masculinity and upper-body strength, as measured via handgrip strength (Fink et al., 2007; Windhanger et al., 2011). Further evidence for this hypothesis comes from research showing that increasing upper-body strength increases the masculinity of men's upper-body shape (see Fan et al., 2005).

Although there is good evidence that more masculine male voices are perceived to be more dominant (e.g., Feinberg et al., 2005; Puts, 2005), only two studies have explored possible relationships between upper-body strength and sexually dimorphic vocal characteristics. Puts et al. (2011) investigated possible relationships between US and Hadza men's arm strength (a composite measure derived from handgrip strength and flexed bicep circumference) and four sexually dimorphic vocal characteristics; fundamental frequency (F0), fundamental frequency's standard deviation (F0-SD), formant dispersion (Df), and formant position (Pf). Values for F0, F0-SD, Df, and Pf are typically larger in women than men (see, e.g., Puts et al., 2011). Stronger US men tended to have more masculine F0-SD and more masculine Pf. Stronger Hadza men tended to have more masculine F0. Df did not predict handgrip strength in either group. Although these correlations suggest men with more masculine voices may be physically stronger, the significant relationships would not have survived correction for multiple comparisons, suggesting they may not be robust (Puts et al., 2011). Indeed, Sell et al. (2010) found no significant relationships between physical strength and either F0 or Df in US, Tsimane, or Andean men, or in a sample of US women.

The current study reports a further test of the hypothesized relationship between upper-body strength and sexually dimorphic acoustic properties of voices in a sample including both White UK and Chinese men and women. Following Fink et al. (2007), Windhanger et al. (2011), and Puts et al. (2011), upper-body strength was assessed via handgrip strength. In addition to the F0, F0-SD, Pf, and Df measures considered by Puts et al. (2011), we measured a fifth sexually dimorphic vocal characteristic (estimated vocal-tract length, VTL, Reby & McComb, 2003). We included VTL because of meta-analytic evidence that it predicts body size in men and women and may, therefore, be related to strength (Pisanski et al., 2014a). Values for VTL are generally larger in men than women (see, e.g., Pisanski et al., 2014a).

Methods

In total, 221 participants took part in the study. These included 58 White UK men and 57 White UK women, all of whom were born and resided in the UK. They also included 53 Chinese men and 53 Chinese women, all of whom were born in China, but currently resided in the UK (mean number of years in the UK = 1.04 years, SD = 0.93 years). Mean age (and SD) for each group of participants is given in Table 1. None of these participants had taken part in our previous research on vocal cues of men's threat potential (Han et al., 2016).

We measured each participant's handgrip strength from their dominant hand two times using a T. K. K. 5001 Grip A dynamometer. Following Fink et al. (2007), the highest recording from each participant (i.e., their maximal handgrip strength) was used in analyses (see Table 1 for means and SDs).

A mono digital voice recording of each participant was also taken, using an Audio-Technica AT-4041 cardioid condenser microphone at a sampling rate of 44.1 kHz at 16-bit amplitude quantization. Each participant was instructed to say "Hi, I'm a student at the University of Glasgow" in their normal speaking voice. White UK participants were recorded speaking English and Chinese participants were recorded speaking Mandarin.

F0, F0-SD, Pf, and Df were calculated using methods described in Puts et al. (2011) and measurements made using PRAAT software (v. 4.4.11). Estimated VTL was also calculated from formant frequency using a formula described in Reby and McComb (2003). Each variable's means (and SDs) are shown in Table 1 for each group of participants. Independent samples t-tests showed that each of these acoustic measures was sexually dimorphic in both White UK (all absolute t>11.0, all p<.001) and Chinese (all absolute t>10.8, all p<.001) speakers.

Table 1. Each variable's means (and SDs) for each group of participants.

	White UK men (N=58)	White UK women (N=57)	Chinese men (N=53)	Chinese women (N=53)
age (years)	22.98 (5.64)	21.83 (3.54)	24.84 (4.38)	24.10 (2.70)
handgrip strength (kgf)	40.69 (8.73)	24.94 (4.58)	41.17 (8.04)	23.57 (3.73)
F0 (Hz)	109.77 (16.75)	216.57 (21.10)	119.64 (14.76)	220.63 (21.88)
F0-SD (Hz)	13.61 (6.50)	42.13 (19.27)	13.15 (4.71)	40.03 (17.43)
Pf	-0.83 (0.41)	0.84 (0.47)	-0.81 (0.55)	0.81 (0.45)
Df (Hz)	997.23 (38.97)	1144.69 (42.54)	995.99 (51.13)	1141.82 (36.81)
VTL	16.87 (0.52)	14.67 (0.49)	16.66 (0.86)	14.47 (0.45)

Results

Analyses were conducted using R version 3.4.2 (R Core Team, 2016). Each of the five acoustic measures (F0, F0-SD, Pf, Df, VTL) was analyzed in a separate model. Handgrip strength was the dependent variable in each model. Predictors were the scaled and centered acoustic measure, speaker ethnicity (effect coded: Chinese = 0.5, White UK = –0.5), speaker sex (effect coded: male = 0.5, female = –0.5), and all possible interactions among these predictors. Full model specifications are given in our Supplemental Materials. Data files and analysis scripts are publicly available at https://osf.io/na6be/.

Each of the five models showed a significant effect of speaker sex (all estimates>12.90, all ts>4.90, all ps<.001), confirming that men had significantly greater handgrip strength than did women (see Table 1). No other main effects (all absolute ts<1.90, all ps>.07) or interactions (all absolute ts<1.90, all ps>.06) were significant in any of the models. None of the models showed effects of acoustic properties that were significant or approached significance (all absolute estimates<1.40, all absolute ts<1.50, all ps>.15). Full results for each model are given in our Supplemental Materials.

Discussion

We investigated hypothesized relationships between five sexually dimorphic acoustic properties (F0, F0-SD, Df, Pf, VTL) of voices and handgrip strength (a widely used proxy for upper-body strength). Our analyses revealed no evidence that stronger individuals had more masculine voices. These results are consistent with other work finding similar null results (Sell et al., 2011), suggesting that previously reported positive correlations between arm strength and sexually dimorphic vocal characteristics (Puts et al., 2011) are not robust. Our null results are also consistent with recent work suggesting that voices may not be a valid cue of men's threat potential (see also Han et al., 2016).

If sexually dimorphic characteristics of voices are not reliably correlated with physical strength, what physical characteristics do they signal? One possibility is that they signal other aspects of threat potential. Consistent with this proposal, a recent meta-analysis found that some sexually dimorphic vocal characteristics (e.g., VTL) do reliably (although weakly) predict within-sex variation in adult body size (Pisanski et al., 2014a). Alternatively, associations between masculine vocal characteristics and threat-related perceptions (e.g., dominance) could be byproducts of sensory biases, such as a generalization of the tendency for larger objects to make lower-pitched sounds (Rendall et al., 2007; Pisanski et al., 2014b). Work exploring this latter possibility may prove fruitful.

In conclusion, our analyses showed no evidence for a positive association between masculine vocal characteristics and handgrip strength. These null results do not support the hypothesis that masculine vocal characteristics are a valid cue of physical strength. Thus, our data suggest that associations between vocal masculinity and physical strength are unlikely to explain positive correlations between men's reproductive potential (Hodges et al., 2011; Puts, 2005) and success (Apicella et al., 2007), as some researchers have proposed.

References

Apicella, C. L., Feinberg, D. R., & Marlowe, F. W. (2007). Voice pitch predicts reproductive success in male hunter-gatherers. *Biology letters,* 3, 682-684.

Han, C., Kandrik, M., Hahn, A. C., Fisher, C. I., Feinberg, D. R., Holzleitner, I. J., ... & Jones, B. C. (2017). Interrelationships among men's threat potential, facial dominance, and vocal dominance. *Evolutionary Psychology*, *15*(1), 1474704917697332.

Fan, J., Dai, W., Liu, F., & Wu, J. (2005). Visual perception of male body attractiveness. *Proceedings of the Royal Society of London B: Biological Sciences*, *272*(1560), 219-226.

Feinberg, D. R., Jones, B. C., Little, A. C., Burt, D. M., & Perrett, D. I. (2005). Manipulations of fundamental and formant frequencies influence the attractiveness of human male voices. *Animal Behaviour*, *69*, 561-568.

Fink, B., Neave, N., & Seydel, H. (2007). Male facial appearance signals physical strength to women. *American Journal of Human Biology,* 19, 82-87.

Hodges-Simeon, C. R., Gaulin, S. J., & Puts, D. A. (2011). Voice correlates of mating success in men: examining "contests" versus "mate choice" modes of sexual selection. *Archives of Sexual Behavior*, *40*, 551-557.

Penton-Voak, I. S., Perrett, D. I., Castles, D. L., Kobayashi, T., Burt, D. M., Murray, L. K., & Minamisawa, R. (1999). Menstrual cycle alters face preference. *Nature*, *399*, 741-742.

Pisanski, K., Fraccaro, P. J., Tigue, C. C., O'Connor, J. J., Röder, S., Andrews, P. W., ... & Feinberg, D. R. (2014a). Vocal indicators of body size in men and women: A meta-analysis. *Animal Behaviour*, *95*, 89-99.

Pisanski, K., Fraccaro, P. J., Tigue, C. C., O'Connor, J. J., & Feinberg, D. R. (2014b). Return to Oz: Voice pitch facilitates assessments of men's body size. *Journal of Experimental Psychology: Human Perception & Performance*, *40*, 1316.

Puts, D. A. (2005). Mating context and menstrual phase affect women's preferences for male voice pitch. *Evolution & Human Behavior*, *26*(5), 388-397.

Puts, D. A. (2010). Beauty and the beast: Mechanisms of sexual selection in humans. *Evolution & Human Behavior*, *31*, 157-175.

Puts, D. A., Apicella, C. L., & Cárdenas, R. A. (2011). Masculine voices signal men's threat potential in forager and industrial societies. *Proceedings of the Royal Society of London B: Biological Sciences*, rspb20110829.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reby, D., & McComb, K. (2003). Anatomical constraints generate honesty: acoustic cues to age and weight in the roars of red deer stags. *Animal Behaviour*, *65*, 519-530.

Rendall, D., Vokey, J. R., & Nemeth, C. (2007). Lifting the curtain on the Wizard of Oz: biased voice-based impressions of speaker size. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 1208.

Sell, A., Bryant, G. A., Cosmides, L., Tooby, J., Sznycer, D., Von Rueden, C., Krauss, A., & Gurven, M. (2010). Adaptations in humans for assessing physical strength from the voice. *Proceedings of the Royal Society of London B: Biological Sciences, 277*, 3509-3518.

Scott, I. M., Clark, A. P., Boothroyd, L. G., & Penton-Voak, I. S. (2013). Do men’s faces really signal heritable immunocompetence?. *Behavioral Ecology, 24*, 579-589.

Thornhill, R., & Gangestad, S. W. (1999). Facial attractiveness. *Trends in Cognitive Sciences*, *3*, 452-460.

Windhager, S., Schaefer, K., & Fink, B. (2011). Geometric morphometrics of male facial shape in relation to physical strength and perceived attractiveness, dominance, and masculinity. *American Journal of Human Biology*, *23*, 805-814.

Code

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Hide

```
library(tidyverse)
library(readxl)
sessionInfo()
```

```
R version 3.4.2 (2017-09-28)
Platform: x86_64-apple-darwin15.6.0 (64-bit)
Running under: macOS Sierra 10.12.6

Matrix products: default
BLAS: /System/Library/Frameworks/Accelerate.framework/Versions/A/Frameworks/vecLib.
framework/Versions/A/libBLAS.dylib
LAPACK: /Library/Frameworks/R.framework/Versions/3.4/Resources/lib/libRlapack.dylib

locale:
[1] en_GB.UTF-8/en_GB.UTF-8/en_GB.UTF-8/C/en_GB.UTF-8/en_GB.UTF-8

attached base packages:
[1] stats     graphics  grDevices utils     datasets  methods   base

other attached packages:
[1] readxl_1.0.0    dplyr_0.7.4     purrr_0.2.4     readr_1.1.1
[5] tidyr_0.7.2     tibble_1.3.4    ggplot2_2.2.1   tidyverse_1.1.1

loaded via a namespace (and not attached):
 [1] Rcpp_0.12.13      cellranger_1.1.0 compiler_3.4.2   plyr_1.8.4
 [5] bindr_0.1         forcats_0.2.0    tools_3.4.2      lubridate_1.6.0
 [9] jsonlite_1.5      nlme_3.1-131     gtable_0.2.0     lattice_0.20-35
[13] pkgconfig_2.0.1   rlang_0.1.2      psych_1.7.8      parallel_3.4.2
[17] haven_1.1.0       bindrcpp_0.2     xml2_1.1.1       stringr_1.2.0
[21] httr_1.3.1        knitr_1.17       hms_0.3          grid_3.4.2
[25] glue_1.1.1        R6_2.2.2         foreign_0.8-69   modelr_0.1.1
[29] reshape2_1.4.2    magrittr_1.5     scales_0.5.0     rvest_0.3.2
[33] assertthat_0.2.0 mnormt_1.5-5     colorspace_1.3-2 stringi_1.1.5
[37] lazyeval_0.2.0    munsell_0.4.3    broom_0.4.2
```

Hide

```
data_raw <- read_xlsx("final_dataset.xlsx")
```

Descriptives

Whole Sample

Hide

```
data_raw %>%
  gather("var", "score", c(age, HGS:VTL_Reby)) %>%
  group_by(var) %>%
  summarise(
    n = n(),
    mean = mean(score),
    sd = sd(score)
  )
```

var <chr>	n <int>	mean <dbl>	sd <dbl>
age	221	2.340136e+01	4.3575690
Df_Puts	221	1.069641e+03	84.8285971
F0	221	1.662691e+02	55.5244990
F0SD	221	2.744994e+01	19.5992055
HGS	221	3.263575e+01	10.6518090
Pf_Puts	221	1.212660e-15	0.9465252
VTL_Reby	221	1.567811e+01	1.2542402

7 rows

Chinese Male

Hide

```
data_raw %>%
  gather("var", "score", c(age, HGS:VTL_Reby)) %>%
  filter(sex == "male", ethnicity == "Chinese") %>%
  group_by(var) %>%
  summarise(
    n = n(),
    mean = mean(score),
    sd = sd(score)
  )
```

var <chr>	n <int>	mean <dbl>	sd <dbl>
age	53	24.8433962	4.3840844
Df_Puts	53	995.9880503	51.1303292

F0	53	119.6396679	14.7579037
F0SD	53	13.1455453	4.7065349
HGS	53	41.1698113	8.0401298
Pf_Puts	53	-0.8051421	0.5511309
VTL_Reby	53	16.6573005	0.8637278

7 rows

Chinese Female

Hide

```
data_raw %>%
  gather("var", "score", c(age, HGS:VTL_Reby)) %>%
  filter(sex == "female", ethnicity == "Chinese") %>%
  group_by(var) %>%
  summarise(
    n = n(),
    mean = mean(score),
    sd = sd(score)
  )
```

var <chr>	n <int>	mean <dbl>	sd <dbl>
age	53	24.1037736	2.6985012
Df_Puts	53	1141.8194969	36.8138047
F0	53	220.6272925	21.8837368
F0SD	53	40.0279943	17.4287878
HGS	53	23.5660377	3.7301239
Pf_Puts	53	0.8051421	0.4479682
VTL_Reby	53	14.4726417	0.4478487

7 rows

White_UK Male

Hide

```
data_raw %>%
  gather("var", "score", c(age, HGS:VTL_Reby)) %>%
  filter(sex == "male", ethnicity == "White_UK") %>%
  group_by(var) %>%
  summarise(
    n = n(),
    mean = mean(score),
    sd = sd(score)
  )
```

var <chr>	n <int>	mean <dbl>	sd <dbl>
age	58	22.9862069	5.6362688
Df_Puts	58	997.2333333	38.9738654
F0	58	109.7733638	16.7474822
F0SD	58	13.6135172	6.4953277
HGS	58	40.6896552	8.7292750
Pf_Puts	58	-0.8280456	0.4112586
VTL_Reby	58	16.8719830	0.5242341

7 rows

White_UK Female

Hide

```
data_raw %>%
  gather("var", "score", c(age, HGS:VTL_Reby)) %>%
  filter(sex == "female", ethnicity == "White_UK") %>%
  group_by(var) %>%
  summarise(
    n = n(),
    mean = mean(score),
    sd = sd(score)
  )
```

var <chr>	n <int>	mean <dbl>	sd <dbl>
age	57	21.8298246	3.5392173
Df_Puts	57	1144.6912281	42.5374870
F0	57	216.5697772	21.0667730
F0SD	57	43.1342912	19.2727416
HGS	57	24.9385965	4.5787457

Pf_Puts	57	0.8425727	0.4682907
VTL_Reby	57	14.6736836	0.4853020

7 rows

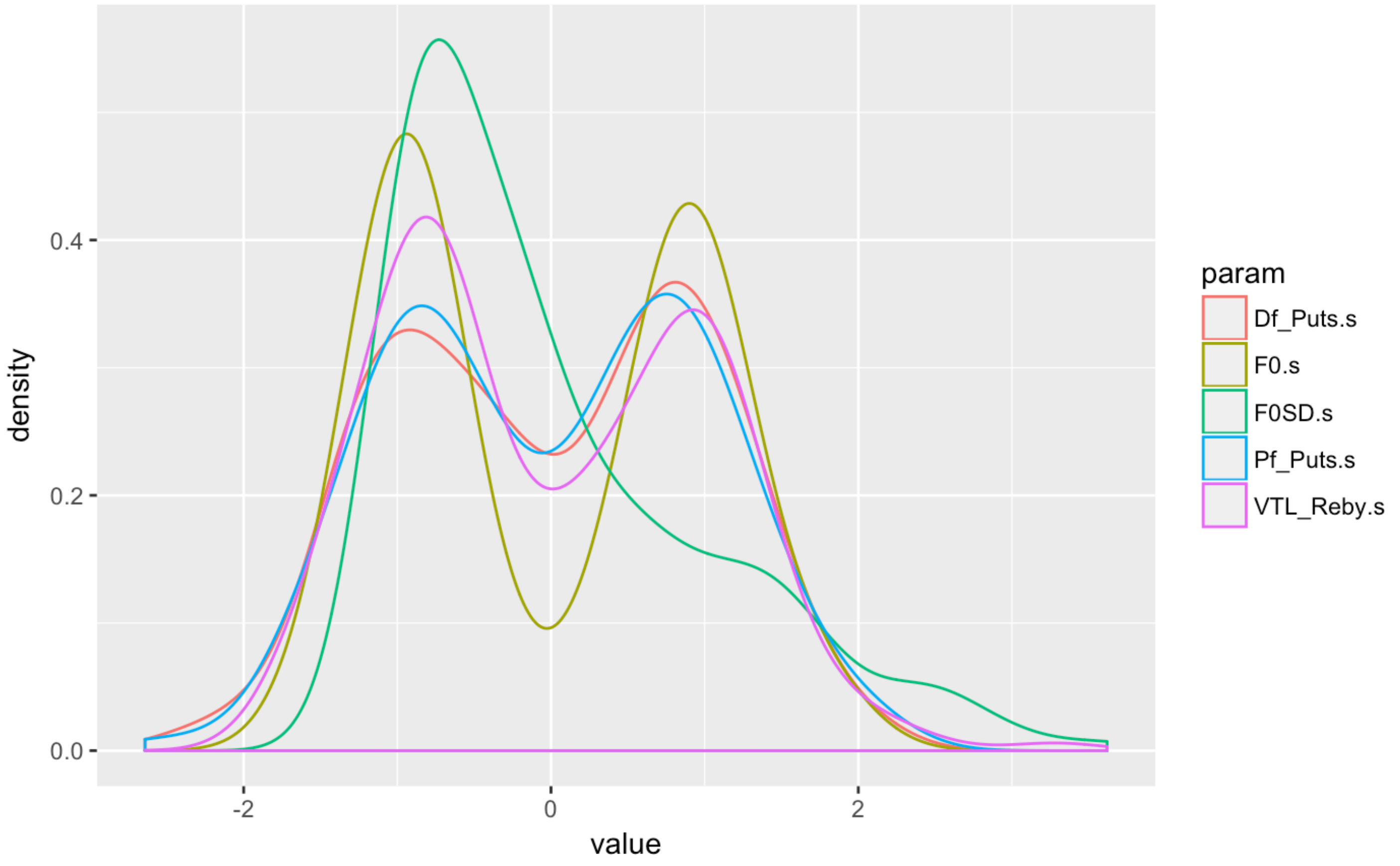
Recoding

Effect-code sex and ethinicity

Scale and center acoustic parameters

Hide

```
data <- data_raw %>%
  mutate(
    sex.e = recode(sex, "male" = 0.5, "female" = -0.5),
    ethnicity.e = recode(ethnicity, "Chinese" = 0.5, "White_UK" = -0.5),
    F0.s = (F0 - mean(F0)) / sd(F0),
    F0SD.s = (F0SD - mean(F0SD)) / sd(F0SD),
    Pf_Puts.s = (Pf_Puts - mean(Pf_Puts)) / sd(Pf_Puts),
    VTL_Reby.s = (VTL_Reby - mean(VTL_Reby)) / sd(VTL_Reby),
    Df_Puts.s = (`Df_Puts` - mean(`Df_Puts`)) / sd(`Df_Puts`)
  )
data %>%
  gather("param", "value", F0.s:Df_Puts.s) %>%
  ggplot(aes(value, colour = param)) +
  geom_density()
```



Analyses

F0

Hide

```
model.F0 <- lm(HGS ~ F0.s * sex.e * ethnicity.e, data = data)
summary(model.F0)
```

```

Call:
lm(formula = HGS ~ F0.s * sex.e * ethnicity.e, data = data)

Residuals:
    Min      1Q  Median      3Q     Max 
-21.618  -3.537  -0.200   3.517  32.677 

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)    
(Intercept)             31.8603     1.3811  23.069  < 2e-16 ***
F0.s                    -2.0092     1.4093  -1.426    0.155    
sex.e                   12.9538     2.7622   4.690 4.89e-06 ***
ethnicity.e             -0.9242     2.7622  -0.335    0.738    
F0.s:sex.e              -1.5474     2.8187  -0.549    0.584    
F0.s:ethnicity.e         1.0007     2.8187   0.355    0.723    
sex.e:ethnicity.e        4.1406     5.5243   0.750    0.454    
F0.s:sex.e:ethnicity.e  -1.6322     5.6373  -0.290    0.772    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.677 on 213 degrees of freedom
Multiple R-squared:  0.6196,	Adjusted R-squared:  0.6071 
F-statistic: 49.56 on 7 and 213 DF,  p-value: < 2.2e-16
```

F0SD

Hide

```
model.F0SD <- lm(HGS ~ F0SD.s * sex.e * ethnicity.e, data = data)
summary(model.F0SD)
```

```
Call:
lm(formula = HGS ~ F0SD.s * sex.e * ethnicity.e, data = data)

Residuals:
    Min      1Q  Median      3Q     Max 
-21.544  -3.834  -0.354   3.610  32.342 

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)    
(Intercept)               31.3410     0.9855  31.803  < 2e-16 ***
F0SD.s                    -0.8998     1.2167  -0.739    0.460    
sex.e                     15.4461     1.9709   7.837 2.17e-13 ***
ethnicity.e                0.2184     1.9709   0.111    0.912    
F0SD.s:sex.e              -3.4035     2.4335  -1.399    0.163    
F0SD.s:ethnicity.e        -0.5382     2.4335  -0.221    0.825    
sex.e:ethnicity.e          0.8864     3.9419   0.225    0.822    
F0SD.s:sex.e:ethnicity.e   1.7547     4.8669   0.361    0.719    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.648 on 213 degrees of freedom
Multiple R-squared:  0.6229,	Adjusted R-squared:  0.6105 
F-statistic: 50.26 on 7 and 213 DF,  p-value: < 2.2e-16
```

Df_Puts

Hide

```
model.Df_Puts <- lm(HGS ~ Df_Puts.s * sex.e * ethnicity.e, data = data)
summary(model.Df_Puts)
```

```
Call:
lm(formula = HGS ~ Df_Puts.s * sex.e * ethnicity.e, data = data)

Residuals:
    Min      1Q  Median      3Q     Max 
-20.538  -3.670   0.041   3.564  34.406 

Coefficients:
                            Estimate Std. Error t value Pr(>|t|)    
(Intercept)                 32.78714    0.91202  35.950  < 2e-16 ***
Df_Puts.s                   -1.33041    0.92203  -1.443    0.151    
sex.e                       14.34417    1.82404   7.864 1.84e-13 ***
ethnicity.e                 -2.77812    1.82404  -1.523    0.129    
Df_Puts.s:sex.e              0.42960    1.84406   0.233    0.816    
Df_Puts.s:ethnicity.e       -0.08136    1.84406  -0.044    0.965    
sex.e:ethnicity.e            1.76628    3.64809   0.484    0.629    
Df_Puts.s:sex.e:ethnicity.e -5.31690    3.68813  -1.442    0.151    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.633 on 213 degrees of freedom
Multiple R-squared:  0.6246,	Adjusted R-squared:  0.6122 
F-statistic: 50.62 on 7 and 213 DF,  p-value: < 2.2e-16
```

Pf_Puts

Hide

```
model.Pf_Puts <- lm(HGS ~ Pf_Puts.s * sex.e * ethnicity.e, data = data)
summary(model.Pf_Puts)
```

```
Call:
lm(formula = HGS ~ Pf_Puts.s * sex.e * ethnicity.e, data = data)

Residuals:
    Min      1Q  Median      3Q     Max 
-19.783  -4.046  -0.259   3.502  34.230 

Coefficients:
                            Estimate Std. Error t value Pr(>|t|)    
(Intercept)                  32.9219     0.9140  36.020  < 2e-16 ***
Pf_Puts.s                    -0.8152     0.9197  -0.886   0.3765    
sex.e                        15.2757     1.8280   8.357 8.31e-15 ***
ethnicity.e                  -3.3535     1.8280  -1.835   0.0680 .  
Pf_Puts.s:sex.e               0.7023     1.8395   0.382   0.7030    
Pf_Puts.s:ethnicity.e        -1.6653     1.8395  -0.905   0.3663    
sex.e:ethnicity.e            -0.9505     3.6560  -0.260   0.7951    
Pf_Puts.s:sex.e:ethnicity.e  -6.6845     3.6790  -1.817   0.0706 .  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.624 on 213 degrees of freedom
Multiple R-squared:  0.6256,	Adjusted R-squared:  0.6133 
F-statistic: 50.84 on 7 and 213 DF,  p-value: < 2.2e-16
```

VTL_Reby

Hide

```
model.VTL_Reby <- lm(HGS ~ VTL_Reby.s * sex.e * ethnicity.e, data = data)
summary(model.VTL_Reby)
```

```
Call:
lm(formula = HGS ~ VTL_Reby.s * sex.e * ethnicity.e, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-19.596  -3.830  -0.213   3.482  34.314

Coefficients:
                             Estimate Std. Error t value Pr(>|t|)
(Intercept)                   33.2342     1.0536  31.544  < 2e-16 ***
VTL_Reby.s                     0.9723     1.0627   0.915    0.361
sex.e                         15.2503     2.1072   7.237 8.18e-12 ***
ethnicity.e                   -3.2355     2.1072  -1.535    0.126
VTL_Reby.s:sex.e              -1.3798     2.1254  -0.649    0.517
VTL_Reby.s:ethnicity.e         0.6936     2.1254   0.326    0.745
sex.e:ethnicity.e              0.4724     4.2144   0.112    0.911
VTL_Reby.s:sex.e:ethnicity.e   6.7576     4.2509   1.590    0.113
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.63 on 213 degrees of freedom
Multiple R-squared:  0.6249,	Adjusted R-squared:  0.6126
F-statistic: 50.69 on 7 and 213 DF,  p-value: < 2.2e-16
```