<div align="center">**Results**</div>

**ANCOVA**

*Introduction*

An analysis of covariance (ANCOVA) was conducted to determine whether there were significant differences in Weight by Side and Level while controlling for Height.

*Assumptions*

**Normality.** The assumption of normality was assessed by plotting the quantiles of the model residuals against the quantiles of a Chi-square distribution, also called a Q-Q scatterplot (DeCarlo, 1997). For the assumption of normality to be met, the quantiles of the residuals must not strongly deviate from the theoretical quantiles. Strong deviations could indicate that the parameter estimates are unreliable. Figure 1 presents a Q-Q scatterplot of model residuals.

**Figure 1**

*Q-Q scatterplot for normality of the residuals for the regression model.*
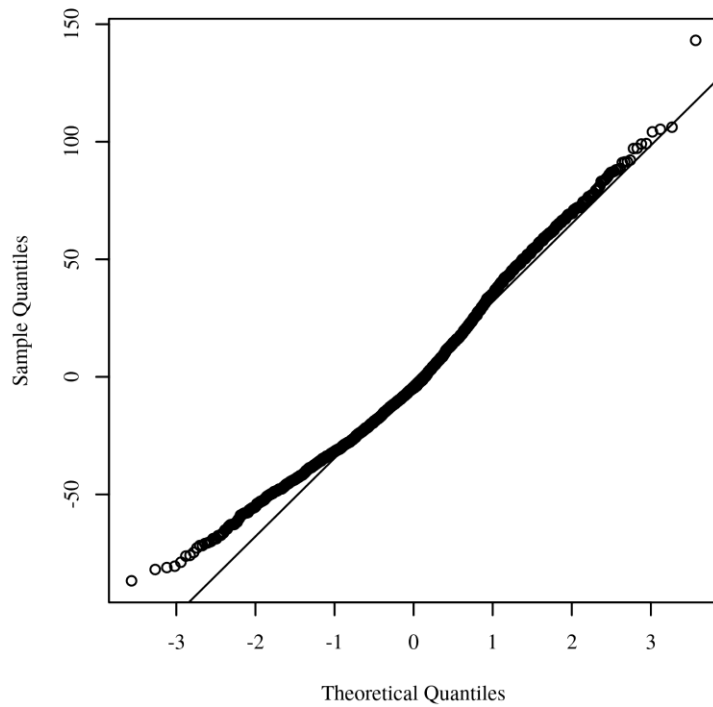
**Homoscedasticity.** Homoscedasticity was evaluated by plotting the residuals against the predicted values (Bates et al., 2014; Field, 2017; Osborne & Walters, 2002). The assumption of homoscedasticity is met if the points appear randomly distributed with a mean of zero and no apparent curvature. Figure 2 presents a scatterplot of predicted values and model residuals.

**Figure 2**

*Residuals scatterplot testing homoscedasticity*
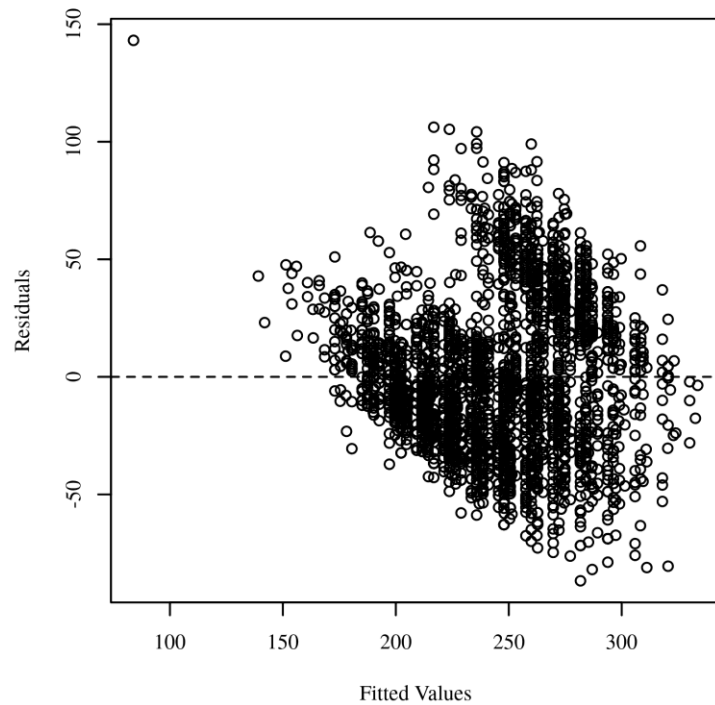
**Outliers.** To identify influential points, Studentized residuals were calculated and the absolute values were plotted against the observation numbers (Field, 2017; Pituch & Stevens, 2015). Studentized residuals are calculated by dividing the model residuals by the estimated residual standard deviation. An observation with a Studentized residual greater than 3.09 in absolute value, the 0.999 quantile of a *t* distribution with 2763 degrees of freedom, was considered to have significant influence on the results of the model. Figure 3 presents the Studentized residuals plot of the observations. Observation numbers are specified next to each point with a Studentized residual greater than 3.09.

**Figure 3**

*Studentized residuals plot for outlier detection*
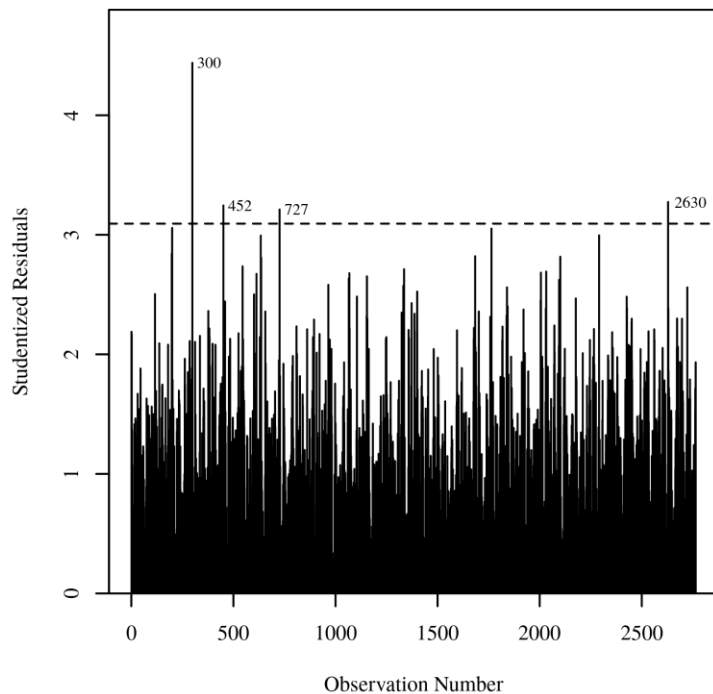
**Homogeneity of regression slopes.** The assumption for homogeneity of regression slopes was assessed by rerunning the ANCOVA, but this time including interaction terms between each independent variable and covariate (Field, 2017; Pituch & Stevens, 2015). If the model with the covariate interaction terms explains significantly more variance than the original ANCOVA model, then there were significant interactions between the covariates and independent variables. The model with covariate-independent variable interactions explained significantly more variance for Weight, $F(6, 2750) = 6.62$, $p < .001$ than the original model. This implies that one or more of the covariates had significant interactions with the independent variables and violated the homogeneity of regression slopes assumption.

**Covariate-IV independence.** Each independent variable and covariate must be independent of each other (Miller & Chapman, 2001). An ANOVA was conducted for each pair of numeric covariates and independent variables to assess independence (Field, 2017). There were significant models for the following pairs of independent variables and covariates based on an alpha of .05, indicating the assumption of independence between covariates and independent

variables was not met (pairs are formatted as covariate-IV): Height-Side ($F(2,2757) = 51.68$, $p <$ .001). All remaining covariate-IV pairs were not significant and met the assumption.

*Results*

The results of the ANCOVA were significant, $F(7, 2{,}756) = 400.78$, $p < .001$, indicating significant differences among the values of Side and Level (Table 1). The main effect for Side was significant, $F(2, 2{,}756) = 28.43$, $p < .001$, $\eta_p^2 = 0.02$, indicating there were significant differences in Weight by Side levels. The main effect for Level was significant, $F(4, 2{,}756) = 8.81$, $p < .001$, $\eta_p^2 = 0.01$, indicating there were significant differences in Weight by Level levels. The means and standard deviations are presented in Table 2.

**Table 1**

*Analysis of Variance Table for Weight by Side and Level*

| Term | SS | df | F | p | $\eta_p^2$ |
|---|---|---|---|---|---|
| Side | 60,121.89 | 2 | 28.43 | < .001 | 0.02 |
| Level | 37,265.00 | 4 | 8.81 | < .001 | 0.01 |
| Height | $2.74 \times 10^6$ | 1 | 2,593.34 | < .001 | 0.48 |
| Residuals | $2.91 \times 10^6$ | 2756 | | | |

**Figure 4**

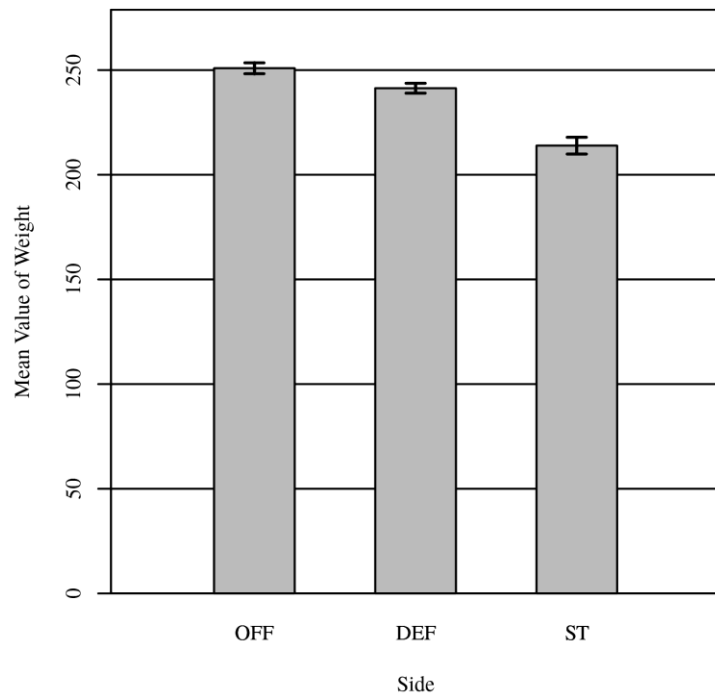*Mean value of Weight by the levels of Side with 95.00% CI Error Bars*

**Figure 5**

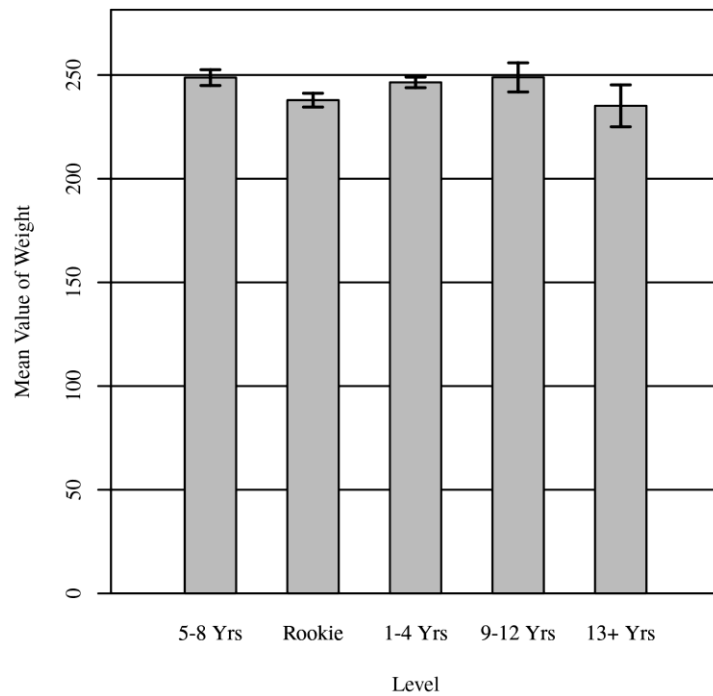*Mean value of Weight by the levels of Level with 95.00% CI Error Bars*

**Table 2**

*Marginal Means, Standard Error, and Sample Size for Weight by Side and Level Controlling for Height*

| Combination | Marginal Means | *SE* | *n* |
|---|---|---|---|
| OFF : 5-8 Yrs | 248.19 | 1.52 | 263 |
| DEF : 5-8 Yrs | 250.56 | 1.49 | 293 |
| ST : 5-8 Yrs | 226.41 | 3.30 | 24 |
| OFF : Rookie | 238.77 | 1.41 | 322 |
| DEF : Rookie | 241.14 | 1.41 | 331 |
| ST : Rookie | 216.98 | 3.26 | 30 |
| OFF : 1-4 Yrs | 245.66 | 1.10 | 662 |
| DEF : 1-4 Yrs | 248.04 | 1.13 | 599 |
| ST : 1-4 Yrs | 223.88 | 3.20 | 32 |
| OFF : 9-12 Yrs | 249.20 | 2.60 | 79 |
| DEF : 9-12 Yrs | 251.58 | 2.61 | 71 |
| ST : 9-12 Yrs | 227.42 | 3.75 | 19 |
| OFF : 13+ Yrs | 238.37 | 5.30 | 18 |
| DEF : 13+ Yrs | 240.75 | 5.32 | 11 |
| ST : 13+ Yrs | 216.59 | 5.71 | 10 |

## Post-hoc

Estimated marginal mean contrasts were calculated to examine the differences between the level combinations using Tukey comparisons based on an alpha of .05. For the main effect of Side, the mean of Weight for OFF ($M$ = 244.04, $SD$ = 51.55) was significantly larger than for ST ($M$ = 222.26, $SD$ = 33.22), $p < .001$. For the main effect of Side, the mean of Weight for DEF ($M$ = 246.41, $SD$ = 51.58) was significantly larger than for ST ($M$ = 222.26, $SD$ = 33.22), $p < .001$. For the main effect of Level, the mean of Weight for 5-8 Yrs ($M$ = 241.72, $SD$ = 39.33) was significantly larger than for Rookie ($M$ = 232.30, $SD$ = 40.32), $p < .001$. For the main effect of Level, the mean of Weight for Rookie ($M$ = 232.30, $SD$ = 40.32) was significantly smaller than for 1-4 Yrs ($M$ = 239.19, $SD$ = 47.72), $p < .001$. For the main effect of Level, the mean of Weight for Rookie ($M$ = 232.30, $SD$ = 40.32) was significantly smaller than for 9-12 Yrs ($M$ = 242.73, $SD$ = 33.75), $p = .002$. No other significant differences were found.

# References

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4: arXiv preprint arXiv, *Journal of Statistical Software*. https://doi.org/10.18637/jss.v067.io1

DeCarlo, L. T. (1997). On the meaning and use of kurtosis. *Psychological Methods,* 2(3), 292-307. https://doi.org/10.1037/1082-989X.2.3.292

Field, A. (2017). *Discovering statistics using IBM SPSS statistics: North American edition.* Sage Publications

Intellectus Statistics [Online computer software]. (2023). Intellectus Statistics. https://statistics.intellectus360.com

Miller, G. A., & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology, 110*(1), 40. https://doi.org/10.1037//0021-843x.110.1.40

Osborne, J., & Waters, E. (2002). Four assumptions of multiple regression that researchers should always test. *Practical Assessment, Research & Evaluation, 8*(2), 1-9.

Pituch, K. A., & Stevens, J. P. (2015). *Applied multivariate statistics for the social sciences* (6th ed.). Routledge Academic. https://doi.org/10.4324/9781315814919

# Glossaries

## ANCOVA (Analysis of Covariance)

An ANCOVA examines the influence of an independent variable on a dependent variable while removing the effect of the covariate factor(s). ANCOVA first conducts a regression of the independent variable (i.e., the covariate) on the dependent variable. The residuals (the unexplained variance in the regression model) are then subject to an ANOVA. Thus the ANCOVA tests whether the independent variable still influences the dependent variable after the influence of the covariate(s) has been removed. The One-Way ANCOVA can include more than one covariate. If the ANCOVA model has more than one covariate, it is possible to calculate the one-way ANCOVA using contrasts just like in the ANOVA to identify the influence of each covariate.

*Fun Fact! Controlling for covariates can not only help eliminate possible confounds from a study, but it also decreases the amount of unexplained (or "error") variability in the analysis. Reducing error variability increases the chances of finding differences between groups.*

**Covariate:** A variable that may be significantly related to the dependent (outcome) variable; also referred to as a control variable.

**Degrees of Freedom (*df*):** Refers to the number of values used to compute a statistic; an *F*-test has two values for *df*: the first is determined by the number of groups being compared, and the second is determined by the number of observations in the sample; used with the *F*-statistic to determine the *p*-value.

**F Ratio (*F*):** The ratio of explained variance to error variance; used with the two *df* values to determine the *p*-value.

**Normality:** Refers to the distribution of the data. The assumption is that the data follows the bell-shaped curve.

**Outlier:** A data point that is abnormally distant from a set of observations.

**p-value:** The probability of obtaining the observed results if the null hypothesis (no differences in the dependent variables by the independent variable) is true.

**Residuals:** Refers to the difference between the predicted value for the dependent variable and the actual value of the dependent variable.

**Studentized Residuals:** Residuals that are scaled by diving the each residual by the estimated standard deviation of the residuals.

**Type I Error:** A variable that may be significantly related to the dependent (outcome) variable; also referred to as a control variable.

# Raw Output

**Analysis of Covariance Table for Weight by Side and Level While Controlling for Height**

Included Variables:
Weight, Side, Level, and Height

Sample Size (Complete Cases):
N = 2764

Check if the Covariates Influence the DV:

Relationship between Weight and Height:

| Term | SS | df | F | p |
|---|---|---|---|---|
| Height | $2.866 \times 10^6$ | 1 | 2,625.991 | 0.00000 |
| Residuals | $3.015 \times 10^6$ | 2762 | | |

Homogeneity of Regression Slopes ANCOVA Results:

| Model | Residual SS | SS | df num | df den | F | p |
|---|---|---|---|---|---|---|
| Original Model | $2.91 \times 10^6$ | | | 2,756 | | |
| Interaction Model | $2.87 \times 10^6$ | 41,488.89 | 6 | 2,750 | 6.62 | .0000006 |

Covariate-IV Independence

| Covariate | IV | df | *F* | *p* |
|---|---|---|---|---|
| Height | Side | (2, 2757) | 51.684 | $9.215 \times 10^{-23}$ |
| Height | Level | (4, 2757) | 0.378 | 0.824 |

ANOVA Results:

| Term | SS | df | F | p | $\eta_p^2$ |
|---|---|---|---|---|---|
| Side | 60,121.893 | 2 | 28.426 | $6.032 \times 10^{-13}$ | 0.0202 |
| Level | 37,264.997 | 4 | 8.809 | $4.586 \times 10^{-07}$ | 0.0126 |
| Height | $2.743 \times 10^6$ | 1 | 2,593.338 | 0.00000 | 0.485 |
| Residuals | $2.915 \times 10^6$ | 2756 | | | |

Marginal Means, Standard Error and Sample Size for Weight by Side and Level Controlling for Height:

| Combination | Marginal Means | SE | n |
|---|---|---|---|
| OFF : 5-8 Yrs | 248.190 | 1.517 | 263 |
| DEF : 5-8 Yrs | 250.564 | 1.487 | 293 |

| | | | |
|---|---|---|---|
| ST : 5-8 Yrs | 226.409 | 3.304 | 24 |
| OFF : Rookie | 238.765 | 1.410 | 322 |
| DEF : Rookie | 241.139 | 1.405 | 331 |
| ST : Rookie | 216.984 | 3.256 | 30 |
| OFF : 1-4 Yrs | 245.663 | 1.095 | 662 |
| DEF : 1-4 Yrs | 248.037 | 1.130 | 599 |
| ST : 1-4 Yrs | 223.882 | 3.199 | 32 |
| OFF : 9-12 Yrs | 249.202 | 2.601 | 79 |
| DEF : 9-12 Yrs | 251.576 | 2.613 | 71 |
| ST : 9-12 Yrs | 227.421 | 3.748 | 19 |
| OFF : 13+ Yrs | 238.372 | 5.297 | 18 |
| DEF : 13+ Yrs | 240.745 | 5.323 | 11 |
| ST : 13+ Yrs | 216.591 | 5.709 | 10 |

Estimated Marginal Mean Contrasts Using Tukey Comparisons:

| Contrast | Mean Contrast | SE | df | t | p |
|---|---|---|---|---|---|
| OFF - DEF | -2.373 | 1.287 | 2756 | -1.845 | 0.155 |
| OFF - ST | 21.781 | 3.215 | 2756 | 6.775 | 0.00000 |
| DEF - ST | 24.155 | 3.208 | 2756 | 7.530 | 0.00000 |
| (5-8 Yrs) - Rookie | 9.425 | 1.837 | 2756 | 5.132 | $3.048 \times 10^{-06}$ |
| (5-8 Yrs) - (1-4 Yrs) | 2.527 | 1.627 | 2756 | 1.553 | 0.528 |
| (5-8 Yrs) - (9-12 Yrs) | -1.012 | 2.852 | 2756 | -0.355 | 0.997 |
| (5-8 Yrs) - (13+ Yrs) | 9.818 | 5.424 | 2756 | 1.810 | 0.368 |
| Rookie - (1-4 Yrs) | -6.898 | 1.540 | 2756 | -4.479 | $7.624 \times 10^{-05}$ |
| Rookie - (9-12 Yrs) | -10.437 | 2.803 | 2756 | -3.724 | 0.00187 |
| Rookie - (13+ Yrs) | 0.393 | 5.397 | 2756 | 0.0728 | 1.000 |
| (1-4 Yrs) - (9-12 Yrs) | -3.539 | 2.674 | 2756 | -1.323 | 0.677 |
| (1-4 Yrs) - (13+ Yrs) | 7.291 | 5.336 | 2756 | 1.366 | 0.649 |
| (9-12 Yrs) - (13+ Yrs) | 10.830 | 5.795 | 2756 | 1.869 | 0.335 |