# CHANGES IN LOWER BODY STRENGTH AND LINEAR SPEED PERFORMANCE IN NCAA DIVISION 2 COLLEGIATE FOOTBALL PLAYERS ACROSS THREE COMPETITIVE SEASONS

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## ABSTRACT

*The implementation of resistance training to enhance muscular strength alongside other physical performance tasks such as linear speed or agility is a primary goal for strength and conditioning practitioners working with American football athletes. This study aimed to investigate changes in body weight, relative and absolute lower body strength, as well as linear speed ability and sprint momentum over three collegiate American football seasons. Additionally, relationships between change scores within the previously mentioned metrics, as well as the effect of Season-1 baseline strength levels on subsequent improvements in strength and linear speed were analyzed. Significant increases in body weight as well as relative and absolute lower body strength and sprint momentum were observed between Season-1 and Season-3. However, no significant improvements in linear speed were observed. Further, only change scores in body weight were found to be significantly related to change scores in the linear speed. Lastly, the group of athletes with lower Season-1 strength levels experienced significantly greater improvements in linear speed (i.e., reduction in 40-yard dash times), compared to the group with higher Season-1 strength levels. Our results indicate that athletes within our sample were able to experience increases in strength and body weight. However, such increases were not accompanied by improvements in the linear speed. While speculative, the significantly greater improvement in linear speed within the group with lower Season-1 relative strength levels may indicate that improvements in linear speed align with increases in strength, until athletes reach a certain level of strength.*

***Keywords***: *American Football, Athlete Monitoring, Strength*

## INTRODUCTION

Strength and conditioning coaches as well as sports scientists have the ability to impact sports success in a number of ways. Primarily, strength and conditioning practitioners aim to improve different components of physical performance within athletes, while simultaneously trying to minimize the risk of sport-related injury. One sport that relies heavily on the implementation of strength and conditioning training is American football. Game demands in American football tend to be very position specific. However, generally speaking, athletes must show proficiency in a variety of physical abilities such as upper and lower body strength and power production ability, rapid accelerations and decelerations, change of direction ability, high running speeds, and muscular endurance (Fullagar et al., 2017).

In American football, one may say that mostly all position groups, except for kickers and punters, rely on some degree of linear speed and acceleration to be successful. For instance, LaPlaca et al. (2020) showed that those running backs with better 40-yard dash times in the National Football League (NFL) combine, also showed better "longest run" statistics during their time in the NFL. Further, the same author suggested that those receivers with better 40-yard dash times in the NFL combine also had better "longest catch" statistics during their time in the NFL. This reliance on linear speed was also reflected within defensive position groups. Within the group of outside linebackers, faster 40-yard dash times were significantly correlated with more games played (LaPlaca et al., 2020).

Such findings may be of interest to strength and conditioning practitioners, aiming to improve aspects of physical performance that are shown to relate to successful on-field performance. In order to establish such connections between physical performance assessments and levels of on-field success, research must aim to connect on-field data such as the ones mentioned above, with physical performance tests and training methodologies used within sports science laboratories as well as strength and conditioning facilities. However, forming this connection has been shown to bring with it various challenges (Hornsby et al., 2021). Small sample sizes, as well as a lack of longitudinal data, have been identified as some of the challenges in connecting on-field success with training methodologies used to improve on-field success, and research is rather scarce aiming to facilitate this connection. Bishop (2008) has proposed however that the observation of athletes in real-world settings, over extended periods of time may be beneficial to sport science practitioners trying to better understand how to optimize performance within a given sport.

As mentioned above, linear speed has been shown to be related to successful on-field performance in American football (Kuzmits & Adams, 2008; LaPlaca et al., 2020; Teramoto et al., 2016). Therefore, it should be of interest to strength and conditioning practitioners working within this population to optimize their training approach toward developing speed. One aspect of physical performance enhancement that receives a lot of attention in most strength and conditioning settings in the development of maximal lower body strength. In 1991, Fry and Kramer (1991) studied a group of division 1-3 collegiate American football players. What they found was that National Collegiate Athletic Association (NCAA) Division-I athletes had higher squat numbers than Division-II athletes, and Division-II athletes had higher squat numbers than Division-III athletes. Another similar study by Barker et al. (1993) found that collegiate American football starters reported a higher barbell back squat one repetition maximum (1RM) when compared to non-starters. However, in this study, the group of starters was also heavier (+8.5 kg) than the group of non-starters, which should be acknowledged when interpreting these results. These findings would suggest that lower body strength is associated with the level of play as well as success among collegiate American football players. Strength and conditioning practitioners aim to enhance lower body strength through the implementation of exercises such as bilateral and unilateral squat variations, as well as bilateral and unilateral hip hinge variations such as deadlifts. An existing body of literature has documented relationships between maximal lower body strength and speed performance (Comfort et al., 2016; Hori et al., 2008, McBride et al., 2009, Seitz et al., 2014). Seitz et al. (2014) performed a systematic review, suggesting that increases in lower body strength transfer positively to sprint performance. In addition, Appleby et al. (2020) recently proposed that while a transfer did not occur equally, both increases in unilateral, as well as bilateral lower body strength led to improvements in 20-m sprint times within a group of rugby union academy players. While the previously highlighted studies have documented a relationship between lower body strength and speed performance, further research is warranted, looking at changes in lower body strength and speed over extended periods of time, such as over multiple athletic seasons, particularly among American football athletes.

Further, the debate about "how strong is strong enough" has been a topic within the realms of strength and conditioning for many years. Stone (2002) has suggested that while in sports such as Olympic weightlifting or powerlifting, continuous increases in strength over time would be advantageous, the agreement with regards to how strong athletes within other sports should be is not as evident. Moreover, this discussion paper highlighted several studies that established relationships between measures of strength and aspects of sports performance, proposing that athletes may never be "too strong". While we partially agree with this statement and also believe there is no such thing as "too strong", we hypothesize/believe that this debate is context-specific and that once athletes hit a certain level of strength, further efforts to increase maximal strength may not optimally complement desired improvements in different aspects of athletic performance, such as speed or agility.

Lastly, Mann et al. (2022) recently proposed that there is a common trend in which collegiate American football players continue to make gains in body mass that are not accompanied by improvements in speed across their collegiate careers. Therefore, it was suggested that practitioners and researchers should take into consideration these increases in body mass by also looking at momentum (i.e., mass x velocity). Solely looking at sprint velocity or sprint completion times may provide practitioners with an incomplete picture of the improvement made over their collegiate careers (Mann et al., 2022).

With the previously discussed points in mind, the primary purpose of this study was to observe and analyze changes in body weight, absolute and relative lower body strength as well as linear speed and sprint momentum in NCAA Division-II American football players across three competitive seasons. For a secondary purpose, we aimed to investigate whether there were relationships between change scores in speed performance and change scores in body weight as well as lower body strength between season one and season three. Lastly, we were interested in whether or not baseline relative strength levels of the athletes in our sample impacted how much they improved or regressed in 40-yard dash performance between season one and season three. The idea was proposed that once athletes hit a certain level of lower body strength, further working on improving maximal strength may not optimally complement further improvements in speed performance.

## METHODS

For the competitive seasons of 2017, 2018, and 2019, data for 16 NCAA Division-II athletes were used as part of this investigation. The sample of athletes was made up of six linebackers, three defensive backs, two quarterbacks, one running back, as well as four receivers. Not all athletes within this sample had data for all three seasons. Participation metrics can be seen in Table 1. Researchers analyzed the data from pre-existing data sets. Data from pre-existing data sets included off-season test results for the weight room-based assessments, as well as on-field tests, resembling the NFL combine for the athletic seasons of 2017-2019. Specifically for this study, the parallel back squat, as well as the 40-yard dash (36.6 meters) were of interest. The 40-yard dash is a commonly utilized assessment of linear speed within American football. These tests were performed and measured yearly, at the end of each respective off-season (middle of April). All physical performance data were anonymous and were provided by the head strength and conditioning coach. Sufficient execution of physical performance tests was ensured through visual observation and verbal feedback by a group of certified strength and conditioning specialists. All testing procedures were preceded by a team-based dynamic warm-up that was led by the teams' certified strength and conditioning coach. The relevant tests used for this study will be highlighted in more detail within the following section. This study did not include data collection involving human subjects because data were already existing in a de-identified fashion within a data set provided and approved by the head strength and conditioning coach at the respective NCAA Division-II school. It was therefore deemed by the Institutional Review Board (IRB) that review and IRB approval were not required.

**Table 1.** *Participation metrics (n, sample sizes) for Seasons 1-3*

| Year | Body Weight (kg) | Absolute Strength (kg) | Relative Strength (Ratio) | 40-yard dash (s) | 40-yard dash Momentum (kg*m/s) |
|---|---|---|---|---|---|
| 1 | 16 | 16 | 16 | 15 | 15 |
| 2 | 16 | 13 | 13 | 14 | 14 |
| 3 | 16 | 16 | 16 | 16 | 16 |

***Testing Procedures***

*Body Weight* – Body weight was measured using an electronic Befour PS 7700 scale (Befour®, Saukville, WI, USA) and recorded in kilograms (kg).

*40-Yard Dash* - The 40-yd dash was conducted with participants beginning in a three-point stance, as performed within the NFL combine, and running as fast as possible for 40 yards (Kuzmits & Adams, 2008). According to Mann et al. (2015) hand timing allows for accurate classification of 40-yard dash performance among college football players. The sprints were performed on an outdoor Mondo sprint track, and lanes on the track gave guidance to the participants. The best of three attempts was used in the analysis. Certified Strength and Conditioning Specialists were in charge of timing runs, using an Accusplit Pro Survivor – A601X Stopwatch, and the same timers were used for all three testing sessions. A minimum of five minutes of rest was provided between sprint trials. Sprint momentum was calculated using suggestions by Mann et al. (2022). The best of the three sprint trials was converted to a velocity by dividing the distance (36.6 m) by the time. Following this, the velocity was multiplied by the subjects' body mass in kg to acquire momentum (kg*m/s).

*Bilateral Back Squat* – Bilateral back squats were performed inside a standard squat rack, with spotters placed behind the athlete, as well as on both ends of the barbell for safety reasons. Certified Strength and Conditioning Specialists ensured all squats were performed correctly. For repetition to count, the athletes' femurs had to be parallel to the ground. Again, certified strength and conditioning specialists visually observed each repetition to ensure the criteria were being met. The athlete's one repetition maximum was calculated from a three-repetition maximum test. The Epley equation was used to estimate a one-repetition maximum from a three-repetition maximum test (DiStasio, 2014). For the sake of this paper, absolute lower body strength is referred to as the respective one repetition maximum number in kilograms for each athlete, while relative lower body strength will be referred to as a ratio between the 1RM number in kilograms, divided by the athletes' body weight in kilograms.

### *Statistical Analysis*

All data were checked for normality using the Shapiro-Wilk test. Linear mixed models were used to investigate mean differences in primary study outcomes (i.e., weight, absolute squat strength, relative squat strength, and 40-yard dash times) across the fixed factor of time, using the individual (ID) as a random factor. All post hoc comparisons were adjusted using the Bonferroni correction. Further, *Cohen's d* effect sizes were calculated (Cohen, 1992). Pearson's correlation coefficient was used to look at correlations between body weight change scores, lower body strength change scores, and 40-yard dash change scores to determine if the magnitude of increased or decreased body weight, as well as lower body strength, was related to the magnitude of improvement in 40-yard dash performance. Further, to observe differences in 40-yard dash change scores based on relative lower body strength levels, our sample was divided into "strong" and "weak" individuals, using the 50th percentile in relative lower body strength during season one as a cutoff point. To analyze if one group experienced significantly larger improvements or regressions in 40-yard dash performance, a student's independent sample t-test was used. Statistical inferences were made using an α level of $p \leq .05$. All data were analyzed using the R statistical computing environment and language (v. 4.0; R Core Team, 2020) via the Jamovi graphical user interface.

## RESULTS

Significant univariate effects for changes in body weight across time were observed ($p$ = .012). Body weight significantly increased from season one to season three ($p$ = .010). There was no significant change in body weight between seasons one and two ($p$ = .273), or two and three (p = 0.479). See Table 2 and Figure 1.

Absolute lower body strength, as measured via the back squat showed significant univariate effects for time ($p < .001$). Significant increases in strength were noted from season one to season two ($p$ = .013) and season one to season three ($p < .001$), as well as season two to season three ($p$ = .050). See Table 2 and Figure 2.

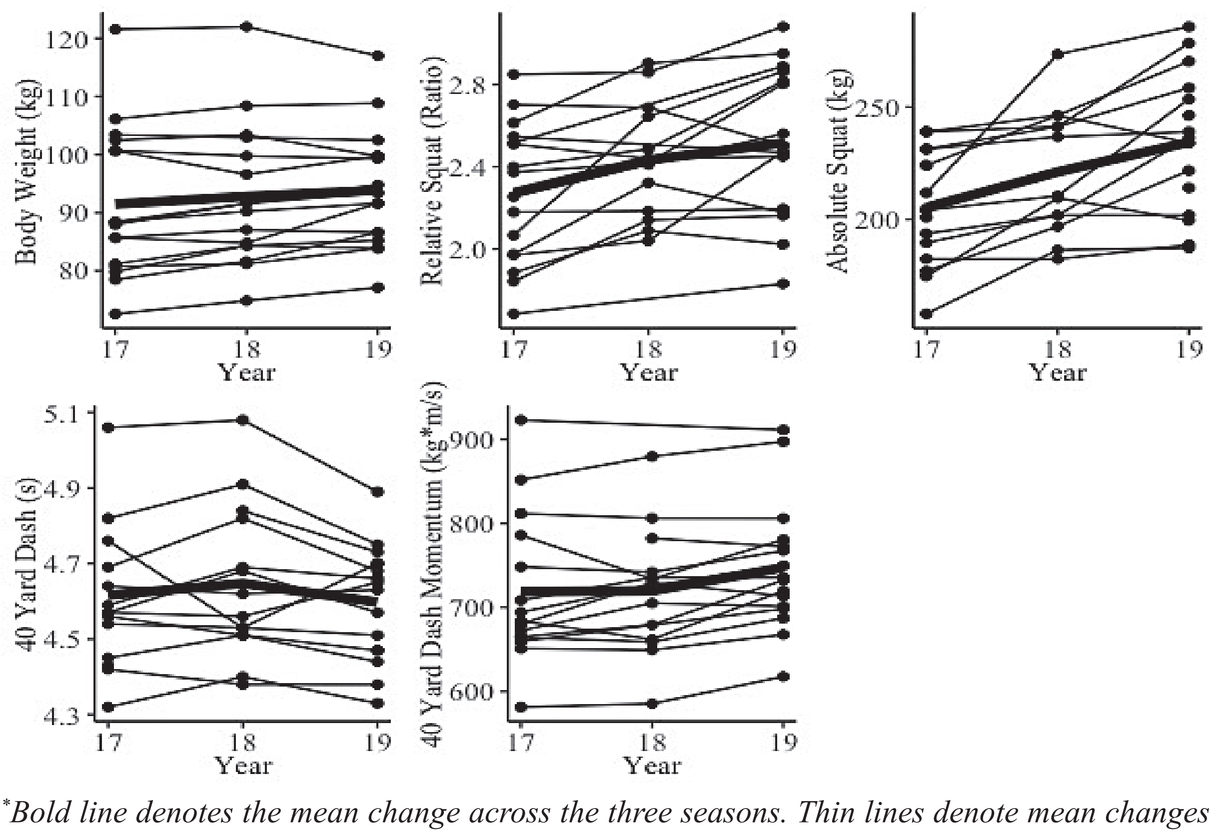
Similar findings were observed for relative lower body strength, showing a significant univariate effect for time ($p < .001$). Season one was shown to be significantly different from season three ($p < .001$), however, season one was not shown to be significantly different from season two ($p$ = .057), and season two was not shown to be significantly different from season three ($p$ = .318). See Table 2 and Figure 3. No significant effects for time were observed for 40-yard dash performance across the three seasons ($p$ = .122). Lastly, significant univariate effects for 40-yard dash momentum across time were observed ($p$ = < .001). More specifically, athletes within our sample experienced significant increases in 40-yard dash momentum between seasons one and three, as well as seasons two and three. Table 2 and Figure 4 display the previously mentioned data, highlighting mean changes, $p$-values, as well as effect sizes.

Further, no significant relationships were observed between change scores in 40-yard dash performance and change scores in absolute and relative lower body strength, between season one and season three. However, a significant negative relationship was observed between change scores in 40-yard dash performance and change scores in body weight between season one and season three ($r$ = -.653, $p$ = .008). These findings are displayed within the correlation matrix in Table 3, and are further visualized in Figures 5, 6, and 7. Our independent sample *t*-test revealed that the "weaker" group of athletes with relative lower body strength scores of under 2.3 times body weight during season one experienced significantly larger improvements in 40-yard dash performance between season one and season three, compared with the "strong" group ($p$ = .006, $d$ = 1.72) (Figure 8). While not statistically significant, the weaker group of athletes also experienced larger increases in relative strength between season one and season three ($p$ = .343, $d$ = .49). These data can be seen in Table 4.

**Table 2.** *Mean changes, p-values, and Cohen's d effect size for changes across seasons*

| | Season 1-2 | | | Season 1-3 | | | Season 2-3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Change** | **p-value** | **Cohen's d** | **Change** | **p-value** | **Cohen's d** | **Change** | **p-value** | **Cohen's d** |
| Body Weight (kg) | +2.88 | .273 | 0.11 | +5.25 | .010* | 0.19 | +2.38 | .479 | 0.08 |
| Absolute Squat Strength (kg) | +35.2 | .013* | 0.60 | +64.0 | < .001* | 1.04 | +28.8 | .050* | 0.45 |
| Relative Squat Strength (Ratio) | +0.145 | .057 | 0.51 | +0.243 | < .001* | 0.70 | +0.098 | .318 | 0.27 |
| 40-yard Dash (s) | +0.020 | 1.00 | 0.15 | -0.029 | .642 | 0.12 | - 0.049 | .134 | 0.28 |
| 40-yard Dash Momentum (kg*m/s) | +7.24 | .841 | 0.08 | +26.07 | < .001* | 0.29 | +18.83 | .020* | 0.22 |

*Effect Sizes: small, d = 0.2-0.6; moderate, d = 0.6-1.2; large, d = 1.2-2.0; and very large d > 2.0.*
** Denotes statistical significance (p ≤ .05). The negative change sign in the 40-yard Dash (s) row indicates a decrease in completion times (i.e., an improvement).*




*Bold line denotes the mean change across the three seasons. Thin lines denote mean changes across three seasons for individual athletes.*

**Figure 1.** *Individual changes for raw data in body weight (kg), absolute squat strength (kg), relative squat strength, as well as 40-yard dash times, and 40-yard dash momentum over three seasons.*

**Table 3.** *Change scores (Season 1-3) correlation matrix.*

| | | 40 Yard Dash$_{\Delta}$ | Absolute Squat Strength$_{\Delta}$ | Relative Squat Strength$_{\Delta}$ | Body Weight$_{\Delta}$ |
|---|---|---|---|---|---|
| 40 Yard Dash$_{\Delta}$ | Pearson's r | - | | | |
| | p-value | - | | | |
| Absolute Squat Strength$_{\Delta}$ | Pearson's r | .006 | - | | |
| | p-value | .984 | - | | |
| Relative Squat Strength$_{\Delta}$ | Pearson's r | -.212 | .956$^{***}$ | - | |
| | p-value | .447 | <.001 | - | |
| Body Weight$_{\Delta}$ | Pearson's r | .653$^{**}$ | -.143 | -.410 | - |
| | p-value | .008 | .597 | .115 | - |
| 40 Yard Dash Momentum$_{\Delta}$ | Pearson's r | .290 | .097 | -.218 | .910$^{***}$ |
| | p-value | .295 | .732 | .435 | <.001 |

*$_{\Delta}$ Denotes change between two time points (Season 1-3). *** indicates statistical significance at the 0.001 level. **indicates statistical significance at the 0.01 level.*

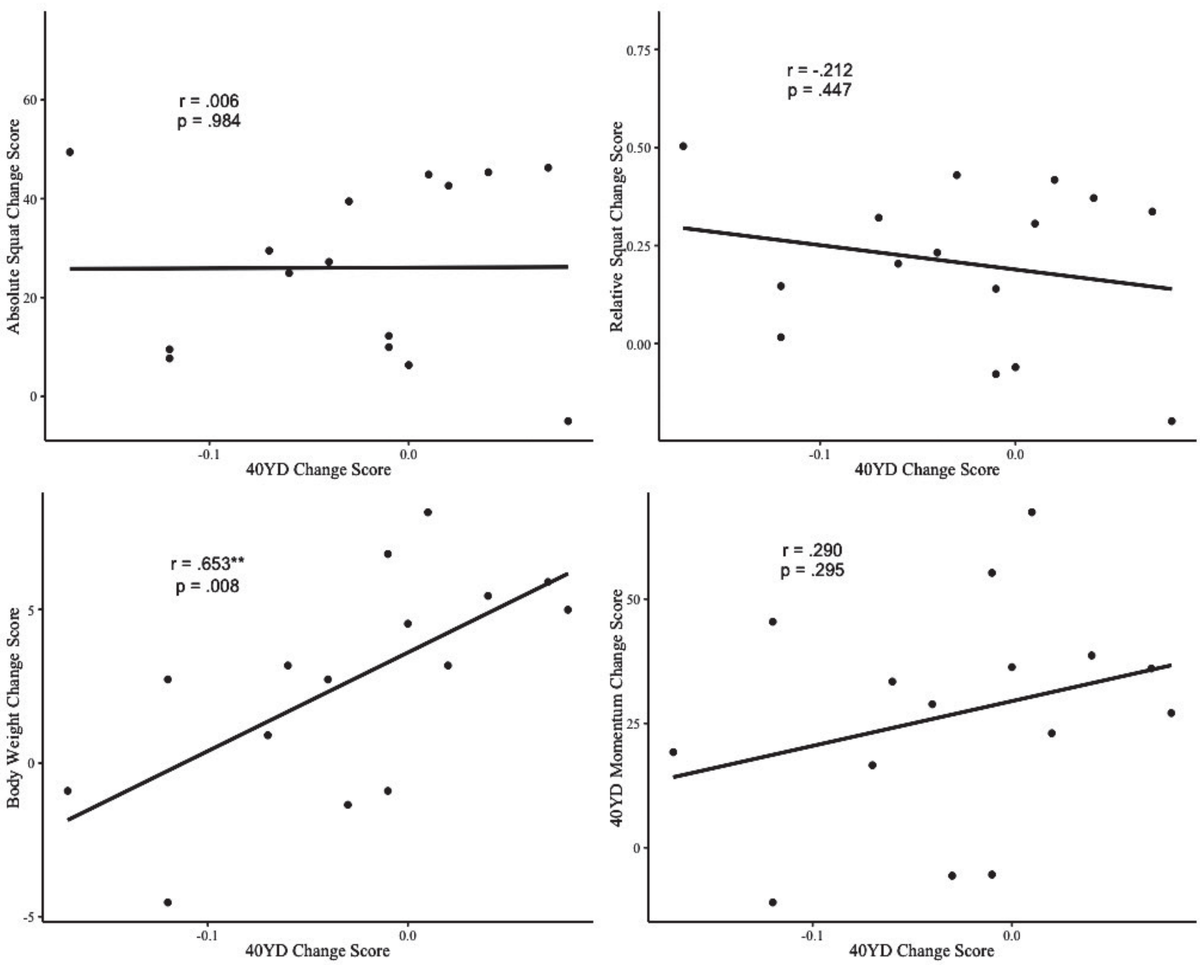



**Figure 2.** *Scatterplots of 40-yard dash change scores (s) (Season 1-3) vs. absolute squat strength change scores (kg), relative squat strength change scores (ratio), body weight change scores (kg), and 40-yard dash momentum change scores (kg*m/s) (Seasons 1-3), with a line of best fit.*

**Table 4.** *Student's independent sample t-test for change scores between "strong" and "weak" groups (Season 1-3).*

| | "Strong" Group | "Weak" Group | Mean Difference | p-value | Cohen's d |
|---|---|---|---|---|---|
| 40-Yard Dash$_{\Delta}$ | 0.023 ± 0.044 | -0.071 ± 0.065 | -0.094 | .005* | -1.74 |
| Relative Squat$_{\Delta}$ | 0.181 ± 0.253 | 0.304 ± 0.247 | 0.123 | .343 | 0.49 |
| Absolute Squat$_{\Delta}$ | 58.5 ± 44.5 | 69.5 ± 51.2 | 11.0 | .653 | 0.23 |
| Body Weight$_{\Delta}$ | 8.50 ± 6.57 | 2.00 ± 8.43 | -6.50 | .107 | -0.86 |
| 40-Yard Dash Momentum$_{\Delta}$ | 30.0 ± 17.4 | 23.7 ± 27.7 | -6.28 | .603 | 0.27 |

** Denotes statistical significance. The negative sign within the 40-Yard Dash$_{\Delta}$ row indicates a decrease in test completion times.*

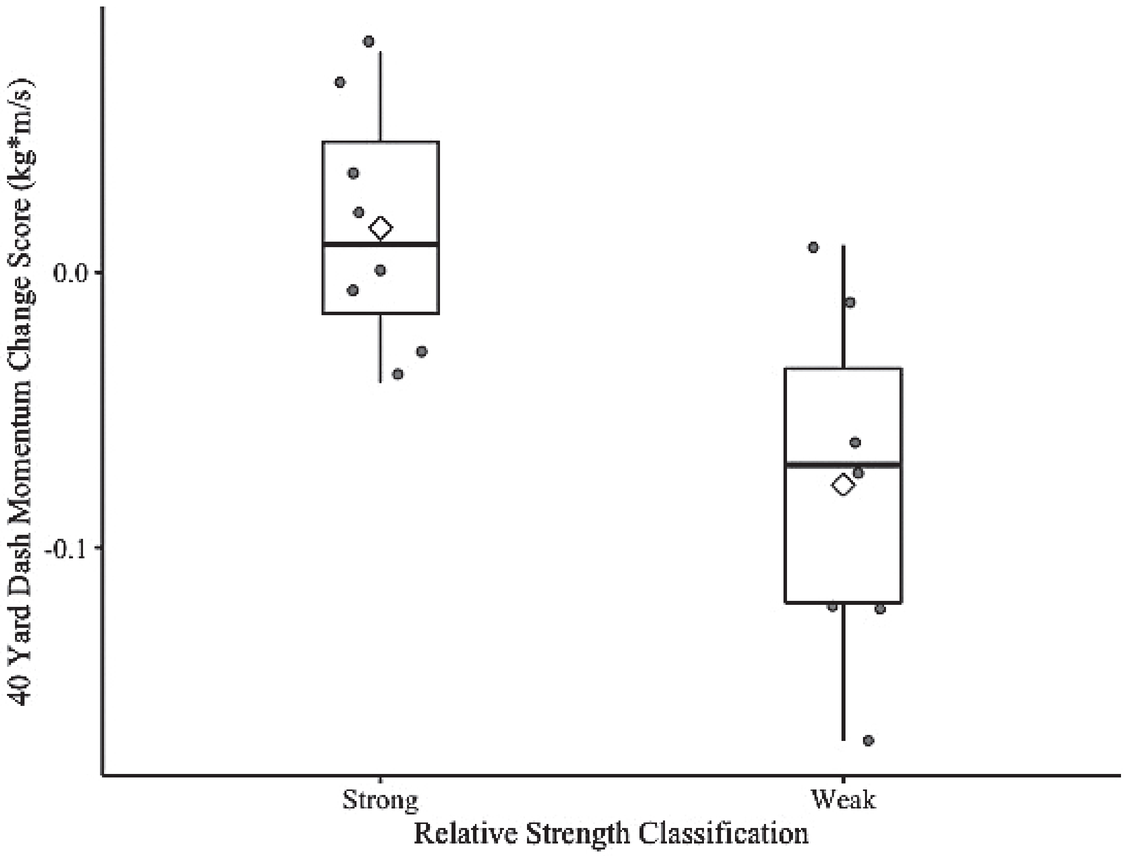



**Figure 3.** *Comparison of mean 40-yard change scores(s) from season 1 to season 3 between groups of "strong" (left boxplot) and "weak" (right boxplot) athletes. The boxplot represents the mean, as well as interquartile ranges and 95% confidence limits for group values.*

**DISCUSSION**

This study sought to address three related aims. Aim one was to investigate changes in body weight, absolute lower body strength, relative lower body strength, as well as 40-yard dash completion times and momentum across three athletic seasons. Aim two was to find whether there were significant relationships between change scores in body weight, lower body strength, and 40-yard dash completion times, in order to investigate the potential strength of these relationships. Lastly, aim three was to explore the impact of relative lower body strength levels during season one on subsequent improvements or regressions in the linear speed.

Descriptive results from our study show that athletes in our sample experienced significant increases in absolute and relative lower body strength across three seasons, while 40-yard dash performance did not improve significantly across time. Further, body weight and sprint momentum increased significantly from Season-1 to Season-3. The current results are in line with findings by Miller et al. (2002), who found that while linear speed did not increase over the course of four years of eligibility among collegiate American NCAA Division-I football players, body mass continued to increase among athletes. Further, Mann et al. (2021) recently highlighted a similar trend in which collegiate American NCAA Division-I football players continued to make gains in body mass across 4 athletic seasons, while improvements in speed plateaued after the first year of play. In our study, athletes also experienced significant increases in body mass and sprint momentum between Season-1 and 3. However, while not statistically significant, improvements in linear speed were not observed between Season-1 and 2, but rather between Season-2 and 3, as well as Season-1 and 3. These findings are reflected in the common thought by American football sports coaches and strength and conditioning coaches that incoming freshmen and sophomores in many cases need to increase strength and body mass to withstand the increased physicality of the college level. While this is true to a certain extent, we believe that the modern game of American football, especially at the skill positions, is much faster, and therefore much more reliant on speed and acceleration qualities. Therefore, we suggest that practitioners focus on increasing strength, while not neglecting the development of speed, and changes in body mass, since findings from this investigation suggest that the relationship between improvements in speed and increases in strength levels may not be as linear and straightforward as previously thought of.

Within the second aim, this study looked to more closely investigate the potential relationship between changes in lower body strength and changes in the linear speed. Specifically, we looked to investigate this relationship by analyzing change scores between body weight, lower body strength, and 40-yard dash performance. Neither change scores in absolute lower body strength nor change scores in relative lower body strength were found to be significantly related to change scores in 40-yard dash completion times. However, change scores for body weight showed a statistically significant relationship with change scores in 40-yard dash completion times. Within our sample, it seems that increases in weight had a negative influence on linear speed over time. One limitation however is that within the realms of this study, body composition changes were not analyzed. Therefore, it is difficult to conclude if those hindering effects of mass gain with regard to speed development came from increases in body fat, lean mass, or a combination of both. Future studies should longitudinally investigate the effects of body composition changes on speed performance among collegiate football players. Therefore, when analyzing longitudinal data on American football athletes, strength and conditioning professionals should aim to focus on changes in body composition, in conjunction with changes in respective strength levels.

Lastly, within aim three, season one strength levels and their impact on subsequent changes in speed performance over time were looked at closer. Athletes were divided into "weak" and "strong" groups, using the 50$^{th}$ percentile for relative lower body strength during season one as a cutoff point. In our sample, the "weak" group consisted of athletes who could squat less than 2.31 times their own body weight during season one, while the “strong” group consisted of athletes who could squat more than 2.31 times their own body weight. This was done to investigate whether baseline relative strength levels had any influence on subsequent improvements in linear speed qualities. Results revealed that the “weak” group experienced significantly larger improvements in 40-yard dash completion times between season one and season three, compared to the “strong” group. While not statistically significant, the “weaker” group also experienced larger increases in relative and absolute strength from season one to season three. While speculative, this finding might support our hypothesis or idea that improvements in speed performance align with improvements in lower body strength until an athlete achieves a certain strength-to-body weight ratio or threshold. After that point, a shift towards addressing other physical qualities such as muscular power, rate of force development, or training other qualities along the force-velocity curve such as strength speed or speed-strength may be more advantageous. These findings may have potential merit for strength and conditioning professionals mapping out long-term athletic development plans for athletes. Future investigations should determine potential strength thresholds above which further increases in maximal strength may not optimally complement further improvements in speed. However, we believe that such thresholds are going to be high population and task specific. Nevertheless, taking into consideration all three seasons, the “strong” group reported faster 40-yard dash times than the “weak” group ($p = .059$, $d = .98$), and relative strength was found to be significantly related to 40-yard dash times ($r = -.491$, $p = .001$), similarly to studies highlighted within the introduction (Comfort et al., 2016; Hori et al., 2008; McBride et al., 2009; Seitz et al., 2014). This would suggest that relative lower body strength does contribute to linear speed performance within our sample, however potentially only to a certain point. Within our investigation, a positive transfer of strength to speed was not observed, which is contrary to the findings suggested by Seitz et al. (2014). Within their systematic review, Seitz et al. (2014) did find a positive transfer of lower-body strength training to sprint performance, which was indicated by very large correlations between effect sizes in squat strength and effect sizes in sprint performance.

While we think that this longitudinal, descriptive study within a high-level sports population has the potential to meaningfully add to the body of evidence, we understand that this study is not without limitations. For one, the small sample size analyzed within this investigation is a limitation. Future investigations should aim for a similar study design with greater sample size. Further, findings are difficult to generalize beyond the sample and population used within this investigation. Additionally, raw 40-yard dash completion times as well as absolute and relative back squat numbers were the only means of measuring linear speed performance as well as lower body strength. Future investigations may incorporate sprint analyses of different distances, as well as different means of measuring lower body strength. Lastly, within our study, relative strength levels were acquired by simply dividing raw strength levels by the athletes’ body weight in kg. Stone (2002) suggested that simply dividing by body mass may not show the whole picture and may not necessarily obviate differences in regional body mass. Future studies should aim toward accounting for differences in body mass, specifically when looking at strength levels in regard to overall and regional body mass. It may also be worthwhile investigating longitudinal changes in vertical (e.g., loaded jumps), and horizontal (e.g., horizontal sprint) force-velocity characteristics and how these changes potentially interact or complement each other. Lastly, future studies should aim to investigate the effects of implementing different training strategies once athletes hit a certain level of strength, in order to further optimize the development of speed as part of a strength and conditioning program.

## CONCLUSION

In summary, our study documented that collegiate NCAA American football players significantly increased body weight, as well as absolute and relative lower body strength levels across three seasons. Nonsignificant improvements in 40-yard dash times were also observed across the three seasons. Change scores in absolute and relative lower body strength showed no significant relationships with change scores in 40-yard dash performance. However, change scores in body weight showed a significant relationship with change scores in 40-yard dash performance. Lastly, when broken into groups of "weak" and "strong" athletes, based on season-1 lower body strength levels, the group of "weak" athletes showed statistically significantly larger improvements in 40-yard dash performance between season one and season three compared to the group of already "strong" athletes. Future studies should investigate longitudinal changes in strength as they relate to changes in speed, taking into consideration different sports populations, as well as different means of capturing linear speed, strength, and body composition. Moreover, primary study implications may suggest that improvements in linear speed align with increases in strength until athletes reach a certain level of strength. These findings may be of acute interest to practitioners such as strength and conditioning coaches interested in improving linear speed amongst athletes.

## REFERENCES

Appleby, B.B., Cormack, S.J., Newton, R.U. (2020). Unilateral and Bilateral Lower-Body Training Does not Transfer Equally to Sprint and Change of Direction Performance, *Journal of Strength and Conditioning Research* 34: 54-54.

Barker, M., Wyatt, T.J., Johnson, R.L., Stone, H., O'Bryant, H.S., Poe, C., Kent, M. (1993). Performance factors, psychological factors, physical characteristics and football playing ability, *Journal of Strength and Conditioning Research 7:* 224-233.

Bishop, D.J. (2008). An applied research model for the sport sciences, *Sports Medicine* 38: 253-263.

Cohen, J (1992). Statistical Power Analysis, *Current Directions in Psychological Science* 1: 98-101.

Comfort, P., Bullock, N., Pearson S.J. (2012). A comparison of maximal squat strength and 5-, 10-, and 20-meter sprint times, in athletes and recreationally trained men, *Journal of Strength and Conditioning Research* 26: 937-940.

DiStasio, T. J. (2014). Validation of the Brzycki and Epley Equations for the 1 Repetition Maximum Back Squat Test in Division I College Football Players (thesis). *OpenSIUC, Carbondale.*

Fry, A.C., Kraemer, W.J. (1991). Physical performance characteristics of American collegiate football players, *Journal of Strength and Conditioning Research* 5: 126-138.

Fullagar, H.H.K., McCunn, R., Murray, A. (2017). Updated Review of the Applied Physiology of American College Football: Physical Demands, Strength and Conditioning, Nutrition, and Injury Characteristics of America's Favorite Game, *International Journal of Sports Physiology and Performance* 12: 1396-1403.

Hori, N., Newton, R.U., Andrews, W.A., Kawamori, N., McGuigan, M.R., Nosaka, K.

(2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? *Journal of Strength and Conditioning Research* 22: 412-418.

Hornsby, G.W., Tice, A.L., Stone, J.D., Merrigan, J.J., Hagen, J., Wagle, J.P., Cunanan, A.J., Stone, M.H. (2021). Changes in maximal strength and home run performance in ncaa division 1 baseball players across 3 competitive seasons: A descriptive study, *Journal of Functional Morphology and Kinesiology* 6.

Kuzmits, F.E., Adams, A.J. (2008). The nfl combine: Does it predict performance in the national football league? *Journal of Strength and Conditioning Research* 22: 1721-1727.

LaPlaca, D.A., McCullick, B.A. (2020). National football league scouting combine tests correlated to national football league player performance, *Journal of Strength and Conditioning Research* 34: 1317-1329.

Mann, J.B., Ivey, P.J., Brechue, W.F., Mayhew, J.L. (2015). Validity and reliability of hand and electronic timing for 40-yd sprint in college football players, *Journal of Strength and Conditioning Research* 29: 1509-1514, 2015.

Mann, J.B., Mayhew, J. L., Dos Santos, M. L., Dawes, J. J., & Signorile, J. F. (2022). Momentum, rather than velocity, is a more effective measure of improvements in Division IA Football Player Performance, *Journal of Strength and Conditioning Research*, *36(2): 551-557*.

McBride, J.M., Blow, D., Kirby, T.J., Haines, T.L., Dayne, A.M., Triplett, N.T. (2009). Relationship between maximal squat strength and five, ten, and forty yard sprint times, *Journal of Strength and Conditioning Research* 23: 1633-1636.

Miller, T. A., White, E. D., Kinley, K. A., Congleton, J. J., & Clark, M. J. (2002). The effects of training history, player position, and body composition on exercise performance in collegiate football players, *Journal of Strength and Conditioning Research*, *16*(1), 44–49.

Seitz, L.B., Reyes, A., Tran, T.T., de Villarreal, E.S., Haff, G.G. (2014). Increases in lower-body strength transfer positively to sprint performance: a systematic review meta-analysis, *Sports Medicine* 44: 1693-1702.

Stone, M.H., Moir, G., Glaister, M., Sanders, R. (2002). How much strength is necessary? *Physical Therapy in Sport* 3: 88-96.

Teramoto, M., Cross, C.L., Willick, S.E. (2016). Predictive value of national football league scouting combine on future performance of running backs and wide receivers, *Journal of Strength and Conditioning Research* 30: 1379-1390.

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