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Seasonal Change in Countermovement Jump Performance in NCAA Women's Golfers

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ABSTRACT

Background of Study: The countermovement vertical jump (CMJ) task has been reported to have positive associations with golf-specific performance variables. Additionally, the CMJ is commonly used to assess neuromuscular fatigue in athletic populations. **Objective:** Thus, this investigation sought to examine the changes in CMJ performance throughout a competitive season in NCAA collegiate women's golfers. **Methods:** Using a longitudinal study design, six collegiate women golfers completed three sessions (pre, mid, and post) of CMJ testing during the spring competition period. During each testing session, two successful jump trials were collected using a portable force platform sampling at 1000 Hz. During each trial, an arm swing was restricted by the use of a dowel placed across the upper back. A one-way repeated measures analysis of variance was used to determine if differences were present between testing sessions. **Results:** Propulsive net impulse significantly increased from pre to mid ($p < 0.05$) and pre to post ($p < 0.05$). No other variables showed a statistically significant change over the duration of the study, though moderate effect size increases were in countermovement depth from pre to mid-testing (0.73) and jump height from pre to post-testing (0.72). **Conclusions:** These findings support previous findings of an increase in vertical jump performance over the course of a season in collegiate golfers, though strategies for maximal performance may shift.

Key words: Golf, Females Athletes, Vertical Jump, Collegiate Athletes, Physical Functional Performance

INTRODUCTION

Golf is a game that requires both technical and tactical decision-making and accurate ball-striking capabilities. Recently, the physical demands of playing golf are more widely recognized as an area where an individual can improve performance (Bishop, Brennan, et al., 2022; Donahue et al., 2021; J. Wells et al., 2018). Leading to an increase in investigating the link between physical fitness attributes and golf-specific performance, most commonly clubhead speed (CHS) (Donahue et al., 2021; Ehlert, 2021; Keogh et al., 2009; Leary et al., 2012; J. E. T. Wells et al., 2019)). A recent systemic review identified both strength and power production as having significant positive relationships to CHS (Ehlert, 2021). When examining the association of strength and CHS, Oranchuk et al. (Oranchuk et al., 2020) identified a positive relationship ($r = 0.64$) between 1-repetition maximal back squat and CHS in collegiate golfers. While interesting, the golf swing is performed in a manner that can be considered ballistic in nature, and the sport-specificity may be lacking when using the 1-repetition max. Thus, the relationship between vertical jump performance and CHS has been more commonly investigated. This relationship has been shown to have both significant and non-significant findings in the literature. Lewis et al. (Lewis et al., 2016) found significantly high relationships ($r = 0.82$) between squat jump height and CHS in a sample of professional male golfers. In contrast, Donahue et al (Donahue et al., 2021) found a non-significant relationship between CHS and countermovement jump (CMJ) height in collegiate male golfers ($r = 0.28$). With such disagreement in the literature and many sports scientists moving away from jump height as a variable of interest when performing vertical jump testing, other CMJ sub-phase metrics, such as propulsive net impulse, have been shown to have positive significant relationships to CHS in male golfers (J. E. T. Wells et al., 2022).

Collegiate golf is unique in that NCAA-sanctioned events occur in two blocks during the year (fall and spring), with a period of no competition in between. Thus, physical preparation is critical during this time period of competition. Previous data has shown that collegiate golfers engaged in organized training programs have increased strength (1-repetition maximal back squat) concurrently with CHS (Doan et al., 2006). During periods in which collegiate golfers are competing,

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physical preparation commonly becomes less of a priority as sport-specific training increases. Recently, Donahue et al. (Donahue, Peel, Shelby A, et al., 2022) showed that during a 10-week competitive period, male collegiate golfers maintained or improved vertical jump performance, while reductions were present in isometric midthigh pull values. Interestingly, a single-subject analysis was also completed with this investigation and showed that group mean changes did not match individual changes, as several individuals saw reductions in vertical jump performance that were masked by others who saw improvement (Donahue, Peel, Shelby A, et al., 2022). In female golfers, only one study investigated the association between CHS and vertical jump performance (Coughlan et al., 2020). This study was completed in a sample of youth golfers (age 13 – 17) and found there to be a positive relationship between CMJ power (r = 0.60) and CHS (Coughlan et al., 2020). This supports previous investigations in male golfers between CMJ metrics and CHS.

As the association between physical performance and CHS has been established, it is important to understand the change in physical performance parameters throughout a competitive season. While previous investigations in other sports have used investigated the change in CMJ performance over a season, only one study has examined changes in CMJ performance over a season within a sample of golfers ((Donahue, Peel, Shelby A, et al., 2022; Emmonds et al., 2020; Gathercole et al., 2015; González-Ravé et al., 2011; Hoffman et al., 2003). It has been suggested that strength and conditioning practitioners working with golf athletes use the CMJ to assess physical performance during a competitive season and when doing so, it is suggested that a force platform is used (Bishop, Brennan, et al., 2022). This is due to the additional variables obtained from the force-time data collected using the force platform. This approach is common amongst various sports because of the insight not only of the jump performance, but also the strategy used to obtain the outcome. This would then allow practitioners to have the data needed to design targeted training programs to improve performance and mitigate injury risk (Bishop, Brennan, et al., 2022). Thus, this investigation examined the seasonal change in CMJ performance in a sample of collegiate female golfers.

METHODS

Participants and Study Design

Six (n=6) members of a Division I Collegiate women's golf program (age 19.33 ± 1.21 years, height 161.67 ± 4.09 cm, body mass 62.03 ± 4.54 kg) participated in this investigation. Within this study only one women's collegiate golf team was examined to ensure that all training (physical, technical and tactical) was the same for each participant. Inclusionary criteria for this investigation consisted of being free from injury for the duration of the study, cleared for sport participation by the university's athletic training and medical staff, and membership on a NCAA Division I collegiate golf roster. Exclusionary criteria consisted of having any injury that precluded the individual to not be able to take part in all team training sessions. All procedures were approved by the university institutional review board and each participant provided written informed consent prior to the first data collection.

A longitudinal study design was used to investigate changes in the CMJ performance over the spring competitive season (15 weeks). Individuals performed testing as a part of their routine athlete monitoring program. Data from week 1 (pre), week 8 (mid) and week 15 (post) were used in this analysis. Each participant engaged in all team activities (resistance training and sport specific training) during the 15 weeks. One to two resistance training sessions occurred per week with all participants performing the same training regimen within each session. Each resistance training session consisted of both upper and lower body exercises, selected to aid in improving strength and power. Progressive overload principles were used over the 15 weeks by manipulating the sets, repetitions, and loads. A certified strength and conditioning professional provided oversight of all training sessions and monitored proper progression throughout the 15 weeks.

Procedures

Jump testing

All testing sessions were a part of the routine athlete monitoring program. All participants had taken part in the testing program for the previous semester leading up to the pretesting. After completing a general dynamic warm- up consisting of lower body movements and three submaximal jump trials, two CMJ trials were performed using a portable force platform (AMTI, Accupower, Watertown, MA, USA) (Carroll et al., 2019). Each trial was completed with a polyvinyl chloride dowel placed on the participant's back in a similar position to a back squat (Donahue et al., 2021; Rush et al., 2022). Each trial was performed by having the participant use a self-selected foot width and countermovement depth (Argus et al., 2011). Participant's were instructed to jump as high as possible, while keeping the dowel in contact with their back the entire duration of the trial. Prior to the initiation of each trial, one second of quiet standing upon the force platform was used to calculate body mass. Each trial was separated by a minimum of thirty seconds.

Data analysis

During each trial, ground reaction force data was collected at 1000 Hz. Raw vertical force-time data was then exported into a custom excel spreadsheet for analysis (Donahue, Peel, Shelby A, et al., 2022; Rush et al., 2022). Each trial was broken into three phases as defined by McMahon et al. (J. J. McMahon et al., 2018). Movement onset was determined using the body mass minus 5SD method. The end of the propulsive phases was defined as the first sample in which ground reaction force fell below 10 N. Variables for interest for this investigation included mean propulsive force, propulsive duration, propulsive net impulse, countermovement depth, time to takeoff, jump height and reactive strength index modified (RSImod).

Statistical Analysis

The reliability of each variable of interest was assessed by calculating the interclass correlation coefficients (ICC) and coefficient of variation (CV). Acceptable reliability was deemed to occur with a CV less than 10% and an ICC greater than 0.8. A repeated measures analysis of variance (ANOVA) was conducted to determine changes in vertical jump performance over the course of the 15 weeks. If significant differences was found, a Fisher's Least Significant Difference post hoc analysis was performed. Hedges g effect sizes were calculated between each time point as and interpreted using the following criteria: trivial (< 0.2), small (0.2 – 0.49), moderate (0.5 – 0.79), and large (> 0.8) (Hopkins, 2002).

Additionally, single-subject analyses were performed on each variable of interest by using individual variability from the pretest (Donahue, Peel, Shelby A, et al., 2022). Variability was assessed using pretest CV values. All statistical analyses were performed using SPSS (version 28.0, IBM, Chicago, IL, USA).

RESULTS

All ICC and CV data is presented in Table 1. All variables of interest displayed acceptable levels of reliability. Propulsive net impulse displayed a significant difference over the 15 weeks [F(2, 14.80) = 9.14, p = 0.006]. Pre testing values were statistically smaller than both mid (p = 0.012) and post (0.026) testing. No statistically significant difference was seen between mid and post testing. All other group mean variables displayed no statistically significant differences between testing sessions (Table 2).

From pre to post, two participants increased mean propulsive force, two had a reduction in force and two had no change (Table 3). Propulsive duration was reduced in one participant, increased in two and no change was seen in three (Table 3). Similar to the mid-test, five participants saw an increase in propulsive net impulse, and one had no change (Table 3). Countermovement depth increased in two participants, was reduced in two participants and no change was seen in two participants (Table 4). Jump height improved in four participants and no change was seen in two participants (Table 4). Time to takeoff was reduced pre to post testing in two participants was increased in one participant, and no change was seen in three participants (Table 4). Lastly, RSImod was increased from pre to post testing in three participants, no change was seen in two participants and one participant had no change (Table 4).

Single subject analysis revealed that from pre to mid testing one participant saw an increase in mean force, one had a decrease in mean force and the remaining four had no change (Table 3). Propulsive duration had one individual reduce time, three increase time and two with no change (Table 3). Propulsive impulse was increased in five participants with no change seen in one (Table 3). Countermovement depth was reduced in one participant, increased in four and no change was seen in one (Table 4). Jump height increased in three participants, reduced in two and no change was seen in one (Table 4). Time to takeoff was reduced in one participant, increased in one participant and the remaining four experienced no change (Table 4). Finally, RSImod was increased in three participants, reduced in two participants and no change was seen in one (Table 4).

Table 1. Intraclass correlation coefficients (ICC) and coefficient of variation (CV)

	ICC (95% Confidence Interval)	CV (95% Confidence Interval)
Mean Propulsive Force (N)	0.81 (0.65 – 0.97)	6.60 (3.57 – 9.62)
Propulsive Duration (ms)	0.84 (0.66 – 0.98)	5.10 (1.70 – 8.49)
Propulsive Net Impulse (N*s)	0.98 (0.83 – 0.99)	1.64 (0.21 – 2.84)
Countermovement Depth (cm)	0.81 (0.65 – 0.97)	3.93 (1.04 – 7.34)
Time to Take-off (ms)	0.92 (0.88 – 0.98)	2.95 (1.94 – 6.65)
Jump Height (cm)	0.93 (0.88 – 0.99)	1.62 (0.73 – 3.34)
RSImodified	0.93 (0.87 – 0.99)	3.23 (3.56 – 8.73)

Table 2. Mean ± SD of countermovement jump performance between time points

	Mean ± SD			Hedges's *g*		
	Pre	Mid	Post	Pre-Mid	Pre-Post	Mid-Post
Mean Propulsive Force (N)	399.19 ± 50.29	406.35 ± 56.43	403.72 ± 57.52	0.13	0.08	0.05
Propulsive Duration (ms)	307.42 ± 39.7	323.42 ± 36.4	323.75 ± 49.48	0.42	0.36	0.01
Propulsive Net Impulse (N*s)	122.15 ± 13.06	130.88 ± 14.12	129.76 ± 15.30	0.64	0.54	0.08
Countermovement Depth (cm)	28.88 ± 2.76	31.06 ± 3.19	30.76 ± 4.75	0.73	0.48	0.07
Time to Take-off (ms)	880.58 ± 140.82	859.33 ± 126.24	873.42 ± 126.59	0.16	0.05	0.11
Jump Height (cm)	19.85 ± 1.53	20.60 ± 1.82	21.17 ± 2.10	0.45	0.72	0.29
RSI modified	0.23 ± 0.05	0.24 ± 0.04	0.25 ± 0.05	0.22	0.40	0.22

Table 3. Propulsive mean force, propulsive duration and propulsive net impulse at each time point (mean ± *SD*)

Subject	Propulsive Mean Force (N)			Propulsive Duration (ms)			Propulsive Net Impulse (N*s)		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
1	465.75 ± 4.15	469.44 ± 5.67	443.05 ± 2.93*	253.50 ± 0.71	288.50 ± 20.51*	306.50 ± 16.26*	119.06 ± 0.71	136.63 ± 11.27*	136.92 ± 8.12*
2	403.30 ± 45.40	425.84 ± 24.43	428.65 ± 4.82	363.00 ± 35.36	364.00 ± 16.97	363.50 ± 3.54	146.54 ± 2.32	155.80 ± 1.69*	156.80 ± 0.24*
3	398.51 ± 37.98	346.50 ± 23.26*	318.21 ± 6.69*	301.50 ± 24.75	347.50 ± 23.33*	397.00 ± 1.41*	120.67 ± 1.64	121.06 ± 0.01	127.25 ± 3.11*
4	413.76 ± 5.91	400.88 ± 55.01	459.53 ± 60.83*	290.00 ± 2.83	325.00 ± 33.94*	267.50 ± 36.06*	120.97 ± 6.00	130.41 ± 4.31*	122.91 ± 0.19
5	309.81 ± 30.70	335.28 ± 12.08	345.49 ± 4.77*	344.00 ± 32.53	344.50 ± 9.19	327.00 ± 1.41*	106.85 ± 0.51	116.30 ± 1.10*	113.81 ± 2.04*
6	404.27 ± 35.03	460.17 ± 50.24*	427.37 ± 26.95	292.50 ± 20.51	271.00 ± 26.87*	281.00 ± 12.73	118.78 ± 2.02	125.03 ± 1.28*	120.82 ± 2.14*

* = values represent individual change greater than the Pre coefficient of variation

DISCUSSION

The purpose of this investigation was to examine the changes in CMJ performance throughout a competitive season in female collegiate golfers. The main finding of this study was that propulsive net impulse increased throughout the study. When using the single subject analysis, it appears this statistically significant increase in propulsive net impulse is due to a shift in jump strategy through greater propulsive durations with no attenuation of force production.

It has been suggested that specific CMJ metrics be used depending on the goal of the assessment (Bishop, Jordan, et al., 2022). Time-based metrics such as RSImod, time to take-off, and propulsive duration should be used when assessing neuromuscular fatigue. While metrics such as jump height and mean propulsive force are used when profiling athletes. Thus, the results of the present study are of particular interest. The increase in propulsive net impulse can be interpreted as a positive adaptation occurring over the 15 weeks. This increase coincides with a non-statistically significant increase in jump height which displayed a moderate effect size from pre-to post-testing ($g = 0.72$.,) However, when using metrics suggested to assess neuromuscular fatigue, group mean data suggests a non-significant increase in propulsive duration and countermovement depth. Both of these have been suggested as negative adaptations. When using the single-subject analysis from the pre to mid-testing sessions more individuals (3 vs 1) experienced an increase rather than decrease in propulsive duration. Group changes in this study were limited in magnitude both by the limitations of sample size due to roster size and individuals remaining injury-free throughout a season. The single-subject data suggests that individuals experience positive and negative adaptations, though all participants took part in similar resistance and sport-specific training sessions. These findings demonstrate the importance of assessing both group and individual changes in the context of athlete monitoring.

The findings of both positive and negative changes in CMJ performance over a competitive season support the previous findings by Donahue et al. (2022) (Donahue, Peel, Shelby A, et al., 2022). Within a sample of male collegiate golfers, they showed that a single individual improved 34% in vertical jump height and reduced time to take-off by 25%, nearly doubling RSImod (Donahue, Peel, Shelby A, et al., 2022). This single individual's change in performance drove much of the group change and masked the individuals who saw negative changes. Within the current investigation, many of the variables of interest did not result in a statistically significant change. However, when performing the single-subject analysis many interesting findings occurred. When examining the changes from pre- to post-testing, five of the six individuals displayed an increase in propulsive net impulse. The one individual that displayed no change in propulsive net impulse, however, had positive changes by way of increasing mean propulsive force (413.76 vs 459.54 N) and reducing propulsive duration (290 vs 267.5 ms). These positive changes resulted in no change in propulsive net impulse but represented a shift in the jump strategy used. Another participant displayed a reduction in force (465.57

Table 4. Countermovement depth, time to take-off, jump height, reactive strength index modified

Subject	Countermovement depth (cm)			Time to take-off (ms)		
	Pre	Mid	Post	Pre	Mid	Post
1	25.56 ± 0.39	29.19 ± 0.93*	32.72 ± 2.28*	725.50 ± 38.89	748.50 ± 17.68	780.50 ± 28.99*
2	33.90 ± 1.76	35.89 ± 1.22*	35.20 ± 1.47	1081.00 ± 114.55	1043.00 ± 77.78	972.00 ± 8.49
3	28.49 ± 1.80	31.92 ± 3.18*	36.69 ± 0.77*	841.50 ± 26.16	874.50 ± 47.38*	988.00 ± 7.07*
4	28.15 ± 0.08	31.72 ± 4.63*	26.22 ± 3.94*	745.00 ± 26.87	741.50 ± 74.45	666.50 ± 79.90*
5	29.28 ± 3.34	31.38 ± 0.78	28.20 ± 3.94	1003.00 ± 49.50	972.00 ± 26.87	949.00 ± 29.70*
6	27.89 ± 1.29	26.28 ± 3.20*	25.56 ± 1.40*	887.50 ± 21.92	776.50 ± 273.58	884.50 ± 16.26
	Jump Height (cm)			Reactive Strength Index modified		
	Pre	Mid	Post	Pre	Mid	Post
1	21.80 ± 0.16	21.04 ± 0.54*	22.04 ± 0.25	0.30 ± 0.01	0.28 ± 0.01*	0.28 ± 0.01*
2	20.89 ± 0.61	23.64 ± 0.53*	24.78 ± 0.31	0.19 ± 0.03	0.23 ± 0.01*	0.25 ± 0.01*
3	18.91 ± 0.42	18.44 ± 0.08*	18.92 ± 0.49	0.22 ± 0.01	0.21 ± 0.01*	0.19 ± 0.01*
4	19.94 ± 0.51	20.67 ± 0.69*	21.39 ± 0.21	0.27 ± 0.02	0.28 ± 0.04	0.32 ± 0.04*
5	17.43 ± 0.13	19.04 ± 0.11*	19.60 ± 0.77*	0.17 ± 0.01	0.20 ± 0.01*	0.21 ± 0.01*
6	20.16 ± 1.03	20.75 ± 0.43	20.27 ± 0.93	0.23 ± 0.02	0.27 ± 0.02*	0.23 0.01

* = values represent individual change greater than the Pre coefficient of variation

vs 443.05 N) and an increase in propulsive duration (253.50 vs 306.50 ms) outside the level of variability while increasing propulsive net impulse (119.06 vs 136.92 N*s). Though propulsive net impulse increased this could be interpreted as a negative change in overall performance. If looking at the group data neither of these situations would have been identified. This supports the need for practitioners examining changes in physical performance to use both group and individual data to understand the changes occurring to the athletes they are working with. Especially, in sports such as golf that are individual rather than team-based. Secondly, this supports previous suggestions in the selection of variables/metrics used from the CMJ (Bishop et al., 2021). Variables such as propulsive net impulse are critical to understanding CMJ, but it is just as important to examine the variables used to calculate propulsive net impulse (mean propulsive force and propulsive duration).

In contrast to the findings of Donahue et al., (2022) (Donahue, Peel, Shelby A, et al., 2022) which showed an increase in mean propulsive force of 6.6% at the group level, the current investigation saw no changes in mean propulsive force. Additionally, Donahue et al. (2022) showed no difference in propulsive duration, whereas an approximate 5% increase in propulsive duration was seen within the current investigation. This can be explained through differences in jump strategies between men and women (J. McMahon et al., 2017; Sole et al., 2018). It has been shown that men typically have a higher relationship between jump height and force-related variables, while women have a higher association of jump outcome metrics with time-related variables (Donahue, Rush, et al., 2022). This is supported by the current study with the increase in propulsive duration and the increase in force from Donahue et al. (2022).

Previous investigations have shown that the propulsive net impulse of the CMJ has a significant positive relationship with CHS within high-level male golfers (Wells et al., 2022). This study did not assess CHS, but future investigations should examine changes in golf-specific performance parameters such as CHS over a competitive season. With the associative relationships between propulsive net impulse and CHS, along with data from the current investigation, it could be hypothesized that an increase in early season CHS could occur as a result of targeted training programs. This investigation is not without its limitations. The sample size used in this investigation is small. However, previous investigations in the golf literature have used similar small sample sizes (Doan et al., 2006). Additionally, this investigation was constrained to one NCAA women's collegiate team to ensure that resistance training and sport-specific training were similar across the entire sample.

This study provides evidence that when examining common CMJ performance metrics (jump height and RSImod) that improvement may be a result of adaptations that are actually negative in nature. Additionally, this study points to the need for practitioners to use single subject analysis when assessing changes in performance. As group values in the current study saw little to no change, each individual experienced adaptations that were not identified at the group level. The use of the single subject analysis in golf performance research is of special importance as golf is an individual game rather than team based. Thus, individual change is of great importance rather than examining group change.

CONCLUSION

The current investigation is novel in the area of women's golf as previous investigations examined the associations between physical performance and CHS over the influence of training on CHS. While both are important to the improvement of golf itself, it is also of importance to understand how physical performance measures change over the course of a competitive season when an emphasis is taken away from physical preparation and placed on the technical skills of the game of golf. Thus, the data in this investigation points to the need to be placed on ensuring strength capacities throughout the season as a shift was seen in jump strategy with greater propulsive durations and larger countermovement depths.

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