POWER, ENDURANCE, AND BODY COMPOSITION CHANGES OVER A COLLEGIATE CAREER IN NCAA DIVISION I WOMEN SOCCER ATHLETES

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KEYWORDS: athlete development, aerobic capacity, vertical jump, fat free mass, female athlete

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ABSTRACT

The purpose of this study was to determine longitudinal changes in fitness and body composition throughout athletes' four-year collegiate soccer careers. Performance testing occurred prior to preseason during freshman, sophomore, junior and senior year in 17 female Division 1 soccer players. Body composition was assessed via air-displacement plethysmography to determine percent body fat (%BF), fat free mass (FFM) and body mass (BM). Maximal countermovement vertical jump height was assessed via contact mat using arm swing (CMJ_{AS}) and hands-on-hips (CMJ_{HOH}) methods to calculate power (CMJ_{watts}/$_{HOHwatts}$). Aerobic capacity (VO_{2max}) and ventilatory threshold (VT) were assessed by indirect calorimetry during a maximal graded exercise test on a treadmill. Linear mixed models were used to assess changes across academic years ($p<0.05$). No changes occurred in %BF, BM, VO_{2max}, VT, CMJ_{AS} or CMJ_{watts}. A Time main effect was seen for FFM ($p= 0.01$) with increases from freshman to senior ($p=0.02$). Time main effects were observed for CMJ_{HOH} ($p<0.001$) and $CMJ_{HOHwatts}$ ($p<0.001$) with increases from freshman to junior ($CMJ_{HOH,}$ $p=0.001$; $CMJ_{HOHwatts}$, $p=0.02$) and senior (CMJ_{HOH}, $p<0.001$; $CMJ_{HOHwatts}$, $p=0.003$) as well as sophomore to senior (CMJ_{HOH}, $p<0.001$, $CMJ_{HOHwatts}$, $p=0.02$). CMJ_{HOH} also increased from sophomore to junior ($p=0.005$). The lower FFM and power capabilities as freshmen compared to upperclassman indicate a potential limited readiness. Coaches and training staff should account for these developmental differences when entering the preseason. Adequate conditioning programs prior to starting a collegiate program may help build a fitness foundation and prepare freshmen athletes to compete at the same level as their upperclassmen counterparts.

INTRODUCTION

National Collegiate Athletic Association (NCAA) teams are faced with a unique set of challenges to athlete development and management as players are limited in their time spent on the team. Collegiate athletes have four seasons of eligibility to compete in their respective sport, giving coaches and training staff a narrow time period to optimize athlete performance before they complete their collegiate careers. A compounding challenge for fall sport coaches and training staff is the limited access allowed to the athletes prior to the start of their season each year. The NCAA rules and regulations stipulate that college athletes and coaching staff cannot engage in supervised athletic activities outside their playing season, which is defined as the period of time between the first official practice session and either the last practice session or date of competition, whichever occurs later (19). These rules present a unique set of challenges to fall collegiate sport teams, as the time coaches are able to spend integrating incoming freshmen into the team is limited leading up to the competitive season.

The NCAA soccer season starts in the beginning of August with a ~2-week preseason (21 unit) that often consists of multiple practices per day (19). This is followed by a 12-week competitive season consisting of ~20 matches followed by tournament play (19). Entering the preseason period in peak physical condition is essential as this 2-week period is associated with the highest workloads seen throughout the year and has been shown to result in several physiological and psychological perturbations which appear to be further exacerbated by the cumulative effects of the season (17). Therefore, coaches expect individual athletes to train on their own in the offseason summer months to adequately prepare for the demands of the season. A major constraint to a team’s offseason fitness plan is incoming freshmen’s knowledge of what is required for conditioning. Freshmen (~18 years old) are expected to compete alongside their senior teammates (~22 years old); however, unlike seniors, freshmen are less familiar with the training demands associated with collegiate sports. Soccer requires both high levels of aerobic fitness and muscular power for on-field success (26, 29), yet freshmen often lack sufficient resistance training knowledge and experience prior to entering college. Thus, freshmen often demonstrate disparities in strength and power capabilities, putting them at greater risk of injury, compared to collegiate upperclassmen (9, 12, 18, 21, 25).

Periodic testing of fitness attributes is crucial to aid in maximizing team success. As soccer is a power-endurance sport, it is important to track changes in these metrics throughout an athlete's career. Changes in performance may be a result of baseline fitness, competitive level of the athlete (starters vs non-starters), off-season activity, and training strategies (11). Body composition also plays a critical role in sport success as significant correlations between body composition variables and physical performance have been found (24). Greater fat mass has been related to slower sprint times and lower aerobic capacity, while greater percent body fat (%BF) has been correlated with lower vertical jump and cardiorespiratory endurance in male collegiate soccer players (24). As such, longitudinal testing may help to ensure adequate development of the physical and performance qualities that are needed for sport success.

While performance data is important to team success, limited research exists on normative values in female collegiate players. Furthermore, the majority of available data rely on field-based testing measurements rather than gold-standard laboratory-based testing procedures

(13, 28). Research assessing female collegiate athlete performance variables utilizing gold-standard testing metrics is warranted. This information can then be used to guide performance goals for coaches and training staff at both the collegiate level as well as the high school level, where players are aiming to transition and secure a role on a NCAA team. Moreover, research aimed at understanding the longitudinal changes in fitness variables throughout an athlete's collegiate career may help to elucidate the differences that occur across academic years. The purpose of this longitudinal study was to determine fitness and body composition changes over a four-year period in a NCAA Division I women's soccer athletes. We hypothesized that these fitness parameters would improve as players progressed from their freshman to senior year.

METHODS

Experimental Approach to the Problem

Maximal performance testing and body composition data were collected over a 7-year period (2013 – 2019) in women collegiate soccer athletes. Testing sessions occurred immediately prior to preseason (in late July) each academic year. Academic years were defined as freshman, sophomore, junior and senior year, respectively.

Subjects

Fitness variables in women collegiate soccer players on a highly ranked NCAA Division I program were assessed as part of an integrative sport science program. A total of 17 players who participated in all 4 testing sessions over their respective four-year academic eligibility period were included in the analysis. Analyses for each variable include athletes with complete testing data (Table 1). All athletes received clearance by the University Sports Medicine staff prior to all testing sessions. This research was approved, and written consent was waived by the Rutgers University Institutional Review Board for the Protection of Human Subjects (IRB#16-050M). All procedures performed were in accordance with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standard.

Procedures

Body Composition

Body composition was assessed using air-displacement plethysmography (BOD POD, COSMED, Concord, CA, USA). Athletes arrived in a normally hydrated state, ≥2 hours fasted, and having refrained from exercise and caffeine ~24 hours prior. Athletes dressed according to manufacturer guidelines for all tests. Body mass (BM) was determined using a calibrated scale and %BF and FFM were calculated using the Brozek formula (1, 3).

Countermovement Jump

Following a ~7 min dynamic warm-up, athletes completed vertical jump testing via a digital contact mat (Just Jump, Probotics, Huntsville, AL, USA) to determine maximal vertical jump height (20). Athletes were given two attempts to achieve maximal jump height using a countermovement jump with arm swing ($\mathrm{CMJ}_{\mathrm{AS}}$) and countermovement jump with hands on hips ($\mathrm{CMJ}_{\mathrm{HOH}}$). $\mathrm{CMJ}_{\mathrm{HOH}}$ was added to the testing battery during the 2016 season as it has been suggested to be a more sensitive metrics to evaluate lower body force production (2), and thus only 9 athletes completed this part of the testing procedures. Muscular power was calculated using the Sayers formula for all jumps ($\mathrm{CMJ}_{\mathrm{watts}}$ and $\mathrm{CMJ}_{\mathrm{HOHwatts}}$) (22).

Aerobic Capacity

Athletes performed a graded exercise test on a treadmill to measure maximal aerobic capacity ($\dot{V}O_{2max}$) via direct gas exchange using an indirect calorimeter (Quark CPET, COSMED, Concord, CA, USA and Parvo Medics, Sandy, UT, USA). Throughout the test, heart rate (HR) was continuously monitored using a chest strap HR monitor (Polar Electro Co., Woodbury, NY, USA). At least three of the following criteria were met verifying attainment of $\dot{V}O_{2max}$: a leveling off or plateauing of $\dot{V}O_2$ with an increase in workload, attainment of age predicted maximal heart rate ±10 bpm (HR_{max}), a respiratory exchange ratio ≥1.10, and/or an RPE ≥18 (27). Subject's VT was calculated after the completion of each test as the point where ventilation increased nonlinearly with $\dot{V}O_2$.

Statistical Analysis

Linear mixed models were used to assess changes in physical performance variables across different academic years in order to account for the unbalanced nature of data arising through repeated measurements of the same individuals. Separate models were constructed for each dependent variable, whereby individual "player ID" was modelled as a random intercept throughout. As per the research questions of interest, “academic year” (“freshman”, “sophomore”, “junior”, “senior”), was specified as categorical fixed effects. Visual checks were used to confirm the assumptions of normality and linearity. Pairwise comparisons were made using Bonferroni-adjusted least squares means tests to assess differences between each level of any given fixed effect. The t statistics from the model comparisons were converted into standardized effect sizes (*d*) which were interpreted as *trivial* (<0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), or *large* (1.20–1.99) (6, 8, 10). Descriptive data by academic year are presented as means and standard deviation. Analyses were conducted in RStudio (v R-3.6.1.) using the *lme4*, *emmeans*, and *effsize* packages.

RESULTS

Body composition and performance metrics across academic years are presented in *Table 1*. No significant changes were seen in %BF, BM, $\dot{V}O_{2max}$, VT, CMJ_{AS}, or CMJ_{watts} across academic years ($p>0.05$). A Time main effect was seen for FFM ($p= 0.01$). Pairwise comparisons revealed the greatest change occurred from freshman to senior year (Δ=1.6kg; d=0.33; $p=0.02$). A significant Time main effect was observed for CMJ_{HOH} (<0.001) and $CMJ_{HOHwatts}$ ($p=0.001$). Pairwise comparisons revealed a significant increase in CMJ_{HOH} occurred from freshman to junior (Δ=4.6cm, d=0.77, $p=0.001$) and senior year (Δ =5.8cm, d=0.97, $p<0.001$), as well as sophomore to junior (Δ=3.8cm, d=1.11, $p=0.005$) and senior year (Δ=5.2cm, d=1.44, $p<0.001$). Pairwise comparisons also revealed a significant increase in $CMJ_{HOHwatts}$ occurred from freshman to junior (Δ=303W, d=0.72, $p=0.02$) and senior year (Δ =373W, d=0.89, $p=0.003$), as well as sophomore to senior year (Δ=300W, d=0.82, $p=0.02$).

INSERT TABLE 1 ABOUT HERE

INSERT FIGURES 1-3 ABOUT HERE

DISCUSSION

While endurance levels (aerobic capacity and VT), CMJ_{AS} and %BF were maintained over the four years, athletes' lower extremity muscular power and FFM significantly improved.

Athletes exhibited the lowest FFM, CMJ_{HOH}, and power outputs as freshmen, indicating a significant development in these areas throughout their collegiate careers. Overall, these findings indicate that incoming collegiate freshmen do not possess the same physical and performance attributes as their older, seasoned collegiate teammates, especially in terms of muscular power capabilities.

In the current study, aerobic capacity and VT did not improve over the four years. The homogeneity in team aerobic performance, as well as the relatively high values seen across academic years, may be reflective of the high-level athlete and the type of training they are accustomed to pursuing in the off-season. It is speculated that without access to team strength coaches and facilities over the summer months, athletes may be more apt to choose endurance-based exercise and soccer specific training programs to maintain fitness leading to the high aerobic capacity values seen prior to preseason.

Given the often limited exposure to strength training at the high school level, the lower FFM observed freshman year is not surprising. In fact, the lower FFM observed at freshmen year in this study are similar to those previously found in men’s collegiate basketball (4). Male basketball players experienced an increase in FFM from freshman to sophomore year with no change from sophomore to junior year (4). In addition, previous cross-sectional data detailing performance characteristics across different academic years in female collegiate soccer players also found freshmen had significantly lower maximal power capabilities compared to upperclassmen, along with lower maximal aerobic capacity (14). It is important to note that although CMJ_{AS} did not change significantly over the four years, this may be a result of a lack of sensitivity of this measure when tested in soccer athletes whose sport does not require the use of arm swing motion for jump proficiency (7). In addition, despite lack of significant changes in this metric over the four-year period, the lowest values were still apparent during freshman year.

Overall, coaches and training staff should recognize the potential limited readiness of freshmen athletes and account for these developmental differences when entering the season. This may aid proper periodization strategies and help to reduce the risk for injury. In fact, studies in collegiate athletes across sports have reported freshmen were at a higher risk for stress fracture occurrence which may be caused by the increase in training demands transitioning from the high school to collegiate level (5). Additionally, as power and body composition differences in freshman appear to be prevalent across multiple sports, coaches and training staff can utilize this information to tailor training in an effort to address these concerns. Due to the limited access to their team, it becomes crucial for coaches and training staff of collegiate fall sports to maximize their time spent with the athletes throughout the year in order to achieve long-term team success. This should include targeted strength and power training, especially for freshman female soccer players. Moreover, for high school athletes, there appears to be a need for improved strength and conditioning programs aimed at increasing FFM and power capabilities beginning prior to sport participation at the collegiate level. Further research is warranted regarding maturation and performance development in youth athletes looking to transition to a collegiate program.

An acknowledged limitation of the current study is lack of training workload information to provide context to the performance changes that were seen over the four-year period. Other studies have shown increased training load improves aerobic fitness (23), but that these training loads may also have a negative effect on sprint and CMJ performance (15, 16). Given the design of a collegiate soccer program, monitoring individual training workloads throughout the years was not possible, particularly during NCAA mandated unsupervised periods. Future research is warranted to assess total training demands in order to help explain the changes in performance and body composition throughout the season. Further research may benefit from this information to help determine optimal loading prescriptions in an effort to mitigate performance decrements in this population. Despite these limitations, this study has many unique strengths. The within-subject design of this study helps to elucidate the developmental changes that occur over time in women soccer athletes. To the authors knowledge, this is the first study to determine longitudinal changes in fitness variables using gold standard testing techniques throughout an entire collegiate soccer career.

PRACTICAL APPLICATIONS

This study highlights the importance of monitoring performance across the entirety of an athlete’s career. Periodic testing may help to ensure adequate development of the physical and performance qualities that are needed for sport success at all levels of play. Performance testing prior to the start of an athlete’s collegiate career may be especially crucial as it allows coaches and training staff to identify athlete’s readiness and immediately implement targeted interventions to address any deficits. This individualized approach to team monitoring becomes essential as not all athletes may adapt to the imposed training demands in a similar manner. In addition, adequate conditioning programs prior to entering a collegiate program may help to build a proper fitness foundation and prepare incoming freshmen athletes to compete at the same level as their upperclassmen counterparts. These findings can guide performance goals for soccer coaches and training staff at both the collegiate and high school levels to better prepare freshmen to compete on the collegiate stage. For women soccer players, these programs should emphasize power development, as these characteristics were the most improved throughout the four-year collegiate period.

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TABLE LEGENDS:

Table 1: Body Composition and Performance Changes Across Academic Years

Results are presented as means and standard deviation. (*) indicates significant differences from freshman ($p<0.05$), (†) indicates significant differences from sophomore ($p<0.05$). VT=ventilatory threshold, CMJ_{AS}=countermovement vertical jump with arm swing, CMJ_{HOH}=countermovement vertical jump with hands on hips, BF=percent body fat, FFM=fat free mass

FIGURE LEGENDS:

Figure 1: Body Composition Changes Over an Academic Career in Female Collegiate Soccer Athletes

Lines represent individual athlete changes over 4 years.

Diamonds represent means for each academic year

BF=percent body fat, FFM=fat free mass

Figure 2: Endurance Changes Over an Academic Career in Female Collegiate Soccer Athletes

Lines represent individual athlete changes over 4 years.

Diamonds represent means for each academic year

CMJ=countermovement vertical jump with arm swing, CMJ_{HOH}=countermovement vertical jump with hands on hips

Figure 3: Power Changes Over an Academic Career in Female Collegiate Soccer Athletes

Lines represent individual athlete changes over 4 years.

Diamonds represent means for each academic year

VT=ventilatory threshold

Table 1

Table 1: Body Composition and Performance Changes Across Academic Years

Academic Years:	**N**	**Freshman**	**Sophomore**	**Junior**	**Senior**	**Time main effect**
BF (%)	11	19.7 ± 3.9	20.3 ± 3.9	18.8 ± 5.7	18.3 ± 5.5	0.40
FFM (kg)	11	53.4 ± 4.8	53.9 ± 4.8	54.6 ± 4.8	55.0 ± 3.8*	0.01
Body Mass (kg)	11	66.4 ± 4.4	67.6 ± 5.4	67.4 ± 5.6	67.5 ± 5.2	0.70
CMJ_{AS} (cm)	17	53.8 ± 6.8	53.8 ± 7.2	55.7 ± 5.6	55.2 ± 5.8	0.27
CMJ_{AS} (watts)	17	4123 ± 515	4179 ± 559	4287 ± 449	4256 ± 505	0.17
CMJ_{HOH} (cm)	9	45.2 ± 6.0	45.8 ± 3.6	49.8 ± 4.8*†	51.0 ± 4.1*†	<0.001
CMJ_{HOH} (watts)	9	3688 ± 419	3761 ± 364	3990 ± 426*	4061 ± 321*†	0.001
$\dot{V}O_{2max}$ (ml·kg^{-1}min^{-1})	16	50.1 ± 2.7	50.0 ± 5.6	48.5 ± 3.6	49.8 ± 3.4	0.37
VT (%$\dot{V}O_{2max}$)	16	80 ± 3	80 ± 5	80 ± 5	79 ± 4	0.79

Figure 1

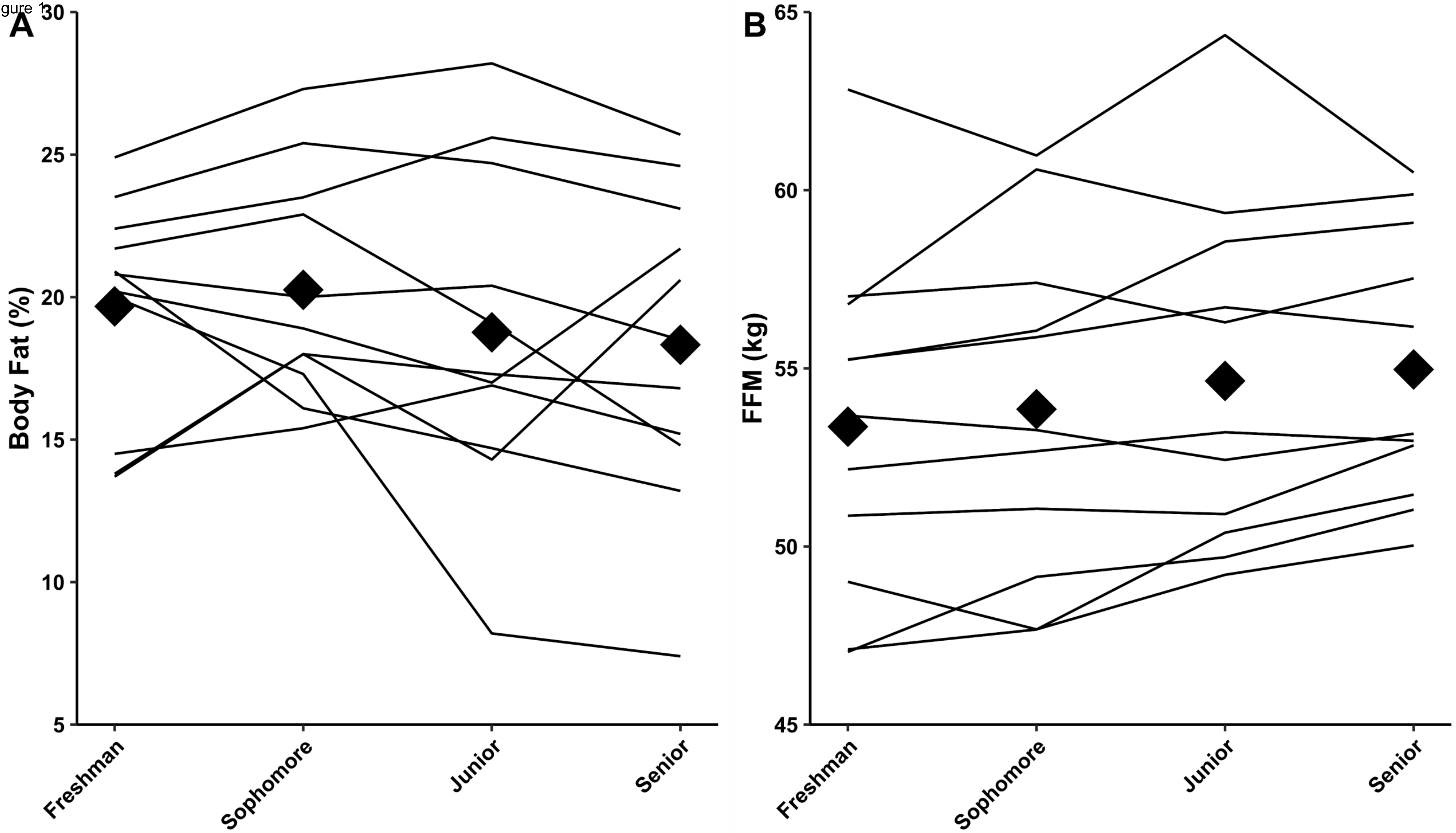

A
B
30
25
20
15
10
5
Body Fat (%)
65
60
55
50
45
FFM (kg)
Freshman
Sophomore
Junior
Senior
Freshman
Sophomore
Junior
Senior

Figure 2

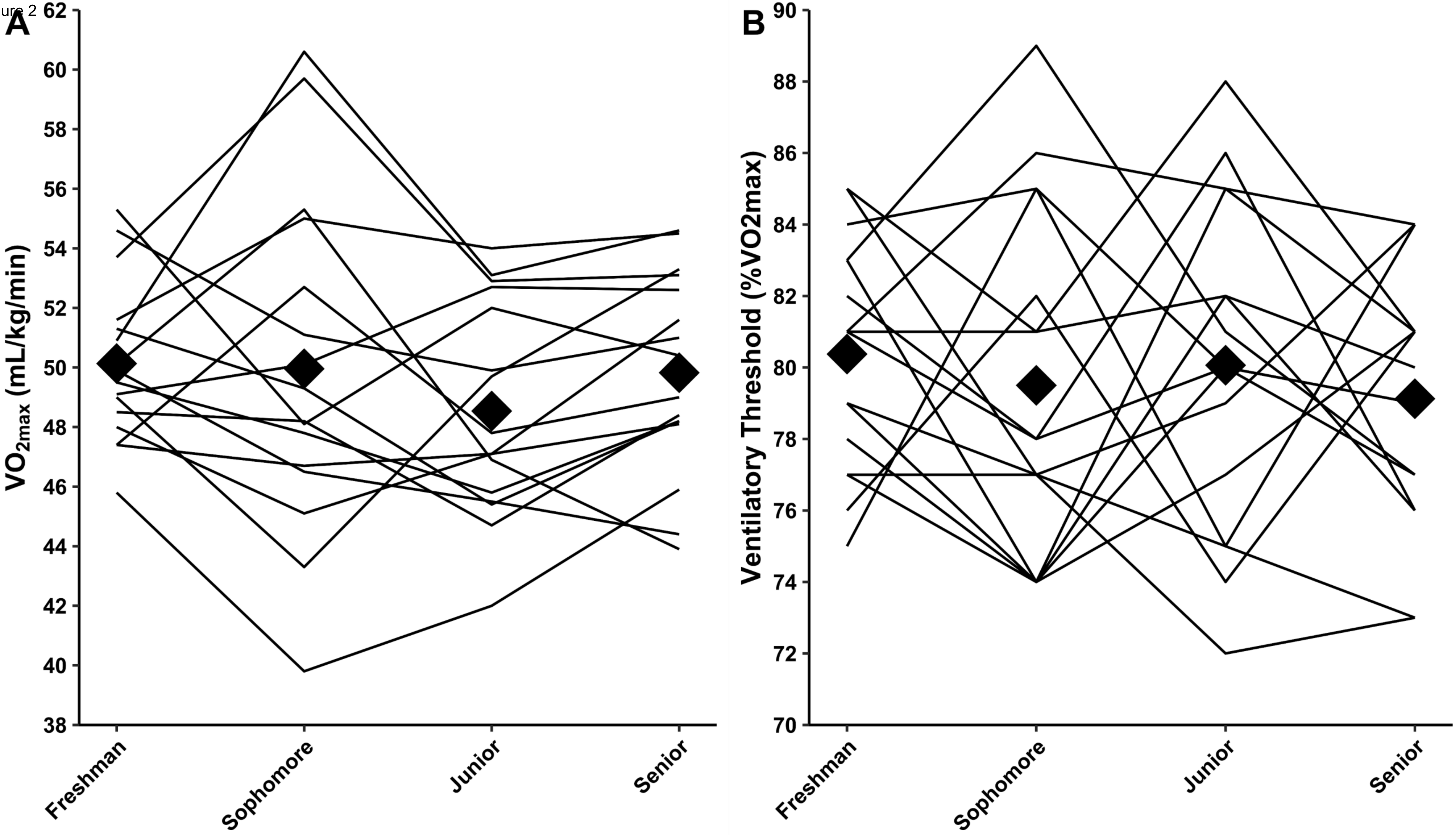
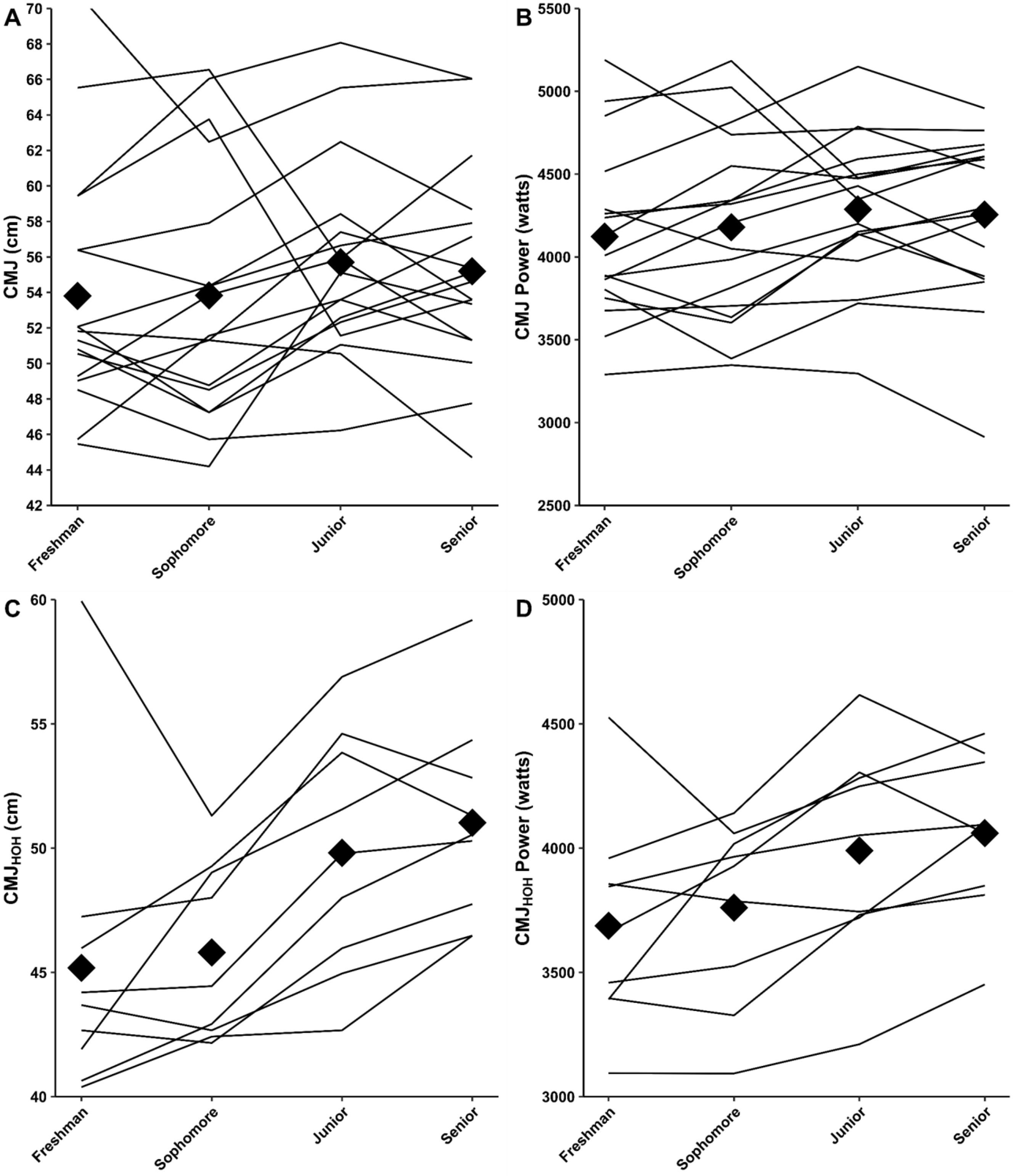

A
VO$_{2max}$ (mL/kg/min)
62
60
58
56
54
52
50
48
46
44
42
40
38
Freshman
Sophomore
Junior
Senior
B
Ventilatory Threshold (%VO2max)
90
88
86
84
82
80
78
76
74
72
70
Freshman
Sophomore
Junior
Senior

Figure 3


A
CMJ (cm)
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
Freshman
Sophomore
Junior
Senior
B
CMJ Power (watts)
5500
5000
4500
4000
3500
3000
2500
Freshman
Sophomore
Junior
Senior
C
CMJ_{HOH} (cm)
60
55
50
45
40
Freshman
Sophomore
Junior
Senior
D
CMJ_{HOH} Power (watts)
5000
4500
4000
3500
3000
Freshman
Sophomore
Junior
Senior