Trends in movement quality in US Military Academy cadets 2005-17: a JUMP-ACL study

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ABSTRACT

Objectives: This study seeks to determine if there were significant trends in lower extremity movement quality, as assessed by the Landing Error Scoring System (LESS) scores and plane-specific LESS subscales, across 12 recent cohorts of incoming USMA cadets.

Design: prospective cohort study.

Setting: United States Military Academy

Participants: 7,591

Main outcome measures: Landing Error Scoring System (LESS) scores, adjusted for sex and ACL injury history.

Results: Statistically significant inverse trends were found between total LESS score and year ($p<0.01$) and sagittal plane subscale and year ($p<0.01$). A statistically significant direct trend was found for the frontal/transverse plane subscale and year ($p<0.01$). However, each of these trends had a small associated effect size, and none were considered clinically meaningful.

Conclusions: There were no meaningful changes in lower extremity movement quality in incoming US Military Academy cadets between 2005 and 2017.

Highlights:

1. Stable movement quality in US Military Academy cadets in 12 recent years.
2. Movement quality stability is surprising in light of recent societal trends.
3. These data provide the largest sample of normative data for the LESS to date

Key words: lower extremity; Landing Error Scoring System (LESS); military; youth sport

INTRODUCTION

The Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) study is a large prospective cohort study examining lower extremity movement quality and injury risk factors in United States Military Academy at West Point (USMA) cadets. Between the years 2005 and 2017, a large sample from each incoming USMA cohort except one (2010) was enrolled and assessed for lower extremity movement quality using the Landing Error Scoring System (LESS).[1] During this period, there were substantial changes in activity levels,[1] sport specialization rates,[2,3] and rates of sports-related ACL injuries[4] among American youth, all of which may have influenced the aggregate lower extremity movement quality of incoming USMA cadets. Data from the JUMP-ACL study provide a unique opportunity to examine trends in lower extremity movement quality in a subset of American youth over this time period.

Substantial declines in several forms of physical activity among American youth occurred in the last decade of the 20th and first decade of the 21st centuries.[2] From 1991 to 2011, the percentage of American high school students participating in daily physical education classes decreased from 42% to 31%.[5] The percentage of time children ages 6 to 12 spent playing outdoors was reduced by 15% between 1997 and 2003, with similar trends noted among adolescents.[6] The period examined in these studies encompasses the childhood and adolescent years of USMA cadets enrolled in the JUMP-ACL study between the years 2005 and 2017. These downward trends in physical activity were postulated to be matched by reciprocal increases in sedentary behaviors, such as electronic device entertainment and motor vehicle transportation.[2] Between the years 1993 and 2006, Hsu et al. reported a significant increase in the proportion of overweight and obese individuals applying to enter the US military.[7] Decreased physical activity levels likely contributed to this obesity trend, suggesting similar declines in physical activity levels may have occurred among the subset of American youth interested in military service as was observed in the general population during this time period.

While the early 21st century saw a general decline in youth physical activity, an increase in sport specialization among American youth athletes also occurred.[8,9] Sport specialization is defined as "intense, year-round participation in a single sport, to the exclusion of other sports."[8] The percentage of American high school athletes practicing moderate or high sport specialization was estimated to be 65.2% in 2015,[10] with estimates of high specialization rates ranging from 28%-38% in other recently published studies.[3,10,11] Specialization in a single sport often entails a reduction in the types and planes of movements in which an athlete engages.[12] This lack of variety may alter movement patterns through muscle strength imbalances[12] or neuromuscular deficits,[13] and is associated with an increased risk of lower extremity injury.[14] Finally, increased rates of ACL injuries among American youth athletes,[15] particularly females[16,17] were present between 2005-2017.

Taken together, the findings of 1) decreased overall youth activity levels 2) increased rates of youth sport specialization, and 3) increased youth sport ACL injuries suggest a potential decline in lower extremity movement quality among American youth in the early 21st century. Determining if and how lower extremity movement quality changed over time is critical for informing the development of childhood physical activity interventions as well as programming to improve movement quality for immediate preparation of incoming military personnel for purposes of injury risk reduction. Therefore, the purpose of this study was to determine if there were significant trends in total LESS scores and plane-specific LESS subscales across 12 recent cohorts of incoming USMA cadets (2005-2017, excluding 2010 due to nonexistence of data). A secondary purpose was to describe normative values for the newly-defined plane-specific subscales of the LESS. We hypothesized that total LESS score and all plane-specific subscale scores would demonstrate significant degradation of lower extremity movement quality across the 12 cohorts, reflecting the societal trends outlined above.

METHODS

Participants

Cadets at the USMA volunteered to participate in the JUMP-ACL study in the years 2005-2017 with the exception of 2010, during which no participants were enrolled. Cadets were included if they completed 3 trials of the jump-landing task[18] and provided written informed consent for the study, which was approved by the [removed for blind review] institutional review board. Cadets who did not complete 3 trials of the LESS or did not provide written informed consent were excluded from this study.

The Landing Error Scoring System (LESS)

The LESS is a clinical screening tool for assessing risk of lower extremity injuries and consists of a simple count of landing technique "errors" on a range of readily observable items of human movement.[1] The LESS was originally developed to assess risk of ACL injury, thus every item is an aberrant motion, or movement "error" that is associated with an underlying mechanism of non-contact ACL injury.[19] The LESS has been found to have good intrarater and interrater reliability (intrarater ICC = 0.91, SEM 0.42; interrater 0.84, SEM 0.71),[1] as well as concurrent and predictive validity.[1,20-22] Differences in biomechanical variables in the frontal, sagittal, and transverse planes have been shown to exist between individuals with low and high LESS scores.[1] Total scores and frequencies of individual LESS test items have also been shown to vary systematically between individuals who subsequently incur an ACL injury[18,22] or lower extremity stress fracture[23,24] and those who do not.

The LESS is conducted using a box 30cm in height and two video camcorders. The cameras were set up at a 90-degree angle from one another. Tape was used to mark a distance on the floor a distance equal to 50% of each participant's height from the front of the box. Participants were instructed to jump forward off the box so that both feet left the box simultaneously, land on both feet just past the line of tape on the floor, and then to immediately perform a vertical jump for maximum height (Figure 1). Practice repetitions were performed, if desired by the participant (typically one or two were taken). No feedback or coaching about the participants' movement technique was provided during testing. The LESS consists of 17 items. Items 1-15 were scored as "absent" or "present" in binary (0/1) fashion, and items 16 and 17 were scored 0, 1, or 2, with 0 representing "excellent," 1 "average," and 2 "poor." All trials were scored by a rater trained in assessing the LESS. Items exhibited on the participant's dominant limb (i.e., limb used to kick a ball for maximal distance) for at least 2 of the trials were considered "present." Items 16 and 17 were graded 0 for "soft" or "excellent" landings, 1 for "average" landings, and 2 for "stiff" or "poor" landings, respectively.[18] A total LESS score was calculated by summing the number of items 1-15 marked "present" along with the scores of items 16 and 17.[18] In years 2015-17, scoring was completed using a depth camera (Microsoft® Kinect™ camera) and markerless motion capture software system (Physimax® (Physimax, Tel Aviv, Israel). This system utilizes a depth camera to capture full-body kinematics and processes these data using cloud-based technology and proprietary kinematic machine learning algorithms. These algorithms "extract, track, and dynamically refine virtual markers on each athlete's body" to assess dynamic motion.[25] In a study comparing performance of this system scoring the LESS against consensus expert scoring, it was found to have prevalence and bias adjusted kappa statistics (PABAK) of 0.71 ±0.27 averaged across all LESS items.[25]

Demographic Data

All participants enrolled in the JUMP-ACL study were asked to report their sex (female or male) and ACL injury history status: "have you ever had an Anterior Cruciate Ligament (ACL) injury?"

Statistical Analyses

power analysis

An *a priori* power analysis was conducted using nQuery Advisor™ software (Statistical Solutions Ltd, Cork, Ireland) using an estimated sample size of 6,000 participants, a multiple linear regression model adjusted for two covariates, and a conservatively estimated R^2 value of 0.01. This analysis yielded a power level greater than 99%.[26] Thus, this study was clearly sufficiently powered. Due to the high level of power determined in our power analysis, we believed it important to consider what value might represent a clinically meaningful change in LESS scores across the cohorts. While no minimally important difference (MID) has been calculated for the LESS, the standard error of the measurement (SEM) has been found to be less than one point (i.e. one test item)[1,19] and injury rates have been shown to differ significantly between groups one point apart in total LESS score.[23] It has also been suggested that due to the binary nature of most LESS items, a one point difference in total LESS score between two individuals indicates significant differences in biomechanical variables associated with injury risk.[1,18] Thus, any cumulative change greater than 1.00 (i.e. one LESS test item) across the 12 cohorts was considered a clinically meaningful change.

statistical analyses

All analyses were completed using SAS 9.4 software (SAS Institute Inc., Cary, NC). Descriptive statistics were calculated for total LESS score as well as frontal/transverse, sagittal, and plane-independent subscales. The frontal/transverse plane subscale was made up of the seven LESS items that occur uniquely in the frontal or transverse planes (Table 1) and was treated as a continuous variable. The sagittal subscale consists of eight LESS items that represent movements unique to the sagittal plane and was treated as a continuous variable. The plane-independent subscale consists of two items that are not unique to any single plane of movement and was treated as a three-level ordinal variable. Constituent items of each subscale were mutually exclusive. Descriptive statistics were also calculated for cohort year, sex, and ACL injury history.

Table 1. Landing Error Scoring System (LESS) subscales

Sagittal plane subscale		
LESS Item	**Plane**	**Type**
Knee Flexion at Initial Contact	Sagittal	Binary
Hip Flexion at Initial Contact	Sagittal	Binary
Trunk Flexion at Initial Contact	Sagittal	Binary
Ankle Plantarflexion at Initial Contact	Sagittal	Binary
Knee Flexion Displacement	Sagittal	Binary
Hip Flexion Displacement	Sagittal	Binary
Trunk Flexion Displacement	Sagittal	Binary
Overall Joint Displacement	Sagittal	Ordinal
Frontal/transverse plane subscale		
LESS Item	**Plane**	**Type**
Medial Knee Position at Initial Contact	Frontal	Binary

Lateral Trunk Flexion Angle at Initial Contact	Frontal	Binary
Wide Stance Width	Frontal	Binary
Narrow Stance Width	Frontal	Binary
Foot Position Externally Rotated	Transverse	Binary
Foot Position Internally Rotated	Transverse	Binary
Medial Knee Displacement	Frontal	Binary

Plane-independent subscale

LESS Item	Plane	Type
Asymmetrical Foot Contact	Independent	Binary
Overall Impression	Independent	Ordinal

Multiple linear regression analyses adjusted for sex, and ACL injury history were used to test for significant linear trends in total LESS score and the frontal/transverse and sagittal subscales. Sex was included as a covariate due to differences in total score and frequency of several LESS items that exist between the sexes, making adjustment for differences in the sex proportion of each cohort critical when analyzing overall trends.[1,27,28] We elected to adjust for history of ACL injury because LESS scores and item frequencies have been shown to differ significantly in those with a previous ACL injury compared to healthy controls.[29] Using the same rationale, multivariable logistic regression using a proportional odds model and table scores was adjusted for sex and ACL injury history to test for linear trends in the plane-independent subscale across the 12 cohorts. Non-parametric locally weighted scatterplot smoothing (LOESS) was also used to visually examine trends in total LESS score and each LESS subscale across the 12 cohorts.

RESULTS

Descriptive Statistics

The overall number of participants included in the study was 7,591. Eighty-seven participants were removed for having zero (n=75) or two (n=12) LESS trials. The number of participants in each cohort ranged from 131 in the 2011 cohort to 1,119 in the 2016 cohort (Table 2). The number of female participants was 1,925 (25.4%), with cohort percentages ranging from 14.1% (2012) to 50.5% (2009). The percentage of participants reporting a history of ACL injury was 4.3% (n=330) (Table 2; Figure 1). Complete demographic statistics are in Table 2. Total LESS scores ranged from 0 to 14 with a mean (SD) value of 4.99 (2.15) (Table 3). Complete descriptive statistics are in Table 3. Sagittal plane subscale scores ranged from 0 to 8 with a mean of 2.13 (1.40). The frontal/transverse subscale score ranged from 0 to 6 and had a mean of 1.67 (1.20). Plane-independent subscale scores ranged from 0 to 3 with a median value of 1.00. The proportion of participants reporting a history of ACL injury ranged from 2.3% (2011) to 6.2% (2008).

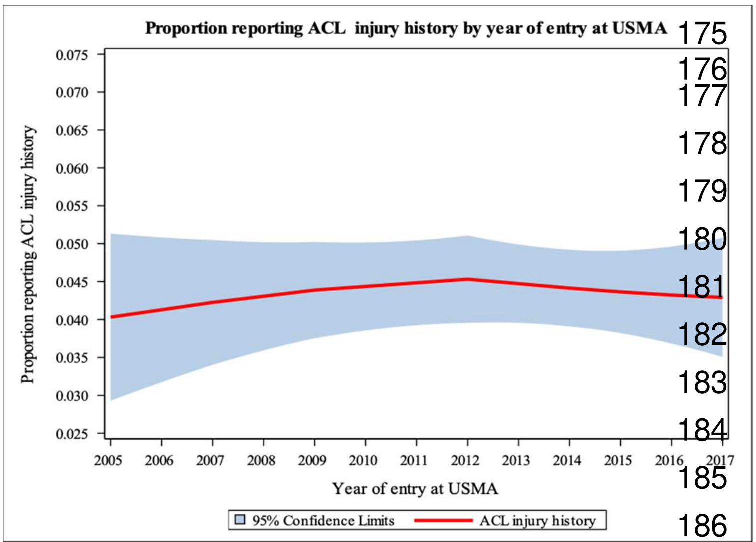

Figure 1. LOESS graph of proportion reporting ACL injury by cohort year. Reproduced with kind permission from [removed for blind review]

Table 2. Participant Demographics

Year of entry	n	%	Female	%	Male	%	History of ACL injury	%
2005	405	5.3%	129	31.9%	276	68.1%	12	3.0%
2006	474	6.2%	130	27.4%	344	72.6%	19	4.0%
2007	536	7.1%	191	35.6%	345	64.4%	22	4.1%
2008	405	5.3%	164	40.5%	241	59.5%	25	6.2%
2009	309	4.1%	156	50.5%	153	49.5%	14	4.5%
2010	---	---	---	---	---	---	---	---
2011	131	1.7%	24	18.3%	107	81.7%	3	2.3%
2012	597	7.9%	84	14.1%	513	85.9%	35	5.9%
2013	565	7.4%	81	14.3%	484	85.7%	23	4.1%
2014	944	12.4%	217	23.0%	727	77.0%	32	3.4%
2015	1113	14.7%	252	22.6%	861	77.4%	51	4.6%
2016	1119	14.7%	257	23.0%	862	77.0%	49	4.4%
2017	993	13.1%	240	24.2%	753	75.8%	45	4.5%
Total	**7591**	**100.0%**	**1925**	**25.4%**	**5666**	**74.6%**	**330**	**4.3%**

Table 3. Descriptive statistics

Year of entry	LESS* score	SD†	Sagittal subscale score	SD	Frontal/transverse subscale score	SD	Plane independent subscale score	SD
2005	5.61	2.39	3.13	1.61	1.24	1	1.24	0.6
2006	5.1	2.01	2.6	1.5	1.38	0.84	1.12	0.5
2007	4.75	1.92	2.8	1.27	0.84	0.91	1.11	0.58
2008	5.12	2.36	2.62	1.52	1.32	0.87	1.18	0.65
2009	7.93	1.94	2.27	1.47	4.35	0.87	1.3	0.52
2010	---	---	---	---	---	---	---	---
2011	5.02	2.15	1.64	1.34	2.06	1.09	1.32	0.61
2012	5.4	2.31	2.06	1.45	2	1.11	1.34	0.63
2013	5.42	2.21	1.93	1.29	2.15	1.1	1.33	0.63
2014	4.84	2.15	1.6	1.22	2	1.14	1.25	0.6
2015	4.36	1.95	1.91	1.26	1.29	1	1.17	0.5
2016	4.56	1.66	1.86	1.27	1.61	0.93	1.08	0.42
2017	4.94	1.78	1.92	1.16	1.44	0.91	1.13	0.49
Overall	4.99	2.15	2.13	1.4	1.67	1.2	1.19	0.55

univariable regression

Simple linear regression was completed utilizing cohort year as the explanatory variable and total LESS score and each continuous subscale score as the response variable. For each subsequent study year, total LESS score decreased by an average of 0.09 points (i.e. items) (β=-0.09, $p<0.01$) (Table 4; Figure 2). Similarly, the sagittal plane subscale score also significantly decreased. (β=-0.09, $p<0.01$). No changes were observed in the frontal/transverse plane subscale ($p=0.26$). Simple logistic regression utilizing a proportional odds model yielded an odds ratio estimate of 1.02 (95% CI: 1.01, 1.03, $p=0.01$) for the plane-independent subscale, suggesting that for each subsequent study year, plane-independent subscale scores increased by an average of 0.02 items. The unadjusted odds ratio for self-reported ACL injury history by cohort year was 1.00 (95% CI: 0.97, 1.02; $p=0.71$).

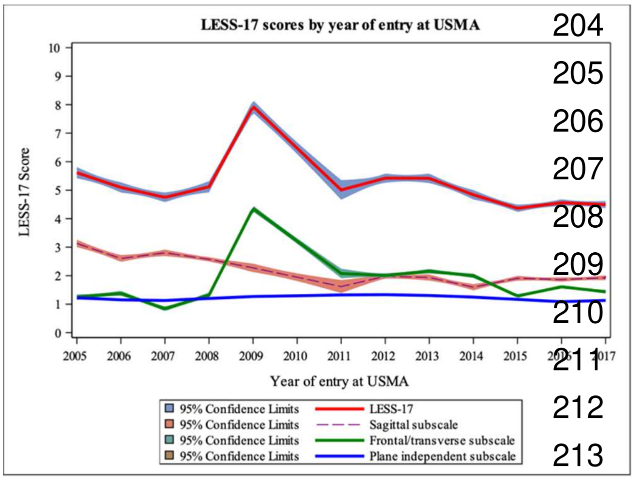

Figure 2. LOESS graph of LESS Variables by cohort year. Reproduced with kind permission from [removed for blind review]

Table 4. Crude and adjusted estimates for changes in Landing Error Scoring System (LESS) variables 2005-2017

	Unadjusted estimates			**Adjusted estimates***		
Variable	Parameter estimate	95% confidence interval	p-value	Parameter estimate	95% Confidence interval	p-value
Total LESS score	-0.09	-0.10, -0.08	<0.01	-0.08	-0.10, -0.07	p<0.01
Sagittal subscale score	-0.09	-0.10, -0.08	<0.01	-0.09	-0.10, -0.08	p<0.01
Frontal/transverse subscale score	0.004	-0.03, 0.01	p=0.26	0.01	0.01, 0.02	p<0.01
Plane independent subscale score†	1.02	1.01, 1.03	p=0.01	1.01	1.00, 1.02	p=0.17
ACL‡ injury history§	1.00	0.97, 1.02	p=0.71	0.99	0.97, 1.02	p=0.67

*adjusted for sex and ACL injury history
† represent odds ratio values obtained from logistic regression using a proportional odds model
‡ Anterior Cruciate Ligament
§ represent odds ratio values obtained from binary logistic regression model

multivariable regression

A multivariable linear regression model adjusted for sex and ACL injury history yielded a parameter estimate of -0.08 ($p<0.01$) for total LESS score, suggesting that for each subsequent year of the study, LESS scores decreased by 0.08 points, adjusted for sex and ACL injury history. The sagittal plane subscale had an estimate of -0.09 ($p<0.01$), and the frontal/transverse subscale had an estimate of 0.01 ($p=0.02$). Multivariable logistic regression utilizing a proportional odds model adjusted for sex and ACL injury history yielded an odds ratio estimate of 1.01 (95% CI: 1.00, 1.02, $p=0.17$) for the plane-independent subscale. The odds ratio for self-reported ACL injury history by cohort year, adjusted for sex, was 0.99 (95% CI: 0.97, 1.02; $p=0.71$).

DISCUSSION

This study is the largest to date examining LESS scores in any population. As such, it provides updated normative values for total LESS scores for each sex. This study is also the first to define and explore subscales of the LESS for potential clinical and research uses.

Mean total LESS scores obtained for all cohorts and both sexes were similar to values reported in previous studies.[1,27,28] There was an inverse relationship between the number of sagittal plane errors and cohort year, and a direct relationship between number of frontal/transverse plane errors and cohort year. However, despite demonstrating statistical significance, both of these associations were weak and neither parameter estimate had a 95% confidence interval with a value large enough to indicate a change greater than or equal to one point (LESS item) occurred during the study period (sagittal parameter estimate -0.09, 95% CI: -0.10, -0.08; frontal/transverse subscale parameter estimate 0.01, 95% CI: 0.01, 0.02) (Table 4). Trends in the plane independent subscale failed to achieve statistical significance (p=0.16 and p=0.78, respectively), and the parameter estimates of both subscales suggest that changes over the study period were minuscule.

The lack of any meaningful change in movement quality during the study period is remarkable in light of the societal trends in youth physical activity levels and sport specialization in recent years. We hypothesized that these trends would have an adverse effect on the lower extremity movement quality of American youth, including incoming cadets at USMA, and that such an influence would be detectable by a valid and reliable test of movement quality like the LESS. Though this study was sufficiently powered to detect such an effect, none was found. One potential reason for this discrepancy is that applicants to USMA may be significantly more likely to participate in diverse modes of physical activity and sports relative to their peers as recreation or in preparation for entry into the Academy. USMA has rigorous physical education and sport participation requirements and military service has fitness requirements that must be maintained at all times. These features likely motivate incoming cadets to engage in a variety of modes of exercise and may dissuade any less experienced or physically fit individuals from applying, leading to a self-selected group that may differ significantly in factors that affect movement quality and consequently LESS scores from their age-group peers. Additional studies should attempt to elucidate 1) if the patterns seen in USMA cadets in this study continue into the future 2) if these patterns occur in other military populations (e.g. individuals enlisting in the general Army) and 3) if these patterns appear in the general public.

The LOESS graphs generated provide great visual insight into trends in all response variables and covariates during the study period. Of particular interest is the spike in both total LESS score and frontal/transverse subscale scores in 2009 (Figure 2). These trends parallel a significant increase in the proportion of females during this year (50.5% female in 2009 versus overall average of 25.4%). Previous research has established that LESS composite scores tend to be greater in females[1,27,28] and that females demonstrate more errors in the frontal plane.[30] However, when LOESS graphs were created stratified on sex the noted trend appeared within females and males, respectively, suggesting that this trend was not driven by the proportion of females but by chance or some other factor unknown to the authors.

Strengths and limitations

There are several strengths and limitations to this study. Strengths include a large sample size and use of a reliable and valid assessment of movement quality to examine trends over time. The primary limitation of this paper is selection bias. Recruitment of participants was dependent on the cooperation of senior leadership at USMA. Due to a heavily congested schedule for incoming cadets, there was limited availability of cadets to participate in this study. Cadets in years 2005-2009 were recruited while waiting in line for additional screenings and interviews. As a part of a separate sub-study study in 2009, an effort was made to maximize the number of females in the sample. In 2011, as a part of another separate sub-study, only a small number of participants was recruited. In 2012, LESS testing was moved to coincide with the timing and location of the Army Physical Fitness Test (APFT) assessment, and as a result study participation increased dramatically. Taken together, these differing recruiting methods and goals over the years may have resulted in a selection bias. However, this is still the largest study to date to examine trends in movement quality in American youth.

Another significant limitation is the delineation of the construct of movement quality to the items on the LESS-17. We limited our analyses to those 17 movement patterns represented in the items LESS-17 because that was the only assessment of movement quality for which we had data for all years in the study period. However, we recognize that the construct of lower extremity movement quality extends beyond the limits of this assessment, and that there are several other valid assessments of lower extremity movement quality.

CONCLUSION

Lower extremity movement quality as assessed by the LESS was stable in incoming USMA cadets during the years 2005-2017. Minor decreases in total LESS score and sagittal plane subscale were observed, along with minor increases in frontal/transverse subscale score. However, these changes were not meaningful and resulted in estimated changes of less than one LESS item over the course of the study period. The findings of this study support the reliability and construct validity of the LESS through observed sex differences in total score and item frequencies.

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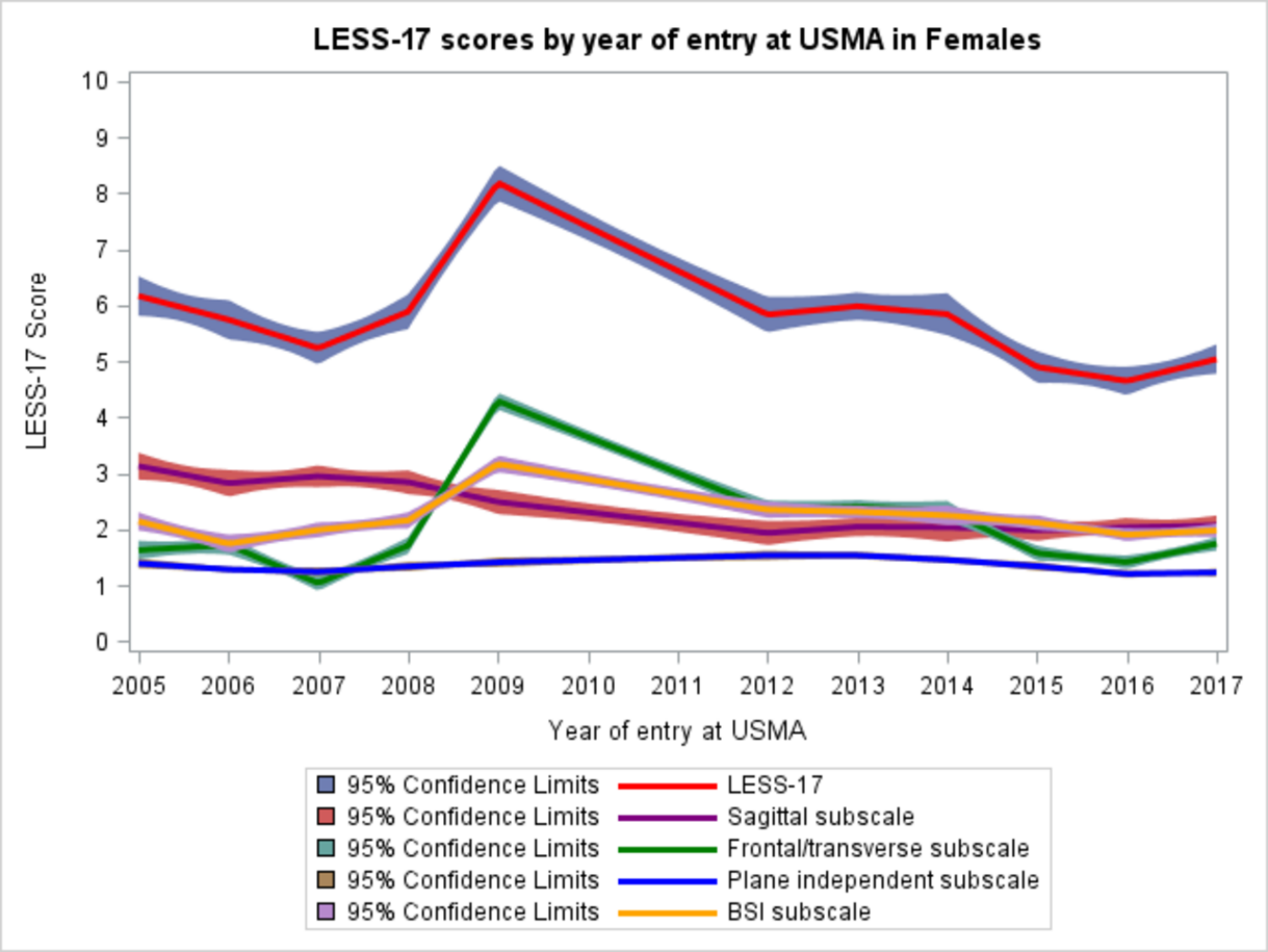
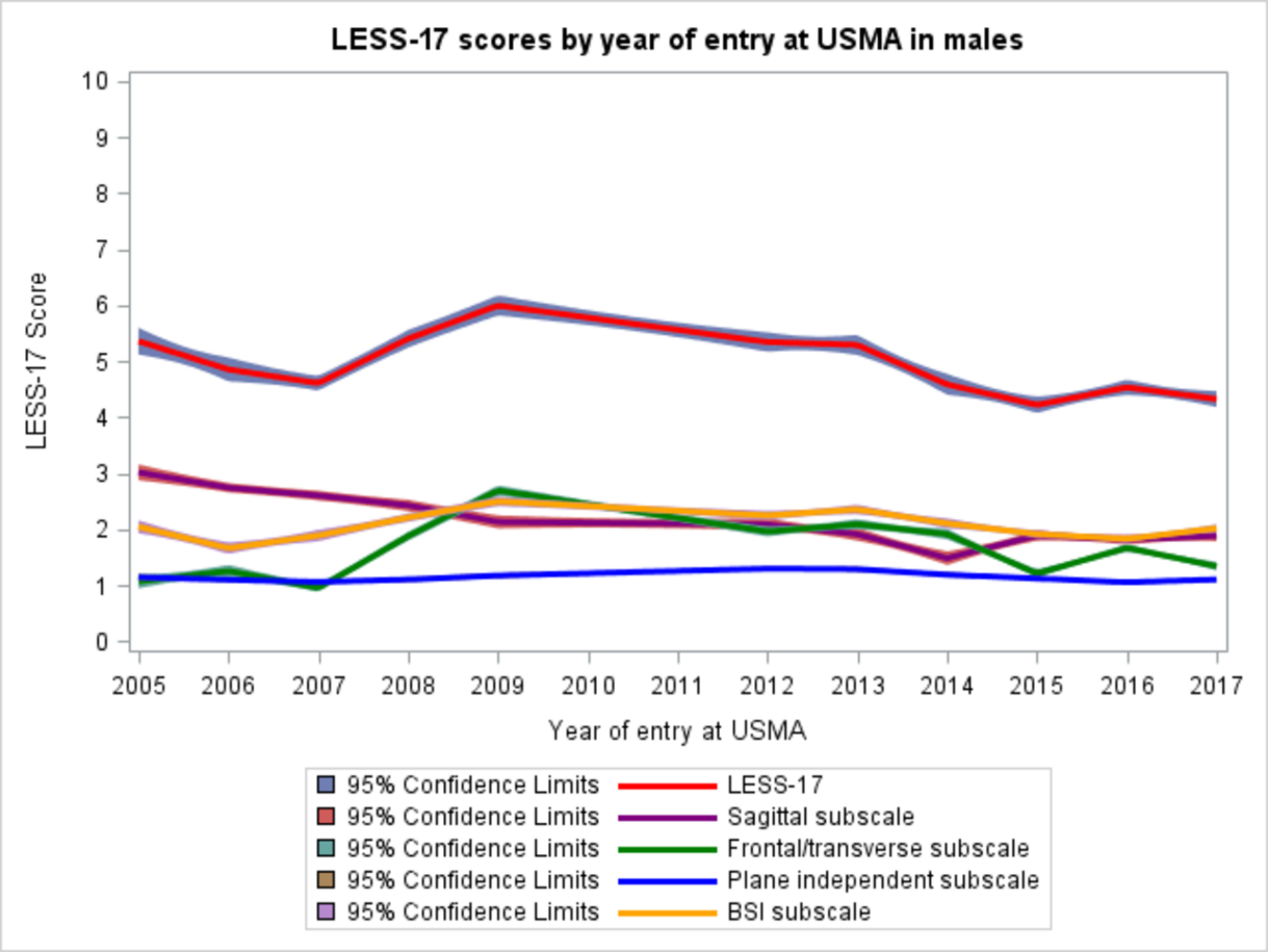

LESS-17 scores by year of entry at USMA in Females
LESS-17 Score
10
9
8
7
6
5
4
3
2
1
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year of entry at USMA
95% Confidence Limits
LESS-17
95% Confidence Limits
Sagittal subscale
95% Confidence Limits
Frontal/transverse subscale
95% Confidence Limits
Plane independent subscale
95% Confidence Limits
BSI subscale


LESS-17 scores by year of entry at USMA in males
LESS-17 Score
0
1
2
3
4
5
6
7
8
9
10
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year of entry at USMA
95% Confidence Limits
LESS-17
95% Confidence Limits
Sagittal subscale
95% Confidence Limits
Frontal/transverse subscale
95% Confidence Limits
Plane independent subscale
95% Confidence Limits
BSI subscale