Title

Cervical vertebrate characteristics as indicators of skeletal maturation near puberty

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Cervical Vertebrae Characteristics as Indicators of Skeletal Maturation near Puberty

Ross I. Mohr

Thesis

Submitted in partial satisfaction of the requirements for the degree of
Master of Science in Oral Biology
In the Graduate Division of the University of California, San Francisco

[redacted]

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I would like to thank Dr. Art Miller who spent many hours with me discussing thoughts on how to set up this study as well as keeping me focused in difficult times. I could not have completed this without his thoughtfulness. I will always appreciate Dr. Miller's constant positive and reassuring attitude.

Dr. Ib Nielsen has been an inspiration throughout my education at UCSF. He is truly an outstanding educator. His contribution to my education has proved invaluable not only in the clinic but also in the classroom with his vast knowledge of growth and development.

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Finally, I want to acknowledge the part-time faculty at UCSF, who selflessly devote their time and energy to orthodontic education. They made the residency a challenging and rewarding experience.

Abstract

Predicting the adolescent growth spurt is important to orthodontists as they influence growth in order to correct skeletal imbalances. Dentofacial orthopedics relies on growth alteration, but if the patient is past his/her adolescent growth spurt, the treatment plan must reflect this, and growth modification is no longer an option. Orthodontists are, therefore, interested in the youngster's stage of maturation so as to appropriately time treatment around the pubertal growth spurt.

Current guides for predicting the pubertal growth spurt include; chronologic age, the hand-wrist radiograph, and the cervical spine. Chronologic age has been shown to be a poor predictor of the pubertal growth spurt. The hand-wrist radiograph is a more accurate predictor than chronologic age, however, it requires an additional radiograph and added costs. The cervical spine may be a convenient alternative for staging skeletal maturation as it is present on a lateral cephalometric radiograph, which is part of a routine radiographic series in orthodontics.

In this study, we evaluated the stages of maturation in 15 female and 12 male subjects with longitudinal height measurements as well as lateral cephalometric radiographs taken at the same timepoints. Landmarks on the bodies of cervical vertebrae 2, 3, and 4 were identified on serial lateral cephalometric radiographs, and linear measurements of these landmarks were recorded.

The purpose of this study was to objectively evaluate the longitudinal morphologic changes of the cervical spine, and relate these changes to peak height velocity. The specific aims of this study were to: 1) evaluate the reproducibility of locating landmarks identified on the cervical vertebrae; 2) determine significant

morphologic changes on C2, C3, and C4, which act as predictors for the pubertal growth spurt; 3) determine the geometric shape changes of the bodies of C2, C3, and C4 based on linear measurements and ratios. The null hypothesis states that there is no correlation between objectively evaluated morphologic changes of the cervical vertebrae and peak height velocity in an adolescent sample.

The results indicate highly significant associations between morphologic characteristics of the cervical vertebrae and peak height velocity, although, there is large individual variability, leading to inaccuracy in predicting an individual's pubertal growth spurt prospectively.

Karin Vargervik

Karin Vargervik, DDS
Thesis Advisor

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I. Introduction

A. The Pubertal Growth Spurt – Methods of Assessment

Predicting the pubertal growth spurt is important to orthodontists who use growth modification to correct skeletal imbalances. Dentofacial orthopedic treatment relies on growth alteration and can only be effective if started before growth is complete. Significant time and effort have been devoted to describe physical maturation and many methods have been developed to assess stages of skeletal maturation. For instance, for many years pediatricians have used standardized growth curves to identify individuals that fall outside the normal range of growth either in timing or amount. Pubertal growth typically consists of an initial phase of acceleration, followed by a phase of deceleration, and growth completion with closure of epiphyses.[1]

Maturational indicators in relation to chronological age have been evaluated in several studies including: sexual maturation characteristics,[2-4] dental maturation,[5,6] height,[7] weight,[8] skeletal development,[9,10] and vertebral development.[11-14] It has also been shown that there is little correlation between age and early, average or late maturation.[15] Therefore, orthodontists cannot rely on the chronologic age of the patient, but instead needs to use skeletal indicators to predict stage of maturation for timing of dentofacial orthopedic intervention. Presently, hand-wrist radiographs, secondary sexual characteristics, and onset of menarche (in females) are used to determine individual maturational stages.[16] A hand-wrist radiograph has proven to be useful in determining stages of skeletal maturation,[10] but a disadvantage of the hand-wrist radiograph is that it adds additional cost and radiation.

The stage of development of the cervical spine of a patient has recently been proposed as an indicator of stage of skeletal maturation.[13,14] It has been shown that sequential morphologic changes occur on the body of the cervical vertebrae, which can be seen on the lateral cephalometric radiograph, routinely taken before orthodontic treatment as part of the orthodontic records.[11,13,14,17] Maturational stages, as seen on hand-wrist radiographs have been compared with cervical vertebrae characteristics, and it has been claimed that the cervical spine maturation stages are as reliable as the hand-wrist for assessing skeletal age.[18,19]

In most studies subjective criteria have been used to assess morphologic changes of cervical vertebrae bodies on longitudinal data with multiple time points for a single individual. The clinician, however, faces a different situation when determining the maturational stage of a patient, with only one available time point. In a majority of earlier studies, the staging methods have been based on subjective visual analysis, without actual quantitative measurement. Moreover, the progressions of the shape changes of the cervical vertebrae bodies during growth, which have been described in several publications, are not consistent in our sample.

Due to the limitations of previous studies, with respect to using subjective criteria for determining the stage of maturation of the cervical vertebrae, this project was designed to quantify the morphologic changes seen on the bodies of C1-4 and relate them to maximum height velocity and chronologic age.

B. Growth of the cervical vertebrae

Normal growth in body height is characterized by an acceleration of growth at puberty, after which growth gradually slows, and stops at the final adult height. Boys typically enter the growth spurt at about 11 years of age, girls at about 9 years of age. It was shown by Bench[20] in a longitudinal growth study of subjects 2-19 years of age that by the age of two, the morphology of the cervical vertebrae is already established. This has since been corroborated by Knutson,[21] who found that the position of the posterior surface of the vertebrae was established at a young age.

Growth of the cervical vertebral bodies 2-7, over a period ranging from newborn to 39 years of age was evaluated, and the authors showed that females had more square vertebral bodies then males in the age range of 7-14 years.[22] In subjects younger than 7 and between the ages of 15-18, the vertebral bodies were found to be similar in males and females with respect to the height and width ratios. Bick[23] demonstrated that longitudinal growth of the vertebrae bodies takes place by means of true epiphyseal cartilage plates, similar to the growth of long bones.

C. Vertebral Anatomy

The anatomy of the vertebrae may influence the identification of the landmarks and the recorded measurements on a two dimensional radiograph of the cervical spine.

Figure 1: Cervical vertebrae C2-C5 on a conventional lateral cephalometric radiograph.

Figure 1 shows the curved cortical outlines of the anterior and superior borders of the bodies of the vertebrae. Notice the posterior aspect of the bodies, and the superimposition of structures overlying the posterior superior junction of the bodies.

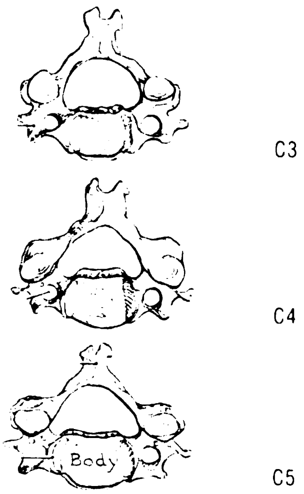

Figure 2: Superior aspects of the cervical vertebrae (Adapted from Williams and Wilkins with permission).

The above diagrams demonstrate the difficulty in accurately identifying the landmarks of the cervical spine. The spinous and transverse processes are located in a more lateral position on the cervical spine, creating structural superimposition of the posterior aspects of the bodies of the vertebrae, which makes point identification difficult. This is in contrast to the anatomy of other vertebrae, where the anatomy is more easily identified. Figure 3 is an example of the lumbar vertebrae. Note the different anatomy of the posterior aspect of the vertebral bodies of the lumbar vertebrae. Structural superimposition on a lateral radiograph in the lumbar region is much less of a problem since the spinous, and transverse processes are positioned more posteriorly and lateral.

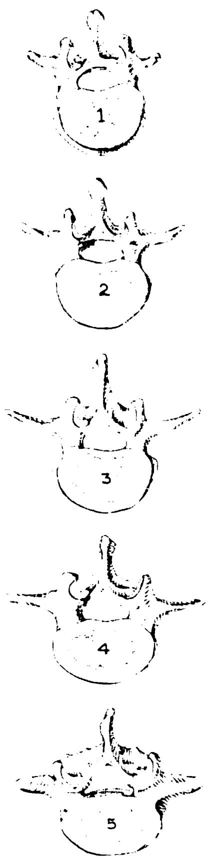

Figure 3: Note the well defined vertebral bodies of the lumbar vertebrae with transverse and spinous processes extending posteriorly creating less overlap from a lateral view (Adapted from Williams and Wilkins with permission).

Radiographic anatomy of the cervical spine was studied by Deluca and Rhea,[24] who identified which anatomic structures are actually superimposed. The authors disarticulated the anatomic components and imaged the same vertebral region with sequential addition of each structure to determine which structures contribute to superimposition. The authors concluded that as many as nine anatomical structures are superimposed on the posterior aspect of the bodies of the cervical spine. Their study illustrates the difficulties in reproducing anatomical landmarks in an objective cephalometric study of the cervical vertebrae.

D. Peak Height Velocity: The "Gold Standard" for Comparison

Our study is based on the findings of previous studies that have shown that the best method for determining the pubertal growth spurt is peak velocity in body height which, for the purpose of this study, is considered the "gold standard." The pubertal growth spurt and the appearance of secondary sex characteristics are the most visible manifestations of puberty.[1] Measuring annual growth in height has been recommended as a routine procedure in orthodontic cases treated over longer periods of time.[25] However, longitudinal height data provide information retrospectively whereas, predicting the growth spurt before treatment is started is more relevant to the clinician.[26]

E. Jaw Growth and Peak Height Velocity

Some studies refute that there is a well defined peak in mandibular growth that correlates to peak height velocity.[27,28] It is important to note that studies should evaluate mandibular growth at the condyle, and not by measuring the entire mandibular length, because certain linear changes may be masked by the influence of mandibular rotation and the associated surface apposition and resorption. This has been demonstrated by Franchi and coworkers,[29] who showed significant morphologic changes of the mandible during the growth interval concomitant with stage 3 to stage 4 in cervical vertebral maturation. They reported that an upward-forward directed condylar growth resulted in an overall "shrinkage" of the mandibular form along the measurement of total mandibular length. This biologic mechanism is particularly efficient in compensating for major increments in mandibular size during the adolescent growth spurt. Franchi and coworkers,[14] also detected that the greatest increment in mandibular and craniofacial growth occurred in the interval from cervical vertebrae stage 3 to stage 4 (Cvs3 to Cvs4), coinciding with peak velocity in statural height. Several studies have reported correlations between the peak pubertal growth spurt in height and the peak in jaw growth.[27,30-33] It has been shown by Hunter[28] that 57% of the maximum facial increments occur at the same time as the maximum growth in statural height. Another study reported that velocity growth curves of statural height to be the most useful aid for estimation of the growth expectation of the mandible.[34] Figure 4 demonstrates the relationship among condylar, sutural and height growth peaks in adolescent boys.[30] Bjork[30] found that during the adolescent growth spurt the increase in mandibular growth velocity is not as pronounced as that of body height, and that there is only a modest, though discernible, increase in growth at the sutures of the maxilla. As seen in Figure 4, there is a close association between peak growth velocity in body height, condylar growth and maxillary suture growth.

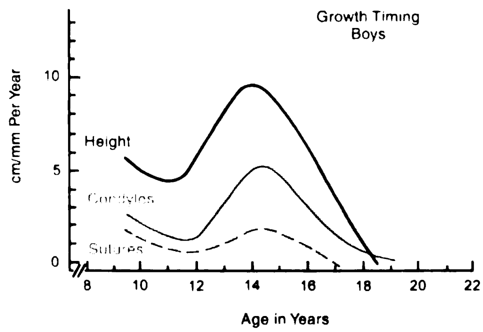

Figure 4: On average, the spurt in growth of the jaws occurs at about the same time as the peak in height. (Bjork, 1966, adapted with permission from The Angel Orthodontist)

F. Previous Studies

Morphologic changes in the cervical spine and the creation of skeletal stages based on these changes was the first proposed by Lamparski.[11] Comparing the changes with the hand-wrist method, he noted high correlations for predicting skeletal maturity.

Later, O'Reilly[35] studied the relationship of mandibular growth to the skeletal stages described by Lamparski, and found significant increases in mandibular length, corpus length, and ramus height associated with specific cervical maturation stages. Cervical vertebrae and hand-wrist maturation, as well as stature increments were then correlated in adolescent girls, confirming the validity of Lamparski's work.[36] Since then, two groups[13,17] have expanded on Lamparski's staging method and described the cervical vertebrae maturation stages (Cvs1-6) and cervical vertebrae maturation index (CVMI). Garcia-Fernandez[12] correlated the CVMI method with the hand-wrist SMI method (developed by Fishman[10]), further confirming the validity with statistically significant correlations between the CVMI method and the hand-wrist analysis for skeletal staging. Continuing their previous work, Baccetti and coworkers[13] were the first to objectively measure morphologic changes on cervical vertebrae 2, 3, and 4. The authors refined their previous staging method and reduced the number of skeletal stages from six to five, and renamed the method, "cervical vertebrae maturational stages I-V" (CVMS I-V).

G. Our rationale for using a quantitative method of evaluation

In studying the headfilms included in this study, it became clear that it would be difficult to categorize skeletal stages using the criteria from previous studies. The consistent progressions of morphologic changes described in the staging methods of previous studies were not consistent on our films. Many vertebrae did not fit well into the CVMI stages, and features common to different maturational stages were often noted in the same headfilm. This individual variability led us to describe the morphologic changes through quantitative analysis. Changes during growth of the cervical spine were evaluated, and points along C2, C3, and C4 were identified, digitized, and used to describe overall geometric changes. Linear measurements, as well as ratios, were developed to eliminate error created by magnification and also distortion due to head rotation in the cephalostat.

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The purpose of this study was to objectively evaluate the longitudinal morphologic changes of the cervical spine, and compare these changes at peak height velocity. The specific aims of this study were to: 1) evaluate the reproducibility of locating landmarks identified on the cervical vertebrae; 2) determine significant morphologic changes on C2, C3, and C4, which act as predictors for the pubertal growth spurt; 3) determine the geometric shape changes of the bodies of C2, C3, and C4 based on linear measurements and ratios. The null hypothesis states that there is no correlation between the objective morphologic changes of the cervical vertebrae and peak height velocity in an adolescent sample.

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II. Manuscript

A. Introduction

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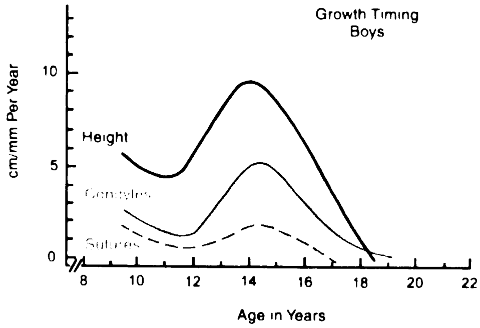

Figure 4: On average, the spurt in growth of the jaws occurs at about the same time as the peak in height. (Bjork, 1966, adapted with permission from The Angle Orthodontist)

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Our Rationale for Using a Quantitative Method of Evaluation

In evaluating the headfilms included in this study, it became clear that it would be difficult to categorize skeletal stages using the criteria from previous studies. The consistent progressions of morphologic changes described in the staging methods of previous studies were not consistent on our films. Many vertebrae did not fit well into the CVMI stages, and features common to different maturational stages were often noted in the same headfilm. This individual variability led us to describe the morphologic changes through quantitative analysis. Changes during growth of the cervical spine were evaluated, and points along C2, C3, and C4 were identified, digitized, and used to describe overall geometric changes. Linear measurements, as well as ratios, were developed to eliminate error created by magnification and also distortion due to head rotation in the cephalostat.

The purpose of this study was to objectively evaluate the longitudinal morphologic changes of the cervical spine, and compare these changes at peak height velocity. The specific aims of this study were to: 1) evaluate the reproducibility of locating landmarks identified on the cervical vertebrae; 2) determine significant morphologic changes on C2, C3, and C4, which act as predictors for the pubertal growth spurt; 3) determine the geometric shape changes of the bodies of C2, C3, and C4 based on linear measurements and ratios. The null hypothesis states that there is no correlation between the objective morphologic changes of the cervical vertebrae and peak height velocity in an adolescent sample.

B. Materials and Methods:

1. Sample, groupings and method of measurement

A sample of thirty male and female subjects was randomly drawn from one hundred individuals treated with functional appliances. All subjects had serial lateral cephalometric headfilms as well as height measurements taken at six month intervals at the Center for Craniofacial Anomalies at the University of California, San Francisco. Six subjects, 1 male 5 female, were randomly drawn from the sample of thirty patients for reliability measurements and error analyses. These six individuals were subjected to two different reliability measurement protocols at two month time intervals. Three of the subjects had only three timepoints, so they were removed from the initial sample of thirty patients as we felt the peak height velocity could not be determined accurately. The final sample consisted of twenty seven subjects, twelve males and fifteen females.

The lateral cephalometric head-films were scanned on an Epson "Expression" 1600 scanner (Epson America, Inc, Long Beach, CA) at the following settings: 8bit gray, 300 resolution, TPU for positive film. Brightness and contrast were then adjusted, and the headfilms were magnified for better visual analysis of the cortical outlines of the vertebral bodies. The scanned headfilms were subsequently analyzed on a 17" Samsung SyncMaster 760 V_{TFT} computer monitor (Samsung America, Inc. Ridgefield Park, NJ) set at 1280x1024 dpi. Using Photoshop 7.0(Adobe Systems Inc, San Jose, CA) measurement tool, linear distances on the cervical vertebrae were recorded.

2. Identification of peak height velocity

The percentage change in height velocity was calculated using the following formula: **Percent PHV per year = M2-M1/M1 x 100/Length of Time (in years)** This requires the height measurements at the beginning, M1, and end of the interval examined, M2, as well as the chronologic age of the individual when measurements were taken.

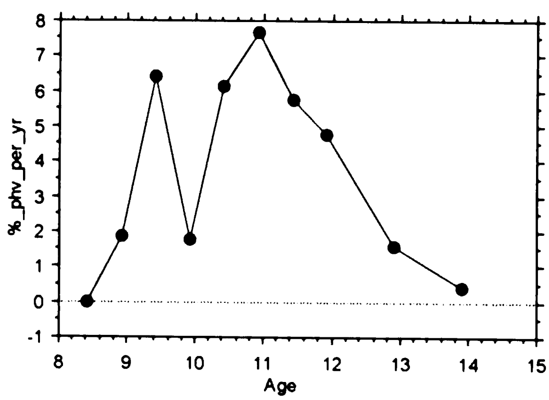

Figure 5: Percent peak height velocity for subject 520 from 8.5 to 14 years of age

Figure 5 illustrates the percentage change in height velocity for subject number 520 from the age of eight years six months, to age fourteen. This analysis was performed for each individual in order to identify the highest point on the velocity curve which was considered the peak height velocity for that patient.

3. Cervical Vertebrae Measurements

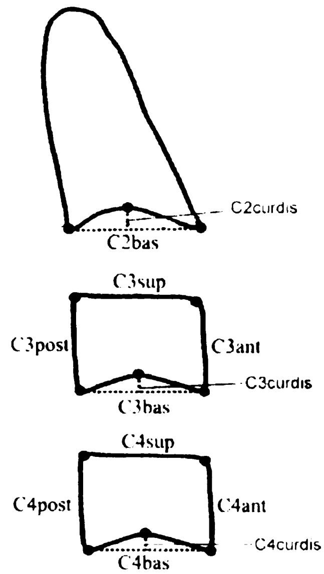

Figure 6: Points identified and linear measurements for C2, C3, and C4

As shown in Figure 6, three reference points were identified on C2, and five points on both C3 and C4. Identifying points on C2, C3, and C4 was difficult as the cortical outline of the vertebrae often were curved in the regions of interest. The more immature vertebrae tended to have curved outlines, especially at the junction of the anterosuperior borders. In instances when the corners of the vertebrae were curved, lines tangent to the side of interest were drawn, and the junctions bisected to locate a point on the curvature.

Locating the depth of the curvature of the vertebrae was accomplished by drawing a line connecting the most inferior points on the vertebrae. The deepest point on the curvature was then located visually, and a perpendicular line was drawn to the inferior border line. The curvature depth was recorded as the length of this perpendicular line. These linear distances were entered into a Microsoft Excel (Microsoft, Redman, WA) spreadsheet, and statistical analyses were performed. The variables are defined as follows:

1. **C2bas, C3bas and C4bas** - the inferior border widths of C2, C3 and C4.
2. **C2curdis, C3curdis and C4curdis** - the linear distance of the depth of the curvature on the inferior border of C2, C3, and C4 measured by a perpendicular from a line connecting the points on the inferior border to the deepest point on the curvature.
3. **C3post and C4post** - the posterior height of the body of C3 and C4.
4. **C3ant and C4ant** – the anterior height of the body of C3 and C4.

4. Ratios

In an attempt to objectively describe longitudinal geometric changes occurring on the vertebrae, ratios were calculated. The ratios used for statistical analysis include: 1) posterior/anterior height ratio (PAR) on C3 and C4; 2) and inferior base width/anterior height ratio (BAR) on C3 and C4. These are the same ratios used by Baccetti and collegues,[13] to objectively evaluate the cervical spine.

5. Statistical Analyses

a. Error of the Method

Reliability of measurements was calculated by comparing six subjects with two different methods of measurement at two month intervals. The first method consisted of hand measurements of the cervical vertebrae on acetate paper tracings, and the second method was completed using the Photoshop version 7.0 measurement tool. Bland-

Altman and Lin's Concordance were used to validate hand and computer measurements.

b. Variability of Anatomy

Descriptive statistics with means and standard deviations were computed on Statview 5.0 (SAS Institute, Cary, NC) and used to quantify the anatomical variation of C2, C3, and C4 at different ages.

c. Correlation of morphological changes to peak height velocity

All linear predictor variables were logarithmically transformed to reduce the influence of outlying observations, and to allow ratios to be formed naturally via linear combinations of the log transformed variables. Analyses were performed using Generalized Estimating Equations via the xtgee command in Stata, Version 7.0 (Stata Corporation, College Station, TX). This is a regression command that accommodates the repeated PHV times available for each subject. Models were determined by backward elimination in a guided fashion, starting with a model which included all the predictors, and eliminating non-statistically significant terms one at a time in an order guided by the previous literature.

C. Results

1. Error of the Method

As Table 1 shows, the most difficult measurements by hand were the base of the third cervical vertebrae (C3bas) and the designation of the depth of the curve in the second vertebra (C2curdis). In contrast to hand measurement, measurements off the computer had a higher concordance. There was strong agreement between both hand and computer measurements of the same position.

		Lin's Concordance	
	Hand vs. Hand	Hand vs. Comp	Comp vs. Comp
C2bas	0.900	0.728	0.846
C2curdis	0.576	0.728	0.961
C3post	0.799	0.925	0.976
C3ant	0.917	0.967	0.971
C3sup	0.748	0.691	0.875
C3bas	0.455	0.666	0.789
C3curdis	0.897	0.873	0.953
C4post	0.753	0.799	0.968
C4ant	0.753	0.976	0.987
C4sup	0.790	0.737	0.942
C4bas	0.701	0.658	0.718
C4curdis	0.843	0.892	0.985

Table 1 Lin's Concordance values for different methods of measurement: Hand = hand measurements, and comp = computer measurements

As Table 2 shows, no systematic bias was noted for any variables, since the means were close to zero and all the standard deviations contained the mean for both methods of measurement

	Hand vs. Hand		Hand vs. Comp		Comp vs. Comp	
C2bas	mean	-0.02	mean	-0.49	mean	-0.14
	SD	0.54	SD	0.86	SD	0.42
	mean+2SD	1.07	mean+2SD	1.22	mean+2SD	0.69
	mean-2SD	-1.11	mean-2SD	-2.22	mean-2SD	-0.98
C2curdis	mean	-0.04	mean	0.09	mean	-0.05
	SD	0.73	SD	0.62	SD	0.24
	mean+2SD	1.42	mean+2SD	1.34	mean+2SD	0.43
	mean-2SD	-1.50	mean-2SD	-1.15	mean-2SD	-0.54
C3post	mean	0.48	mean	-0.57	mean	-0.06
	SD	1.42	SD	0.67	SD	0.47
	mean+2SD	3.34	mean+2SD	0.78	mean+2SD	0.88
	mean-2SD	-2.36	mean-2SD	-1.93	mean-2SD	-1.01
C3ant	mean	0.33	mean	0.34	mean	-0.28
	SD	1.15	SD	0.65	SD	0.59
	mean+2SD	2.63	mean+2SD	1.64	mean+2SD	0.90
	mean-2SD	-1.96	mean-2SD	-0.96	mean-2SD	-1.47
C3sup	mean	-0.16	mean	0.41	mean	0.08
	SD	0.87	SD	0.85	SD	0.54
	mean+2SD	1.58	mean+2SD	2.12	mean+2SD	1.18
	mean-2SD	-1.90	mean-2SD	-1.29	mean-2SD	-1.01
C3bas	mean	-0.38	mean	-0.55	mean	-0.46
	SD	1.68	SD	0.91	SD	0.45
	mean+2SD	2.98	mean+2SD	1.26	mean+2SD	0.43
	mean-2SD	-3.75	mean-2SD	-2.38	mean-2SD	-1.37
C3curdis	mean	-0.14	mean	0.00	mean	-0.14
	SD	0.40	SD	0.47	SD	0.26
	mean+2SD	0.66	mean+2SD	0.95	mean+2SD	0.38
	mean-2SD	-0.94	mean-2SD	-0.95	mean-2SD	-0.67
C4post	mean	0.79	mean	-1.09	mean	0.01
	SD	1.62	SD	1.2	SD	0.52
	mean+2SD	4.03	mean+2SD	1.30	mean+2SD	1.06
	mean-2SD	-2.44	mean-2SD	-3.49	mean-2SD	-1.03
C4ant	mean	-0.58	mean	-0.29	mean	-0.11
	SD	1.93	SD	0.48	SD	0.39
	mean+2SD	3.27	mean+2SD	0.67	mean+2SD	0.67
	mean-2SD	-4.45	mean-2SD	-1.25	mean-2SD	-0.89
C4sup	mean	-0.09	mean	-0.05	mean	0.08
	SD	0.79	SD	0.83	SD	0.34
	mean+2SD	1.48	mean+2SD	1.60	mean+2SD	0.76
	mean-2SD	-1.68	mean-2SD	-1.72	mean-2SD	-0.6
C4bas	mean	0.05	mean	0.18	mean	-0.43
	SD	0.67	SD	0.67	SD	0.42
	mean+2SD	1.41	mean+2SD	1.53	mean+2SD	0.41
	mean-2SD	-1.30	mean-2SD	-1.16	mean-2SD	-1.27
C4curdis	mean	-0.17	mean	-0.08	mean	0.07
	SD	0.46	SD	0.42	SD	0.25
	mean+2SD	0.74	mean+2SD	0.76	mean+2SD	0.58
	mean-2SD	-1.10	mean-2SD	-0.92	mean-2SD	-0.43

Table 2: **Bland-Altman** evaluation for systematic bias between measurement methods. Hand = hand measurements and comp = computer measurements

2. Descriptive Statistics

In Figure 7, C2 showed little change in the base width, and a moderate amount of change in the curvature distance, increasing steadily over time. Note that, on average, a curvature was present on the inferior border of C2 as early as eight years of age. If one considers the variability of the curvature, there may or may not be curvature present on the base of C2 up to eleven years of age.

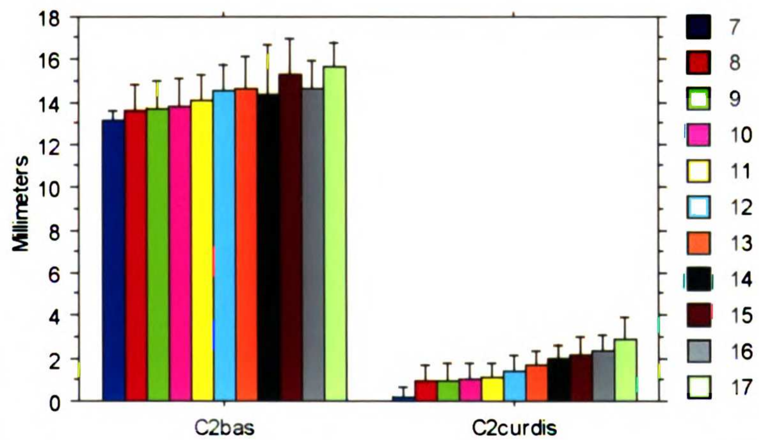

Figure 7: Bar chart of C2 base width and C2 curvature distance representing males and females from 7-17 years of age. Error bars = ± 1 standard deviation.

The most noteworthy change on C3 was the increase in the posterior and anterior border heights which confirm the results of previous publications that the cervical vertebrae tend to transform from a wedge, to horizontal rectangular shape, and finally a vertical rectangular shape near growth completion[12,17] (Figure 8). The curvature distance on C3 displays the largest transition in depth. Note the variability demonstrated by the standard deviation bars on the base curve distance on C3. On average, curvature was present by eight years of age and may or may not be present up to age twelve.

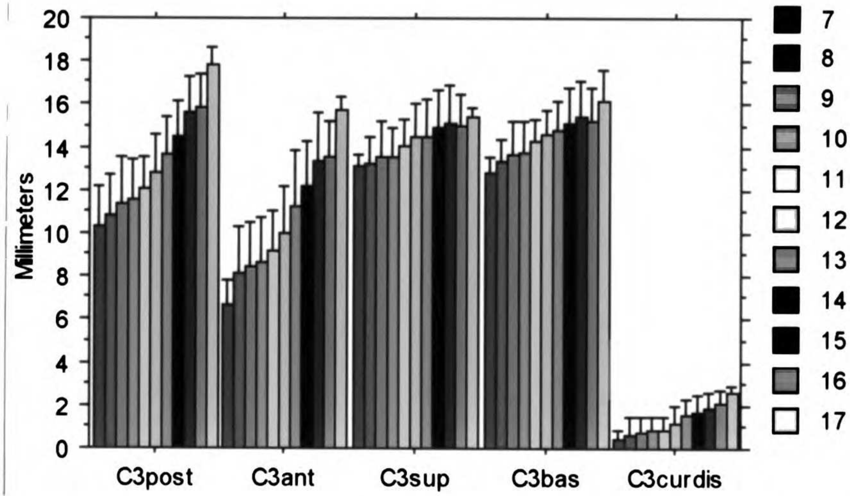

Figure 8: Bar chart of C3 posterior and anterior heights, superior width and base width as well as C3 curve distance representing males and females from 7-17 years of age. Error bars = ± 1 standard deviation.

The fourth cervical vertebra (Figure 9) shows similar changes to that of the third vertebra. The posterior and anterior borders demonstrate the greatest increases in size, with minimal changes seen on the superior and inferior borders. Curvature was again, on average, present by age eight, and showed much variability as to whether present or absent up to age thirteen.

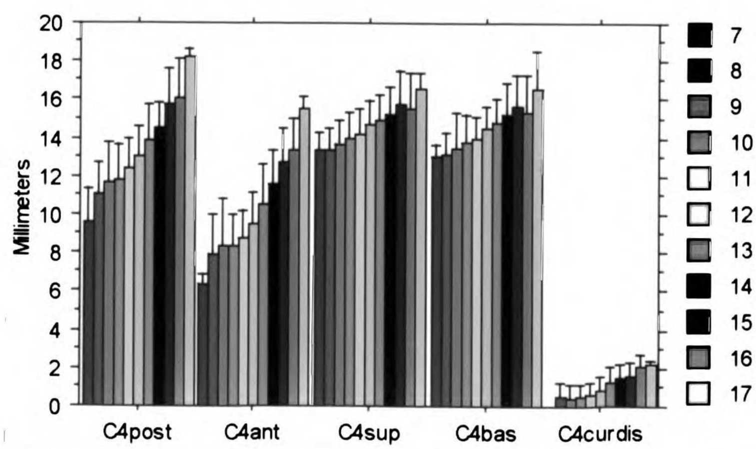

Figure 9: Bar chart of C4 posterior and anterior heights, superior width and base width as well as C4 curve distance representing males and females 7-17 years of age. Error bars = ± 1 standard deviation.

Figure 10 demonstrates the average longitudinal curvature distance change on C2, C3, and C4. Similar patterns are noted among all three vertebrae. Most notable are the large variations seen on the vertebrae with respect to chronologic age. C3 shows the greatest amount of change with the least variability, whereas C2 has the highest variability.

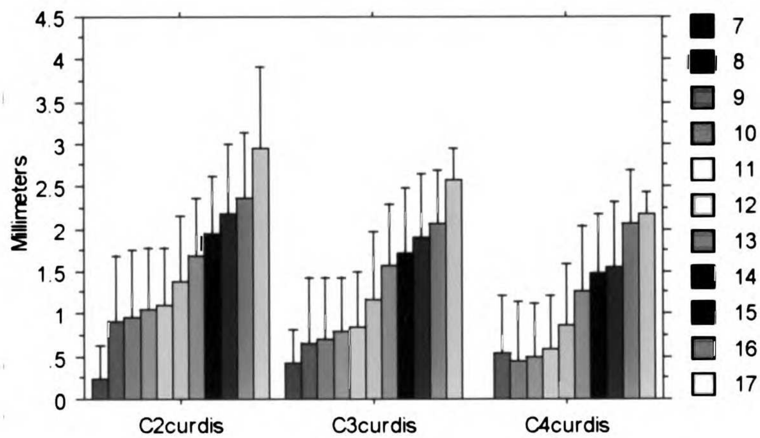

Figure 10: Male and Female C2, C3, and C4 base curve distances from 7-17 years of age. Error bars = ± 1 standard deviation.

3. Correlations of morphologic changes related to peak height velocity

The data had a normal distribution and, therefore, parametric statistics were used. There were no significant differences noted between males and females relative to skeletal age, shown by the equal gender distribution of data points shown in Figure 10. Based on this, the data were combined in the skeletal age models.

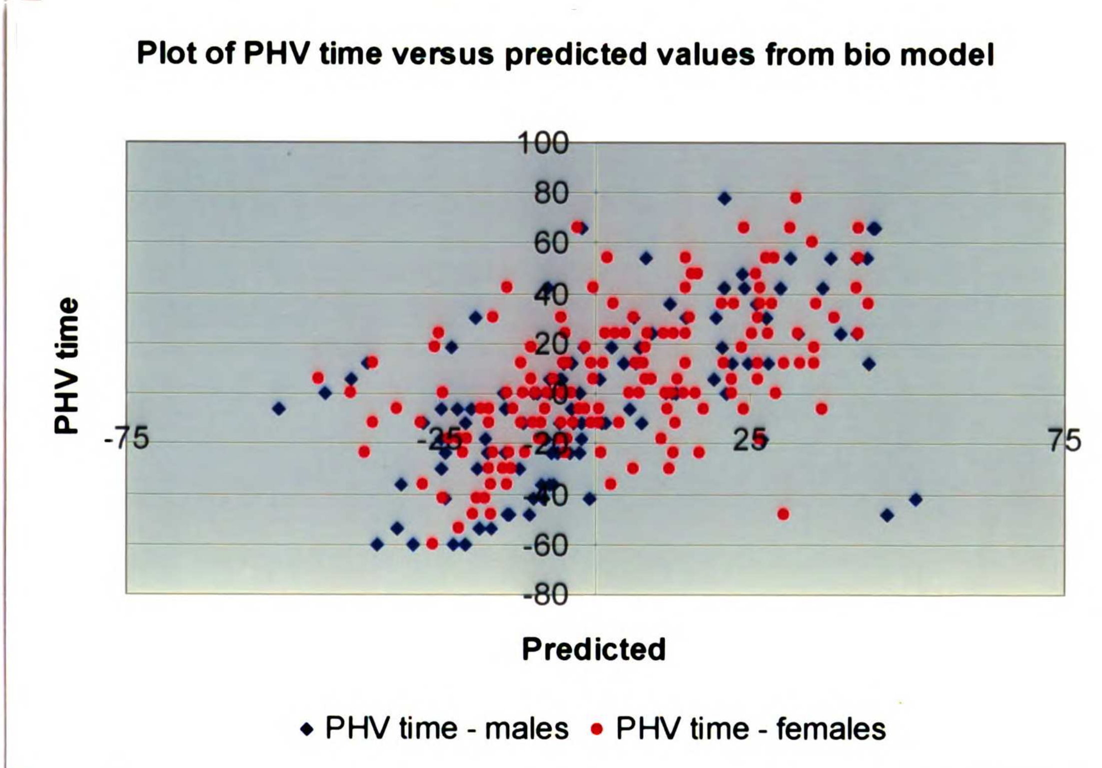

Figure 11: Plot of Peak Height Velocity time versus predicted values from biological model. This indicates a similar gender distribution so males and females were combined in skeletal age models. Bio model refers to the skeletal age model based on the cervical spine.

A difference was noted between male and female subjects in the chronologic age model. Females were, on average, about 9 months ahead of males in their predicted time-to-peak height velocity as shown in Figure 12.

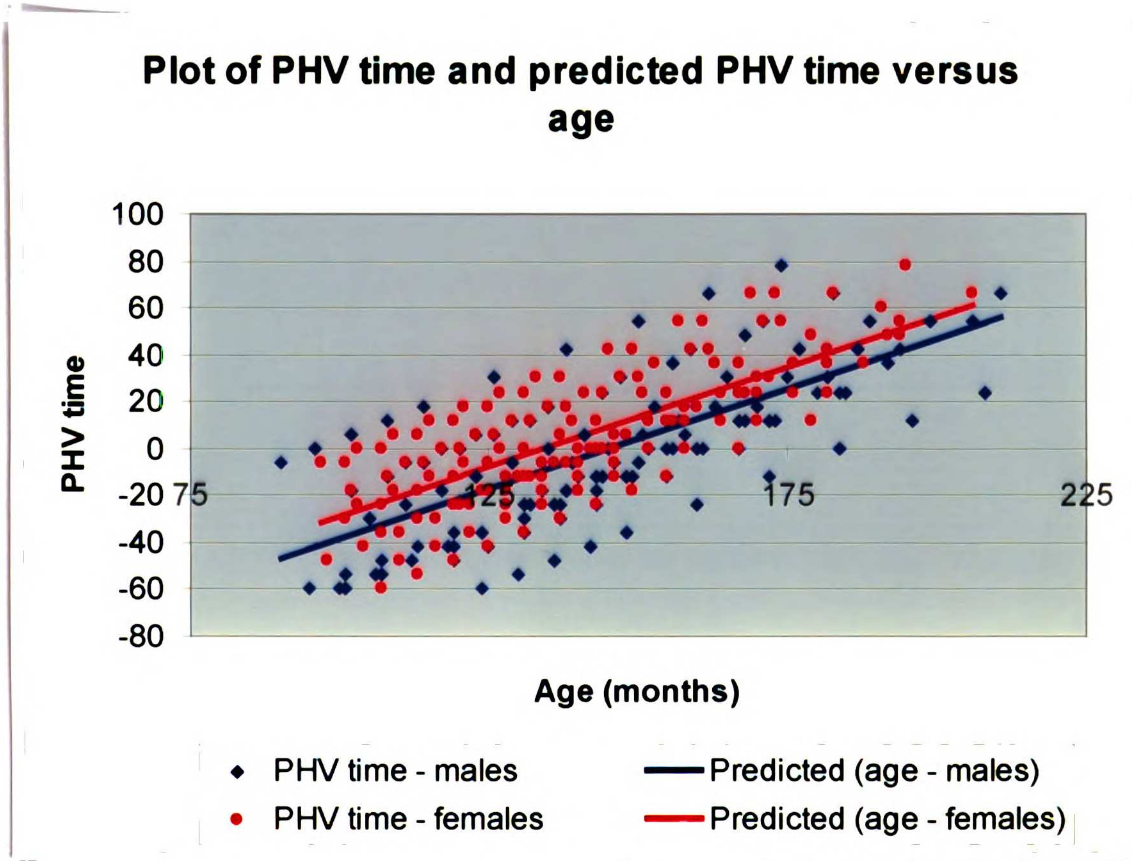

Figure 12: Plot of PHV time and predicted PHV time versus chronologic age for males and females. Females were 9 months ahead of males in reaching peak height velocity.

Three highly statistically significant variables were identified and chosen for inclusion into a time-to-peak height velocity prediction equation. The variables are shown in Table 3 and include: C4 posterior height, C3 curve distance, and C3BAR (base : anterior height ratio).

Table 3 Final prediction model

phvtime	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lc4post	**50.7865**	**12.66245**	4.01	**0.000**	25.96855	75.60445
lc3curd	**2.695161**	**.7852345**	3.43	**0.001**	1.156129	4.234192
lc3bar	**-44.93242**	**9.040711**	-4.97	**0.000**	-62.65189	-27.21295
_cons	-106.794	35.18377	-3.04	0.002	-175.7529	-37.83505

Lc4post = log of posterior height of C4, lc3curd = log of inferior curve distance of C3, lc3bar = log of base width : anterior height ratio of C3.

Table 3: Shows the final prediction model attained from a backwards stepwise regression with corresponding p-values. All predictors were highly statistically significant. The prediction equation generated from Table 3 is as follows:

-106.794 + 50.7865 x log (C4post) + 2.695161 x Log (C3curve distance) + 44.93242 x Log (C3BAR).

This equation can be used to predict a subject time to peak height velocity in months.

Table 4 – Correlation table

```
. pwcorr phvtime        predage predages predagesk predsk
```

	phvtime	predsk	predage	predages	predagesk	predsk
predage	**0.7255**	0.6940	1.0000			
predages	**0.7426**	0.7033	0.9771	1.0000		
predagesk	**0.7500**	0.7571	0.9673	0.9552	1.0000	
predsk	**0.5555**	0.9826	0.6685	0.7032	0.7407	1.0000

The last part of the name indicates which model the prediction came from: Chronologic age=age only, ages=age+sex, agesk=chronologic age+skeletal age variables, sk= skeletal age variables alone.

Table 4 shows correlation values (r) between different models and time-to-peak height velocity. The highest correlation value is chronologic age plus skeletal age. Chronologic age does better than skeletal age alone, chronologic age plus gender is about the same as chronologic age alone, and chronologic age plus the skeletal age variables are slightly better than chronologic age alone and about the same as chronologic age plus gender.

Table 5 – Mean absolute error of prediction models

```
. summ          aresidage aresidages aresidagesk aresidsk
```

Variable	Obs	**Mean**	Std. Dev.	Min	Max
aresidage	263	**16.87313**	12.02704	.0718884	48.59288
aresidages	263	**16.32848**	11.83535	.2701168	53.75716
aresidagesk	262	**15.84099**	12.12811	.0195589	51.19623
aresidsk	262	**20.39366**	15.28832	.0067158	87.92796

The last part of the name indicates which model the prediction came from: Chronologic age=age only, ages=age+sex, agesk=chronologic age+skeletal age variables, sk= skeletal age variables alone.

Table 5 shows the "mean absolute error of the prediction" models in months which may be a more tangible way to view the previous correlations. Skeletal age had the highest mean error which was roughly twenty months. In fact, chronologic age alone is a better predictor of peak height velocity than skeletal age (twenty months versus roughly seventeen months).

D. Discussion

This study evaluated longitudinal records of 27 individuals (twelve male and fifteen female) to quantify morphologic changes occurring on cervical vertebrae two, three and four during adolescence. The goals of the study included identification of cervical vertebrae points, reliability of locating the points, the objective assessment of morphologic changes associated with peak height velocity, and the use of these morphologic changes to predict peak height velocity.

1. Identification of points (landmarks)

The results indicate a high concordance for point identification of the cervical vertebrae. The measurements done by hand were less accurate than repeated computer measurements. This may be due to the fact that the computer allows adjustment of the headfilm to enhance the cortical outline of the vertebrae as well as the ability to view the regions of interest under magnification.

The linear measurements were validated not only by repeated measurements but also by utilizing two separate methods of evaluation, hand tracing as well as computer analysis. High concordance values were noted as well as no evidence of systematic bias between the two methods.

2. Assessment of morphologic change

Some of the findings of this study are consistent with results previously published that the main areas of change are the anterior and posterior borders of C3, and C4. In addition, the base curvatures appear to deepen over time. There seems to be a curvature present on C3, and C4 prior to reaching peak height velocity, which is not consistent with previous subjective staging methods.[14] One must take note of the large variability which may create problems in accuracy with this method of skeletal staging. For example, the inferior border of the bodies of second, third and fourth cervical vertebrae are supposed to be flat in a skeletally immature individual, and during maturation eventually become curved. The curvatures have been described to occur in a sequential manner forming first on C2, then C3, and finally C4. Evaluation of our data revealed significant variation, since often C3 appeared to have a curvature prior to C2. Variation from the described methods leads us to question the accuracy of the current published subjective methods, and the individual variability has not been discussed in these studies. It is possible that during the creation of the published staging methods, the investigators had the ability to evaluate multiple time points of a single patient side-by-side. This offers the advantage of following the growth a single individual over an extended period of time. This not only sensitizes the researcher to the subtle morphologic features present in any one stage, but also allows one to train their eyes to the features characteristic of the cervical vertebrae stages. The clinical situation is quite different, as the clinician may not have the training or the opportunity to compare multiple time points of his or her patients to determine the maturational stage.

3. Correlations

Several highly significant associations were found between morphologic changes of the cervical vertebrae and peak height velocity. The ultimate goal of the study was to identify the significant associations as well as the variability. The variables identified to be highly significant were two related to size: the posterior length of the fourth cervical vertebrae, and the depth of the curvature of the third cervical vertebrae, and one shape variable: the base:anterior ratio of the third cervical vertebrae. These significantly associated variables were used to create an equation to predict an individual's maturational level relative to peak height velocity. Even though high associations are present, the prediction equation proved to be of minimal value since we found chronologic age to be a better predictor of peak height velocity than the skeletal age based on the cervical spine analysis in this study.

E. Conclusion

Based on the findings of this study, one can conclude that there are significant associations among the cervical vertebrae morphologic characteristics and peak height velocity. We reject the null hypothesis that there is no correlation between the objective morphologic changes on the cervical vertebrae and peak height velocity in an adolescent sample. However, skeletal staging of the cervical spine may not be an accurate method for predicting peak height velocity since chronologic age alone was a more accurate predictor. The individual variability of the morphology of the cervical vertebrae makes predicting peak height velocity unreliable. Future work will evaluate the accuracy of our prediction equation in estimating the time-to-peak height velocity prospectively.

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III. Appendix

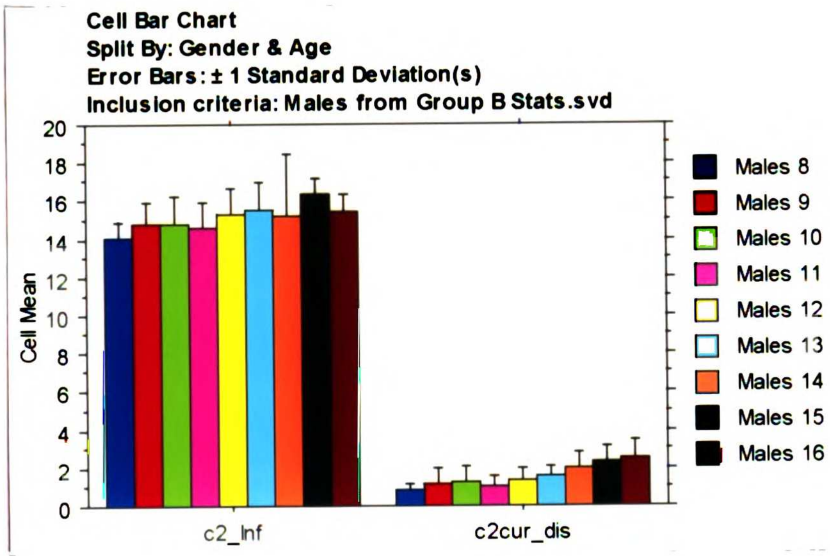


Figure 13

Descriptive Statistics
Split By: Gender & Age
Inclusion criteria: Males from Group B Stats.svd

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
c2_Inf, Total	15.022	1.582	.150	111	6.600	17.500	0
c2_Inf, Males 8	14.040	.811	.257	10	12.900	15.600	0
c2_Inf, Males 9	14.843	1.054	.282	14	12.800	16.500	0
c2_Inf, Males 10	14.757	1.466	.392	14	12.100	16.800	0
c2_Inf, Males 11	14.622	1.311	.309	18	12.300	17.100	0
c2_Inf, Males 12	15.313	1.335	.345	15	12.500	17.100	0
c2_Inf, Males 13	15.477	1.496	.415	13	12.000	17.400	0
c2_Inf, Males 14	15.180	3.231	1.022	10	6.600	17.500	0
c2_Inf, Males 15	16.325	.871	.308	8	14.600	17.200	0
c2_Inf, Males 16	15.425	.967	.484	4	14.700	16.800	0
c2cur_dis, Total	1.421	.872	.083	111	0.000	4.300	0
c2cur_dis, Males 8	.790	.398	.126	10	0.000	1.500	0
c2cur_dis, Males 9	1.114	.857	.229	14	0.000	3.600	0
c2cur_dis, Males 10	1.279	.852	.228	14	.600	4.000	0
c2cur_dis, Males 11	1.022	.495	.117	18	0.000	1.900	0
c2cur_dis, Males 12	1.307	.635	.164	15	0.000	2.400	0
c2cur_dis, Males 13	1.523	.603	.167	13	0.000	2.300	0
c2cur_dis, Males 14	1.990	.803	.254	10	0.000	2.700	0
c2cur_dis, Males 15	2.313	.786	.278	8	.700	3.000	0
c2cur_dis, Males 16	2.550	.843	.421	4	1.700	3.500	0

Results for totals may not agree with results for individual cells because of missing values for split variables.

Table 6

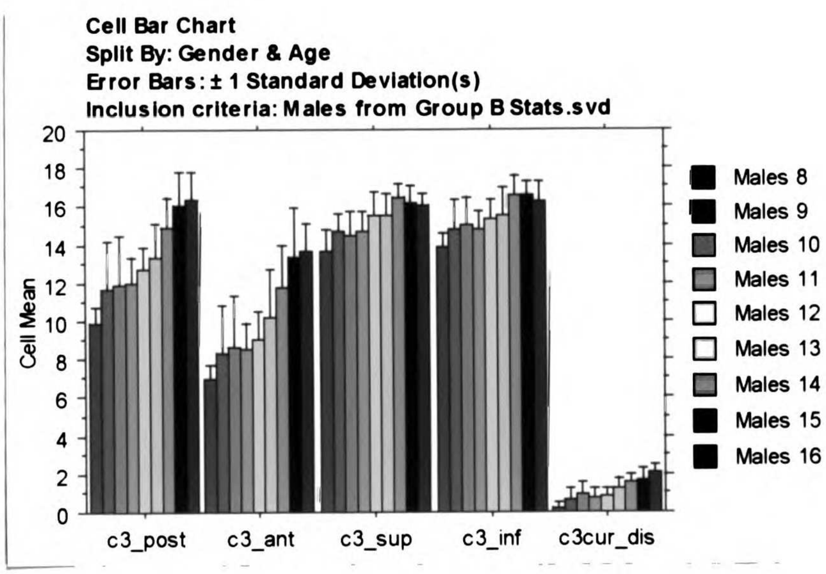


Figure 14

Descriptive Statistics
Split By: Gender & Age
Inclusion criteria: Males from Group B Stats.svd

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
c3_post, Total	12.828	2.582	.245	111	8.000	20.000	0
c3_post, Males 8	9.870	.887	.280	10	8.500	11.200	0
c3_post, Males 9	11.643	2.494	.667	14	9.400	19.700	0
c3_post, Males 10	11.886	2.547	.681	14	9.600	20.000	0
c3_post, Males 11	11.983	1.387	.327	18	10.000	15.700	0
c3_post, Males 12	12.700	1.196	.309	15	10.900	15.100	0
c3_post, Males 13	13.346	1.709	.474	13	11.300	17.400	0
c3_post, Males 14	14.850	1.595	.504	10	11.800	16.500	0
c3_post, Males 15	16.012	1.795	.635	8	13.100	18.500	0
c3_post, Males 16	16.400	1.421	.711	4	14.800	18.100	0
c3_ant, Total	9.624	2.862	.272	111	5.600	17.700	0
c3_ant, Males 8	7.030	.646	.204	10	6.200	8.200	0
c3_ant, Males 9	8.357	2.449	.655	14	6.400	16.500	0
c3_ant, Males 10	8.657	2.695	.720	14	6.600	17.700	0
c3_ant, Males 11	8.511	1.337	.315	18	6.900	12.600	0
c3_ant, Males 12	9.020	1.461	.377	15	7.300	12.600	0
c3_ant, Males 13	10.215	2.456	.681	13	7.300	16.200	0
c3_ant, Males 14	11.770	2.188	.692	10	7.700	14.900	0
c3_ant, Males 15	13.325	2.566	.907	8	10.200	17.000	0
c3_ant, Males 16	13.625	1.457	.728	4	12.300	15.600	0
c3_sup, Total	15.065	1.315	.125	111	11.500	17.700	0
c3_sup, Males 8	13.640	1.149	.363	10	12.100	15.900	0
c3_sup, Males 9	14.664	.951	.254	14	13.400	16.200	0
c3_sup, Males 10	14.471	1.262	.337	14	11.500	16.500	0
c3_sup, Males 11	14.661	1.053	.248	18	12.500	16.300	0
c3_sup, Males 12	15.487	1.237	.320	15	12.800	16.800	0
c3_sup, Males 13	15.469	1.183	.328	13	12.900	17.000	0
c3_sup, Males 14	16.420	.761	.241	10	15.300	17.300	0
c3_sup, Males 15	16.150	.906	.320	8	14.700	17.700	0
c3_sup, Males 16	16.050	.656	.328	4	15.300	16.600	0
c3_inf, Total	15.233	1.411	.134	111	12.200	18.700	0
c3_inf, Males 8	13.830	.747	.236	10	13.000	15.400	0
c3_inf, Males 9	14.807	1.506	.403	14	12.600	18.700	0
c3_inf, Males 10	14.971	1.452	.388	14	12.700	18.400	0
c3_inf, Males 11	14.828	.885	.209	18	13.100	15.900	0
c3_inf, Males 12	15.327	.992	.256	15	13.000	17.600	0
c3_inf, Males 13	15.538	1.465	.406	13	12.400	18.100	0
c3_inf, Males 14	16.530	1.056	.334	10	14.800	18.700	0
c3_inf, Males 15	16.538	.758	.268	8	15.200	17.500	0
c3_inf, Males 16	16.250	1.028	.514	4	15.000	17.500	0
c3cur_dis, Total	.995	.723	.069	111	0.000	2.900	0
c3cur_dis, Males 8	.200	.337	.106	10	0.000	.900	0
c3cur_dis, Males 9	.621	.603	.161	14	0.000	2.100	0
c3cur_dis, Males 10	.893	.693	.185	14	0.000	2.900	0
c3cur_dis, Males 11	.728	.531	.125	18	0.000	1.600	0
c3cur_dis, Males 12	.860	.427	.110	15	0.000	1.600	0
c3cur_dis, Males 13	1.231	.554	.154	13	0.000	2.200	0
c3cur_dis, Males 14	1.540	.462	.146	10	.800	2.100	0
c3cur_dis, Males 15	1.712	.554	.196	8	.700	2.300	0
c3cur_dis, Males 16	2.075	.395	.197	4	1.500	2.400	0

Results for totals may not agree with results for individual cells because of missing values for split variables.

Table 7

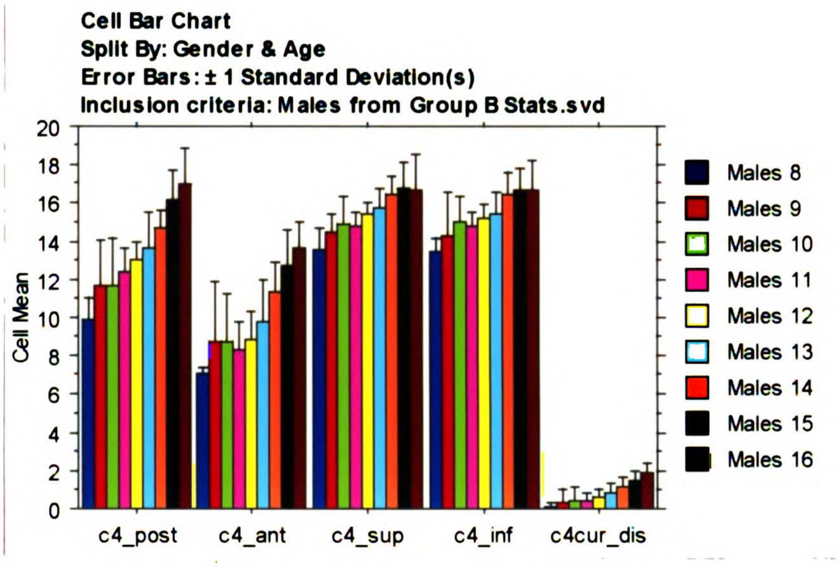

Cell Bar Chart
Split By: Gender & Age
Error Bars: ± 1 Standard Deviation(s)
Inclusion criteria: Males from Group B Stats.svd
Cell Mean
20
18
16
14
12
10
8
6
4
2
0
c4_post
c4_ant
c4_sup
c4_inf
c4cur_dis
Males 8
Males 9
Males 10
Males 11
Males 12
Males 13
Males 14
Males 15
Males 16

Figure 15

Descriptive Statistics
Split By: Gender & Age
Inclusion criteria: Males from Group B Stats.svd

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
c4_post, Total	12.936	2.592	.246	111	7.700	19.700	0
c4_post, Males 8	9.940	1.115	.353	10	8.300	12.000	0
c4_post, Males 9	11.621	2.483	.664	14	9.000	19.300	0
c4_post, Males 10	11.686	2.511	.671	14	9.100	19.700	0
c4_post, Males 11	12.350	1.297	.306	18	10.800	16.100	0
c4_post, Males 12	12.980	.935	.241	15	11.700	15.000	0
c4_post, Males 13	13.646	1.897	.526	13	11.100	18.300	0
c4_post, Males 14	14.650	.962	.304	10	12.800	15.700	0
c4_post, Males 15	16.125	1.614	.571	8	13.300	18.100	0
c4_post, Males 16	16.975	1.926	.963	4	15.000	19.000	0
c4_ant, Total	9.511	2.718	.258	111	5.800	17.800	0
c4_ant, Males 8	7.040	.403	.128	10	6.400	7.700	0
c4_ant, Males 9	8.786	3.139	.839	14	6.700	17.800	0
c4_ant, Males 10	8.721	2.541	.679	14	7.000	17.300	0
c4_ant, Males 11	8.383	1.446	.341	18	6.800	13.300	0
c4_ant, Males 12	8.900	1.446	.373	15	7.300	12.700	0
c4_ant, Males 13	9.815	2.129	.590	13	7.600	15.700	0
c4_ant, Males 14	11.310	1.652	.522	10	8.400	13.600	0
c4_ant, Males 15	12.687	1.890	.668	8	9.600	14.300	0
c4_ant, Males 16	13.600	1.374	.687	4	12.300	15.500	0
c4_sup, Total	15.214	1.402	.133	111	12.100	19.400	0
c4_sup, Males 8	13.560	1.099	.347	10	12.100	15.400	0
c4_sup, Males 9	14.464	1.002	.268	14	13.300	16.300	0
c4_sup, Males 10	14.893	1.417	.379	14	12.400	17.700	0
c4_sup, Males 11	14.761	.807	.190	18	13.000	16.100	0
c4_sup, Males 12	15.380	.632	.163	15	13.800	16.100	0
c4_sup, Males 13	15.700	1.067	.296	13	13.800	17.100	0
c4_sup, Males 14	16.430	.920	.291	10	14.700	17.700	0
c4_sup, Males 15	16.800	1.288	.456	8	14.700	18.100	0
c4_sup, Males 16	16.650	1.845	.922	4	15.500	19.400	0
c4_inf, Total	15.149	1.582	.150	111	8.100	19.300	0
c4_inf, Males 8	13.440	.756	.239	10	12.600	14.700	0
c4_inf, Males 9	14.286	2.305	.616	14	8.100	19.100	0
c4_inf, Males 10	14.993	1.312	.351	14	13.300	18.800	0
c4_inf, Males 11	14.794	.695	.164	18	13.500	16.100	0
c4_inf, Males 12	15.260	.694	.179	15	14.000	16.700	0
c4_inf, Males 13	15.400	1.120	.311	13	13.000	16.900	0
c4_inf, Males 14	16.490	1.098	.347	10	15.100	18.500	0
c4_inf, Males 15	16.650	1.196	.423	8	15.300	19.100	0
c4_inf, Males 16	16.675	1.595	.797	4	15.400	18.700	0
c4cur_dis, Total	.698	.708	.067	111	0.000	2.500	0
c4cur_dis, Males 8	.110	.233	.074	10	0.000	.600	0
c4cur_dis, Males 9	.336	.663	.177	14	0.000	2.300	0
c4cur_dis, Males 10	.450	.706	.189	14	0.000	2.500	0
c4cur_dis, Males 11	.411	.464	.109	18	0.000	1.600	0
c4cur_dis, Males 12	.620	.443	.114	15	0.000	1.300	0
c4cur_dis, Males 13	.862	.504	.140	13	0.000	2.100	0
c4cur_dis, Males 14	1.170	.548	.173	10	0.000	1.800	0
c4cur_dis, Males 15	1.475	.456	.161	8	.800	2.100	0
c4cur_dis, Males 16	1.925	.465	.232	4	1.300	2.400	0

Results for totals may not agree with results for individual cells because of missing values for split variables.

Table 8

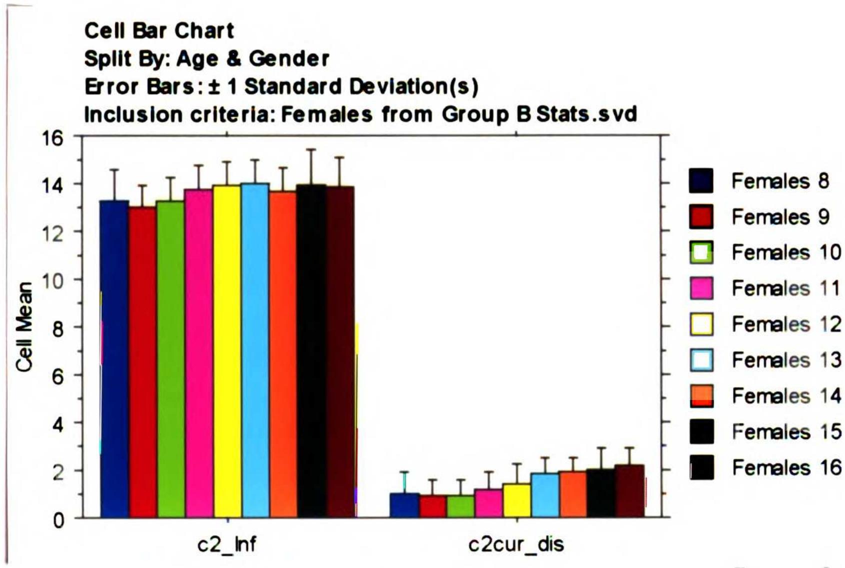


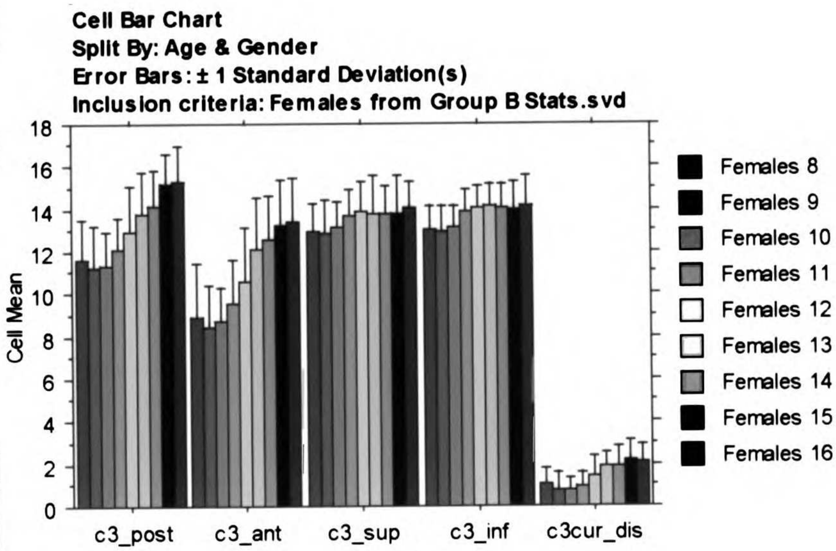
Figure 16

Descriptive Statistics
Split By: Age & Gender
Inclusion criteria: Females from Group B Stats.svd

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
c2_Inf, Total	13.563	1.072	.086	155	11.200	15.700	0
c2_Inf, Females 8	13.236	1.345	.360	14	11.200	15.500	0
c2_Inf, Females 9	13.039	.876	.183	23	11.800	15.300	0
c2_Inf, Females 10	13.256	.993	.191	27	11.900	15.500	0
c2_Inf, Females 11	13.725	1.023	.193	28	11.900	15.700	0
c2_Inf, Females 12	13.955	.927	.198	22	12.200	15.300	0
c2_Inf, Females 13	13.969	1.071	.268	16	12.100	15.600	0
c2_Inf, Females 14	13.692	.941	.261	13	12.000	14.800	0
c2_Inf, Females 15	13.917	1.504	.614	6	11.700	15.200	0
c2_Inf, Females 16	13.800	1.252	.626	4	12.400	15.000	0
c2cur_dis, Total	1.292	.854	.069	155	0.000	3.100	0
c2cur_dis, Females 8	1.014	.938	.251	14	0.000	2.900	0
c2cur_dis, Females 9	.883	.737	.154	23	0.000	2.900	0
c2cur_dis, Females 10	.926	.630	.121	27	0.000	1.900	0
c2cur_dis, Females 11	1.146	.785	.148	28	0.000	2.700	0
c2cur_dis, Females 12	1.423	.868	.185	22	0.000	2.500	0
c2cur_dis, Females 13	1.838	.703	.176	16	.600	2.700	0
c2cur_dis, Females 14	1.892	.605	.168	13	.900	2.700	0
c2cur_dis, Females 15	2.017	.889	.363	6	.900	2.900	0
c2cur_dis, Females 16	2.175	.763	.382	4	1.500	3.100	0

Results for totals may not agree with results for individual cells because of missing values for split variables.

Table 9


Cell Bar Chart
Split By: Age & Gender
Error Bars: ± 1 Standard Deviation(s)
Inclusion criteria: Females from Group B Stats.svd
Cell Mean
18
16
14
12
10
8
6
4
2
0
c3_post
c3_ant
c3_sup
c3_inf
c3cur_dis
Females 8
Females 9
Females 10
Females 11
Females 12
Females 13
Females 14
Females 15
Females 16
Figure 17

Descriptive Statistics
Split By: Age & Gender
Inclusion criteria: Females from Group B Stats.svd

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
c3_post, Total	12.490	2.153	.173	155	8.500	18.300	0
c3_post, Females 8	11.586	1.946	.520	14	8.600	14.400	0
c3_post, Females 9	11.257	1.981	.413	23	8.700	16.400	0
c3_post, Females 10	11.344	1.560	.300	27	8.500	14.600	0
c3_post, Females 11	12.129	1.511	.285	28	9.200	16.400	0
c3_post, Females 12	12.895	2.154	.459	22	10.200	18.300	0
c3_post, Females 13	13.800	1.944	.486	16	11.100	17.200	0
c3_post, Females 14	14.177	1.672	.464	13	11.800	16.500	0
c3_post, Females 15	15.150	1.460	.596	6	12.800	17.100	0
c3_post, Females 16	15.250	1.702	.851	4	13.000	16.800	0
c3_ant, Total	10.108	2.664	.214	155	5.500	18.300	0
c3_ant, Females 8	8.950	2.530	.676	14	5.900	14.100	0
c3_ant, Females 9	8.413	2.001	.417	23	5.500	14.800	0
c3_ant, Females 10	8.696	1.607	.309	27	6.200	14.100	0
c3_ant, Females 11	9.532	2.077	.393	28	6.500	15.800	0
c3_ant, Females 12	10.627	2.496	.532	22	7.600	18.300	0
c3_ant, Females 13	12.081	2.467	.617	16	8.900	17.600	0
c3_ant, Females 14	12.538	2.070	.574	13	8.600	15.200	0
c3_ant, Females 15	13.250	2.159	.882	6	9.800	15.700	0
c3_ant, Females 16	13.375	2.076	1.038	4	11.500	15.800	0
c3_sup, Total	13.441	1.436	.115	155	10.500	18.100	0
c3_sup, Females 8	12.943	1.317	.352	14	11.400	16.400	0
c3_sup, Females 9	12.874	1.583	.330	23	10.500	18.100	0
c3_sup, Females 10	13.096	1.212	.233	27	10.900	15.300	0
c3_sup, Females 11	13.654	1.250	.236	28	11.400	15.600	0
c3_sup, Females 12	13.832	1.460	.311	22	11.000	16.600	0
c3_sup, Females 13	13.756	1.808	.452	16	10.800	16.300	0
c3_sup, Females 14	13.746	1.302	.361	13	11.700	15.900	0
c3_sup, Females 15	13.817	1.716	.701	6	11.500	16.000	0
c3_sup, Females 16	14.025	1.282	.641	4	12.300	15.000	0
c3_inf, Total	13.608	1.169	.094	155	10.800	15.800	0
c3_inf, Females 8	13.029	1.129	.302	14	10.900	14.600	0
c3_inf, Females 9	12.922	1.208	.252	23	10.900	15.700	0
c3_inf, Females 10	13.152	.969	.187	27	10.800	15.000	0
c3_inf, Females 11	13.829	1.071	.202	28	10.800	15.600	0
c3_inf, Females 12	14.068	1.042	.222	22	11.800	15.700	0
c3_inf, Females 13	14.119	1.068	.267	16	11.500	15.500	0
c3_inf, Females 14	14.054	1.106	.307	13	11.500	15.400	0
c3_inf, Females 15	13.967	1.279	.522	6	11.600	15.400	0
c3_inf, Females 16	14.200	1.349	.675	4	12.500	15.800	0
c3cur_dis, Total	1.200	.907	.073	155	0.000	3.500	0
c3cur_dis, Females 8	.993	.813	.217	14	0.000	2.700	0
c3cur_dis, Females 9	.752	.804	.168	23	0.000	2.900	0
c3cur_dis, Females 10	.752	.592	.114	27	0.000	1.900	0
c3cur_dis, Females 11	.900	.727	.137	28	0.000	2.100	0
c3cur_dis, Females 12	1.400	.902	.192	22	0.000	3.500	0
c3cur_dis, Females 13	1.856	.718	.180	16	1.000	3.100	0
c3cur_dis, Females 14	1.846	.936	.260	13	.700	3.400	0
c3cur_dis, Females 15	2.150	.952	.389	6	1.000	3.100	0
c3cur_dis, Females 16	2.050	.900	.450	4	.800	2.800	0

Results for totals may not agree with results for individual cells because of missing values for split variables.

Table 10

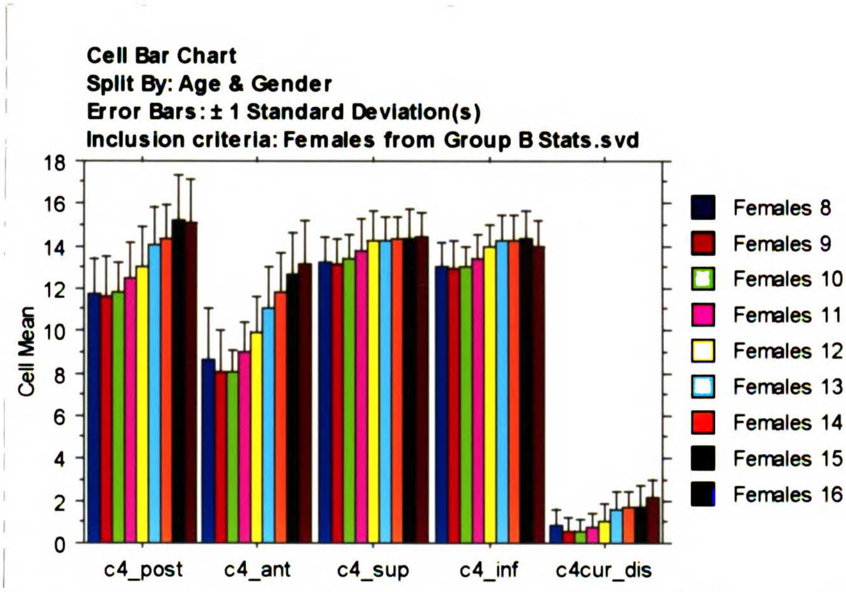

Cell Bar Chart
Split By: Age & Gender
Error Bars: ± 1 Standard Deviation(s)
Inclusion criteria: Females from Group B Stats.svd
Cell Mean
18
16
14
12
10
8
6
4
2
0
c4_post
c4_ant
c4_sup
c4_inf
c4cur_dis
Females 8
Females 9
Females 10
Females 11
Females 12
Females 13
Females 14
Females 15
Females 16

Figure 18

Descriptive Statistics
Split By: Age & Gender
Inclusion criteria: Females from Group B Stats.svd

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
c4_post, Total	12.775	2.060	.166	154	8.300	18.200	1
c4_post, Females 8	11.743	1.662	.444	14	9.500	15.200	0
c4_post, Females 9	11.670	1.825	.381	23	9.300	16.600	0
c4_post, Females 10	11.781	1.457	.280	27	8.300	14.300	0
c4_post, Females 11	12.463	1.725	.332	27	9.600	15.500	1
c4_post, Females 12	13.077	1.819	.388	22	10.200	16.200	0
c4_post, Females 13	14.031	1.851	.463	16	11.100	16.900	0
c4_post, Females 14	14.369	1.571	.436	13	11.900	16.700	0
c4_post, Females 15	15.233	2.093	.855	6	12.000	17.700	0
c4_post, Females 16	15.075	2.048	1.024	4	13.100	17.800	0
c4_ant, Total	9.533	2.323	.188	153	5.900	15.200	2
c4_ant, Females 8	8.607	2.465	.659	14	6.100	14.400	0
c4_ant, Females 9	8.057	1.961	.409	23	5.900	14.200	0
c4_ant, Females 10	8.088	1.040	.204	26	6.600	10.500	1
c4_ant, Females 11	9.007	1.431	.275	27	6.800	11.200	1
c4_ant, Females 12	9.909	1.741	.371	22	7.100	13.000	0
c4_ant, Females 13	11.094	1.959	.490	16	8.500	14.900	0
c4_ant, Females 14	11.808	1.924	.534	13	7.800	14.300	0
c4_ant, Females 15	12.667	1.953	.797	6	9.400	14.800	0
c4_ant, Females 16	13.125	2.039	1.019	4	11.000	15.200	0
c4_sup, Total	13.777	1.317	.106	154	9.100	17.100	1
c4_sup, Females 8	13.214	1.230	.329	14	10.900	14.900	0
c4_sup, Females 9	13.157	1.167	.243	23	11.000	15.800	0
c4_sup, Females 10	13.419	1.089	.210	27	10.900	15.000	0
c4_sup, Females 11	13.759	1.522	.293	27	9.100	16.400	1
c4_sup, Females 12	14.264	1.348	.287	22	11.900	17.100	0
c4_sup, Females 13	14.206	1.195	.299	16	11.700	16.800	0
c4_sup, Females 14	14.300	1.112	.308	13	11.700	16.100	0
c4_sup, Females 15	14.300	1.424	.581	6	12.200	15.700	0
c4_sup, Females 16	14.400	1.192	.596	4	12.900	15.500	0
c4_inf, Total	13.540	1.223	.099	153	10.500	16.700	2
c4_inf, Females 8	12.986	1.211	.324	14	10.500	14.700	0
c4_inf, Females 9	12.978	1.261	.263	23	10.700	15.800	0
c4_inf, Females 10	13.015	.994	.195	26	11.000	14.900	1
c4_inf, Females 11	13.441	1.047	.201	27	10.900	15.000	1
c4_inf, Females 12	13.927	1.062	.226	22	11.600	15.500	0
c4_inf, Females 13	14.262	1.236	.309	16	11.600	16.700	0
c4_inf, Females 14	14.231	1.207	.335	13	11.500	15.700	0
c4_inf, Females 15	14.367	1.283	.524	6	12.000	15.700	0
c4_inf, Females 16	13.950	1.256	.628	4	12.100	14.900	0
c4cur_dis, Total	.967	.871	.070	154	0.000	2.900	1
c4cur_dis, Females 8	.829	.760	.203	14	0.000	2.500	0
c4cur_dis, Females 9	.530	.716	.149	23	0.000	2.800	0
c4cur_dis, Females 10	.530	.570	.110	27	0.000	1.800	0
c4cur_dis, Females 11	.719	.690	.133	27	0.000	2.000	1
c4cur_dis, Females 12	1.018	.860	.183	22	0.000	2.600	0
c4cur_dis, Females 13	1.587	.816	.204	16	.500	2.800	0
c4cur_dis, Females 14	1.731	.692	.192	13	.600	2.800	0
c4cur_dis, Females 15	1.650	1.102	.450	6	0.000	2.800	0
c4cur_dis, Females 16	2.200	.837	.418	4	1.100	2.900	0

Results for totals may not agree with results for individual cells because of missing values for split variables.

Table 11

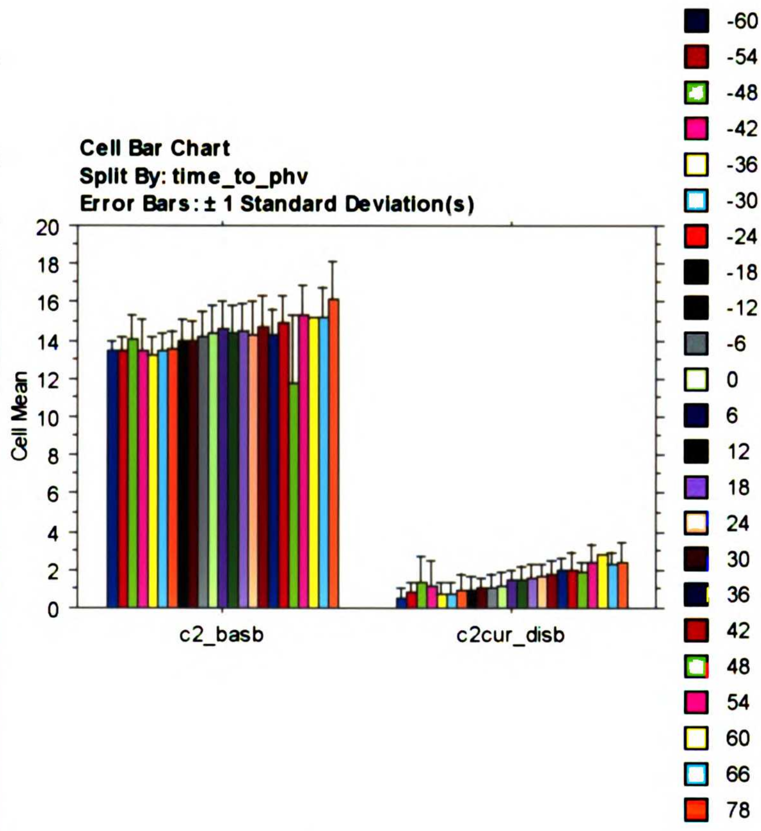


Figure 19

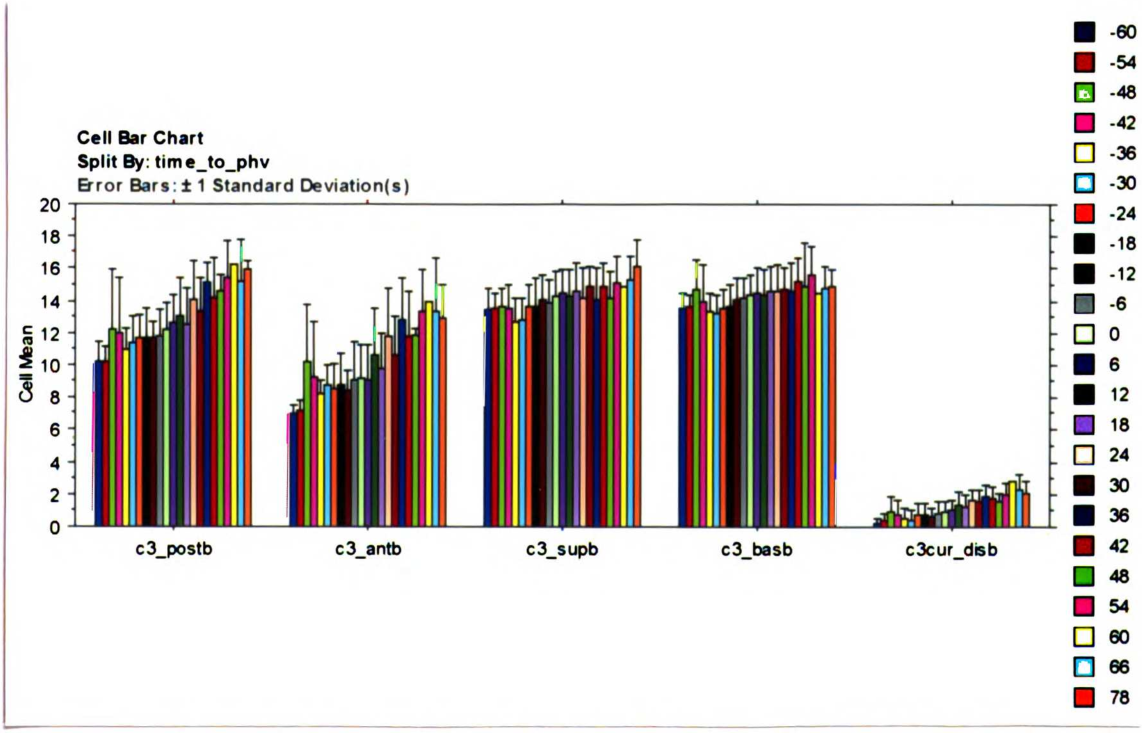


Figure 20

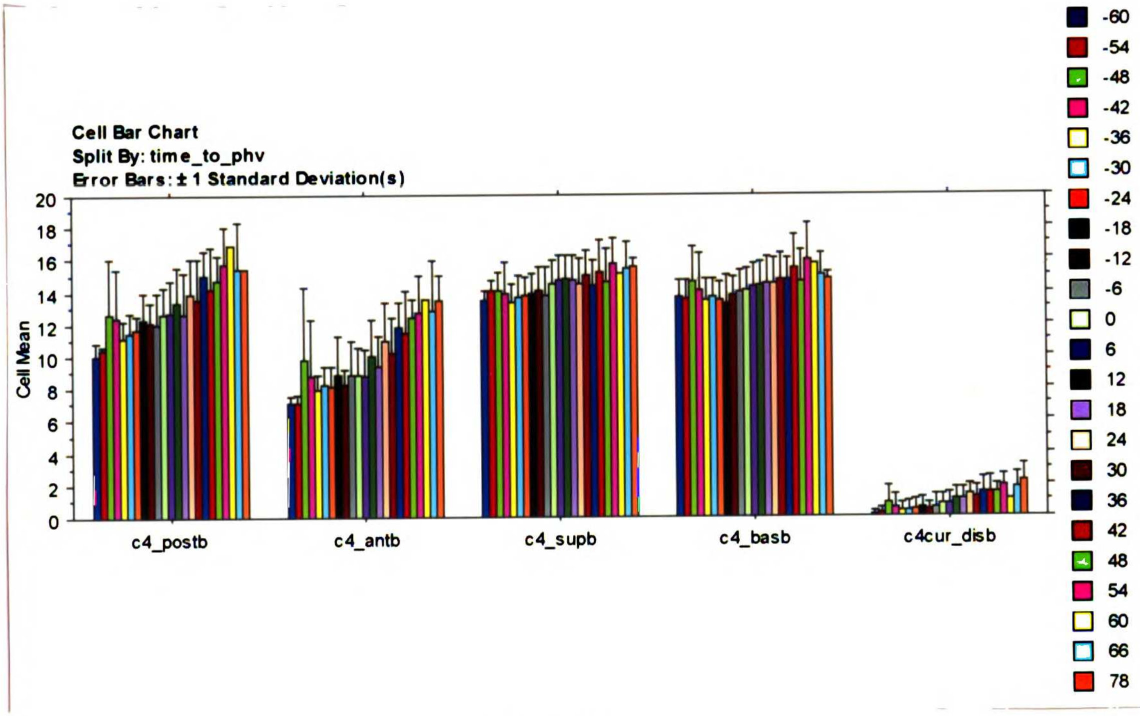


Figure 21

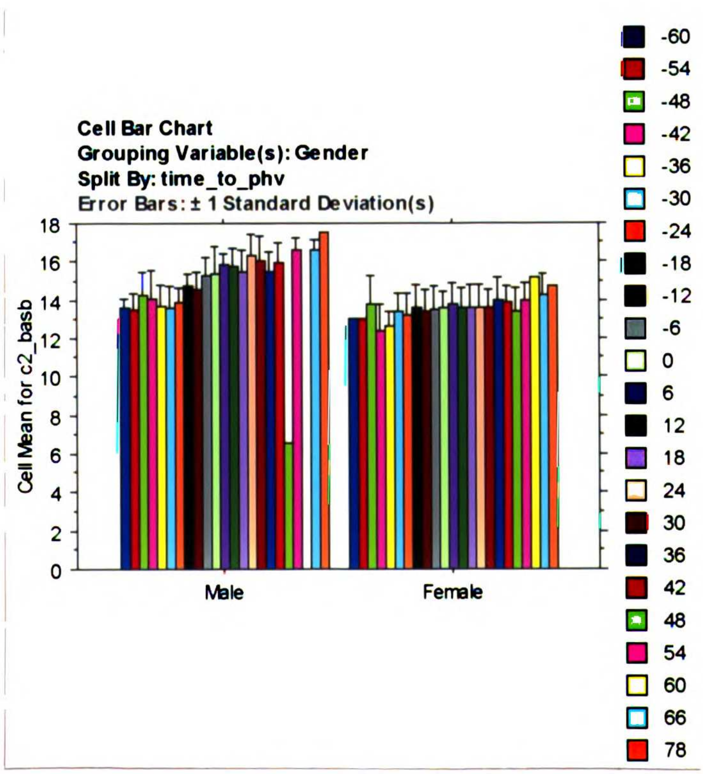


Figure 22

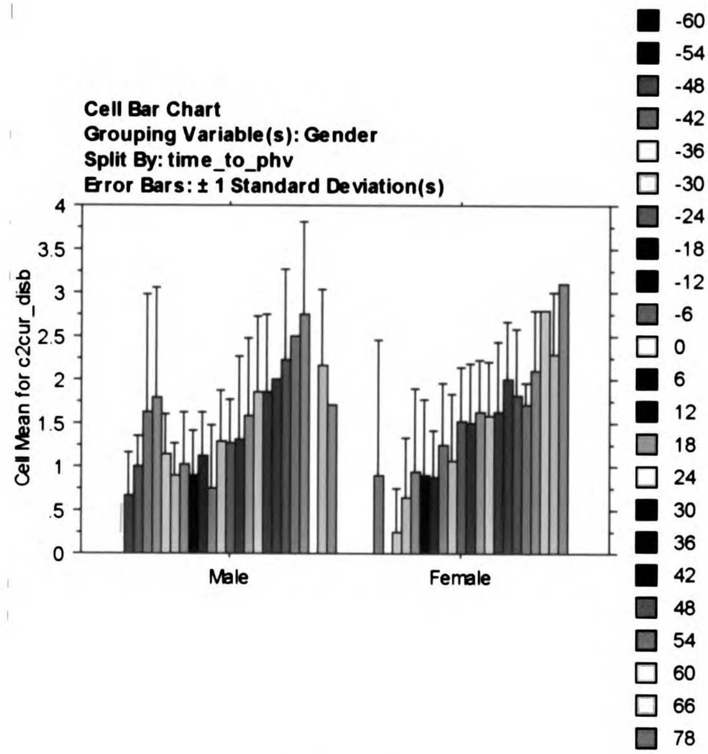


Figure 23

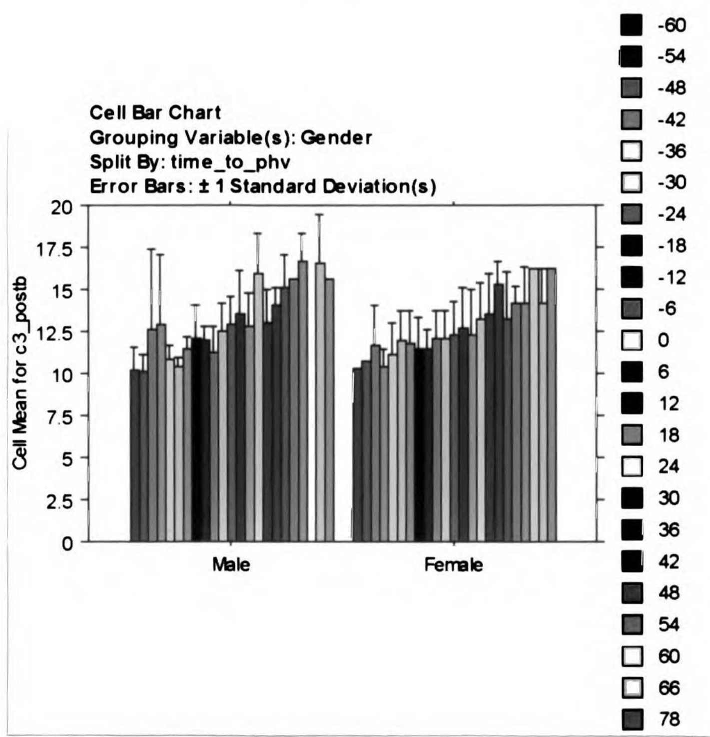


Figure 24

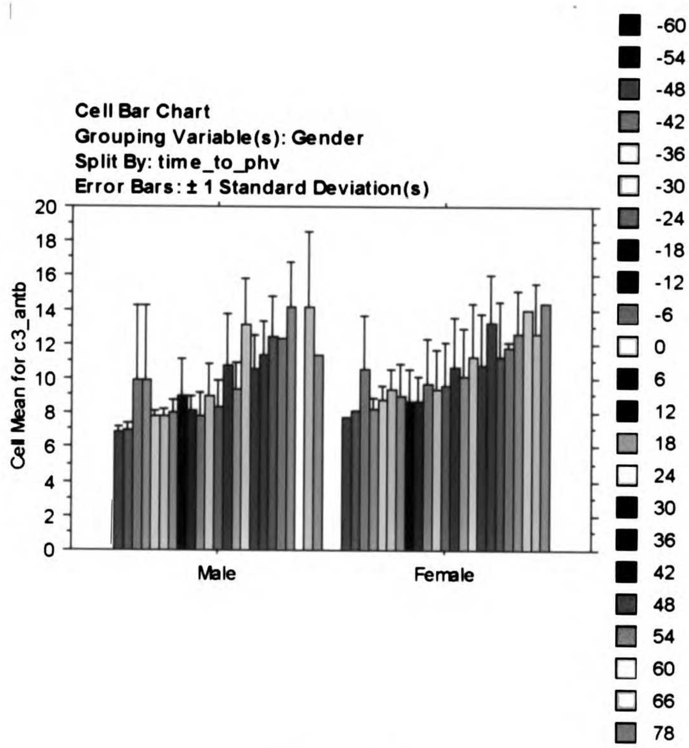


Figure 25

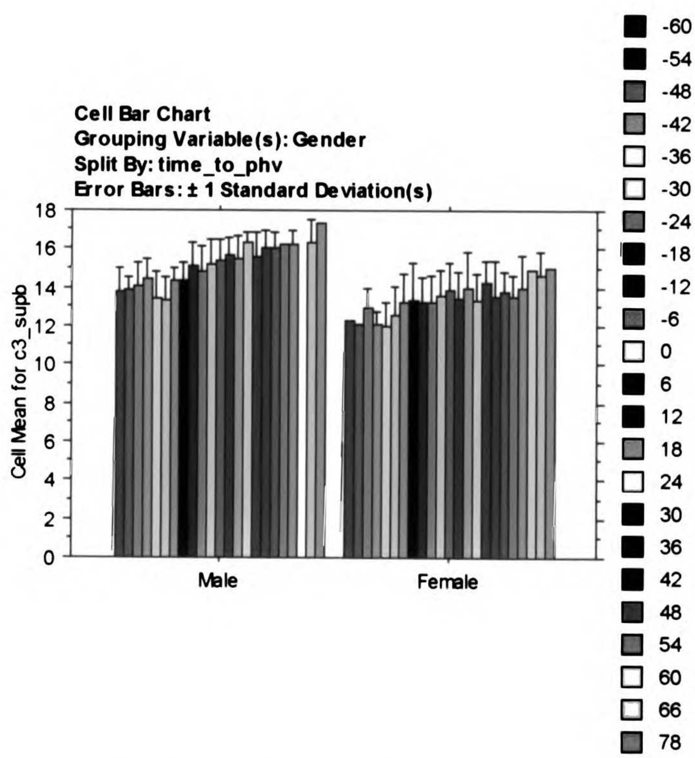


Figure 26

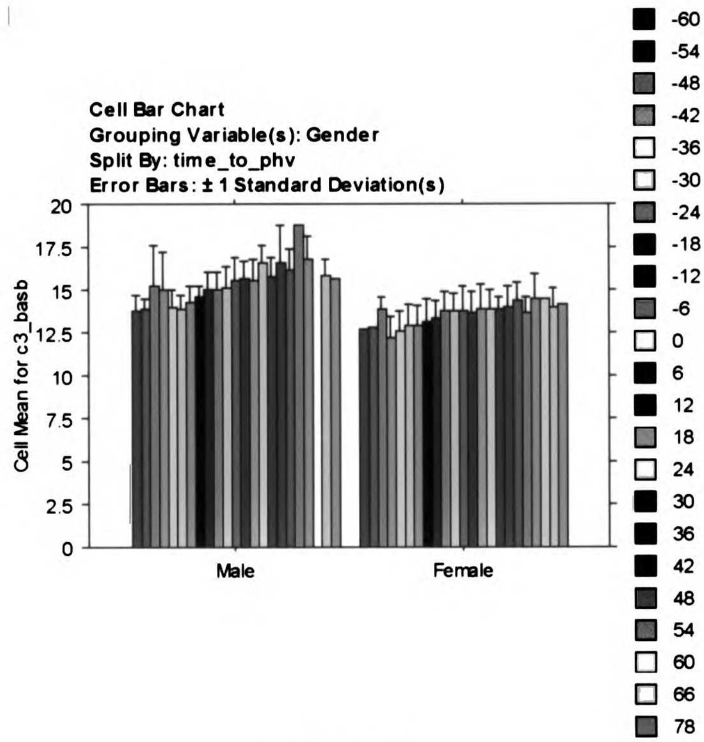


Figure 27

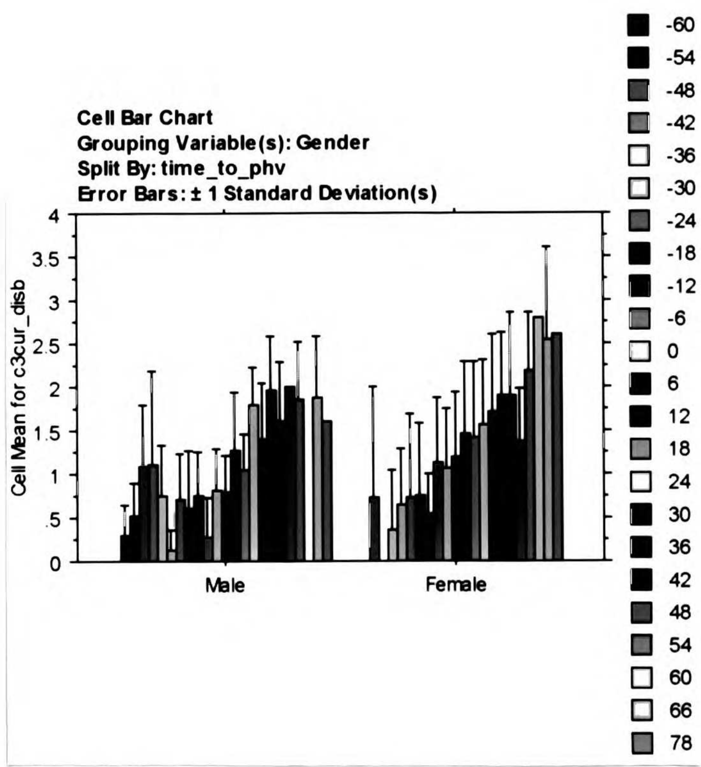


Figure 28

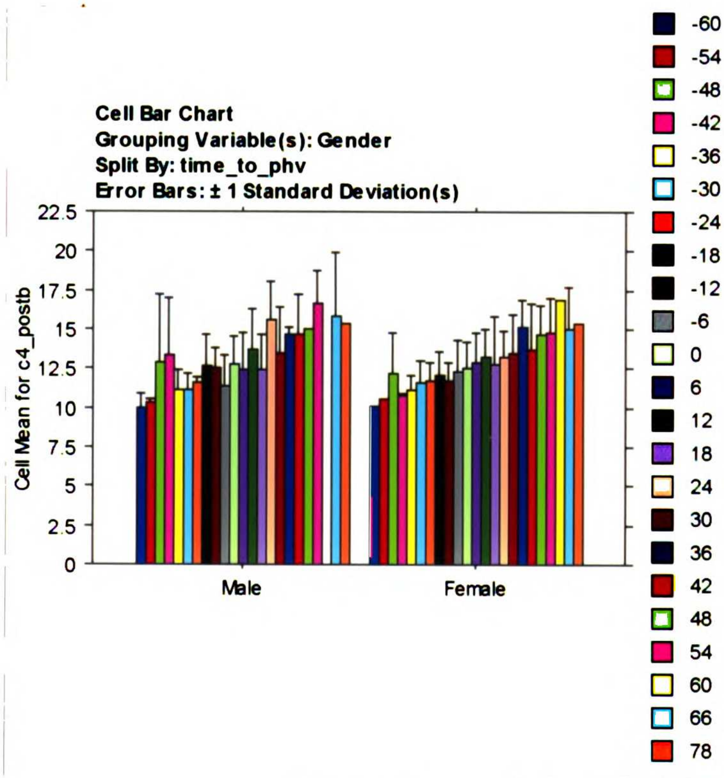


Figure 29

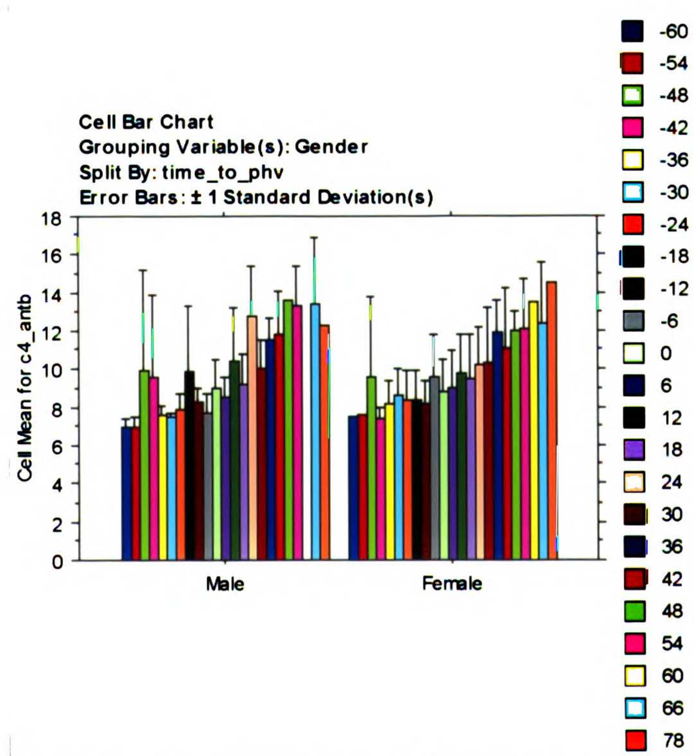


Figure 30

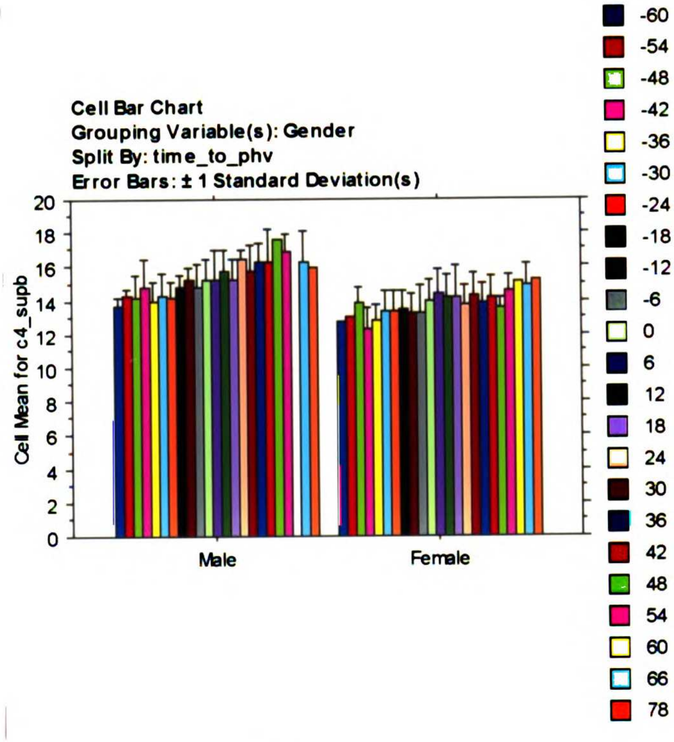


Figure 31

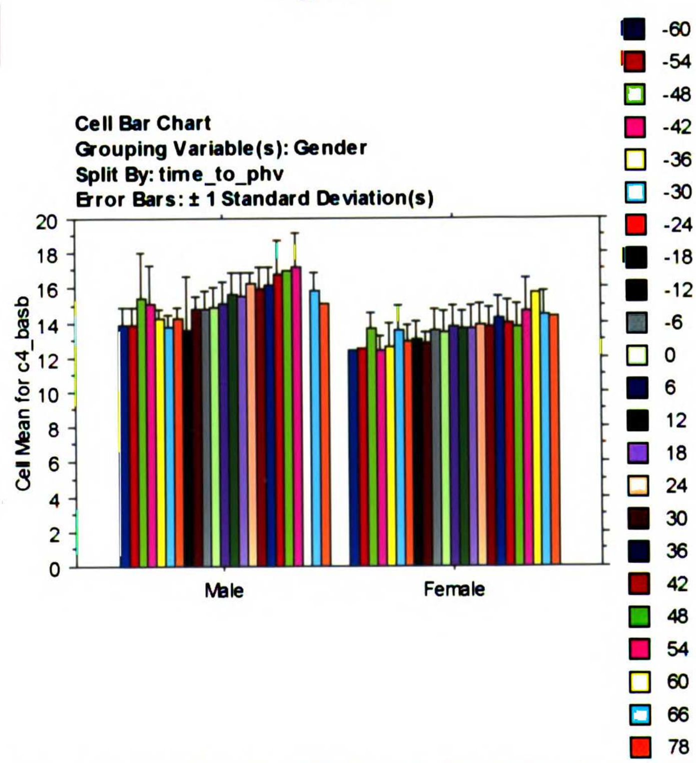


Figure 32

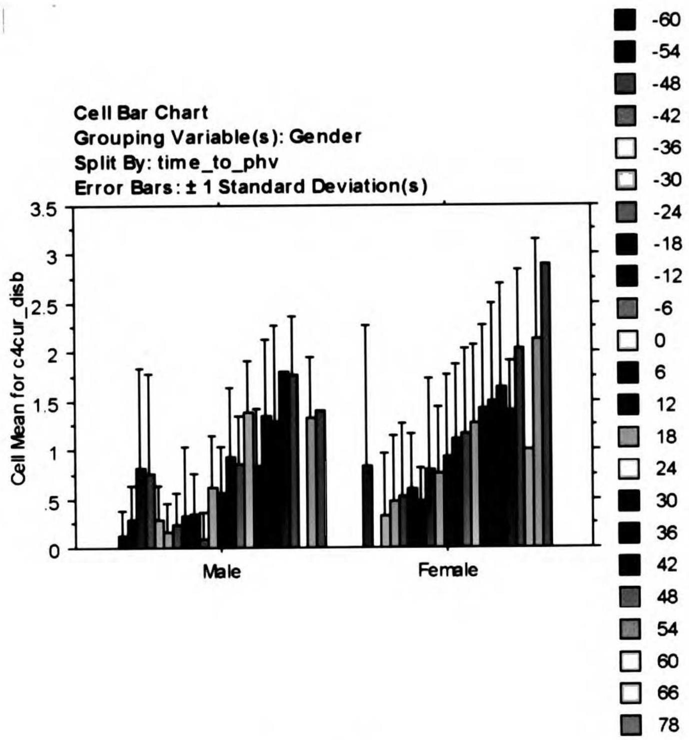


Figure 33

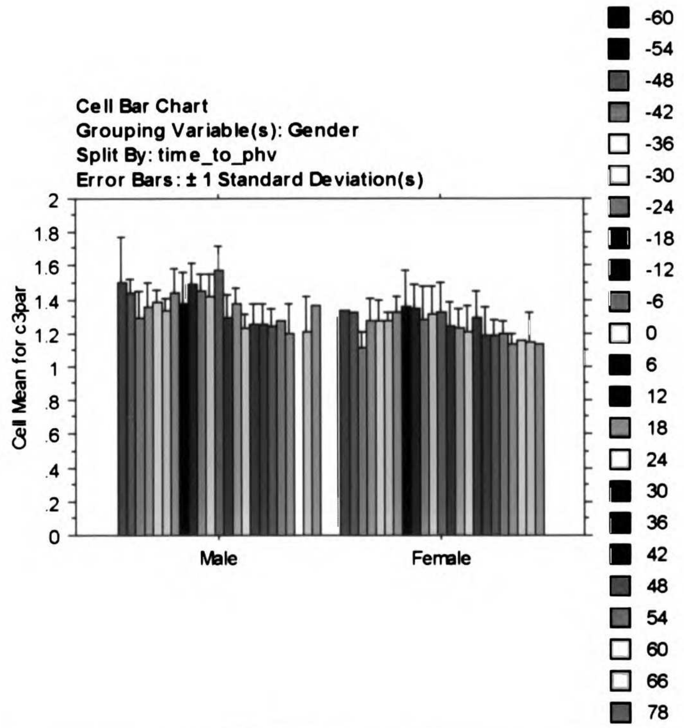


Figure 34

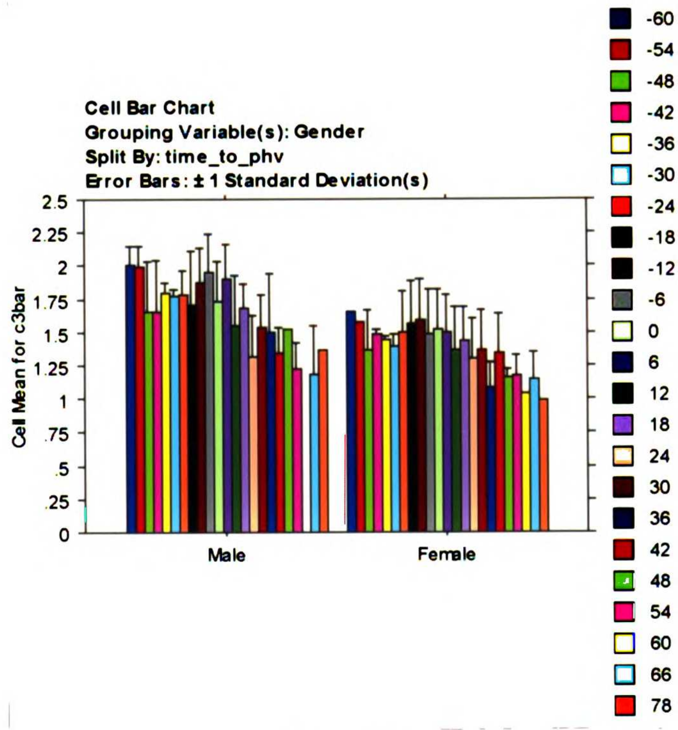


Figure 35

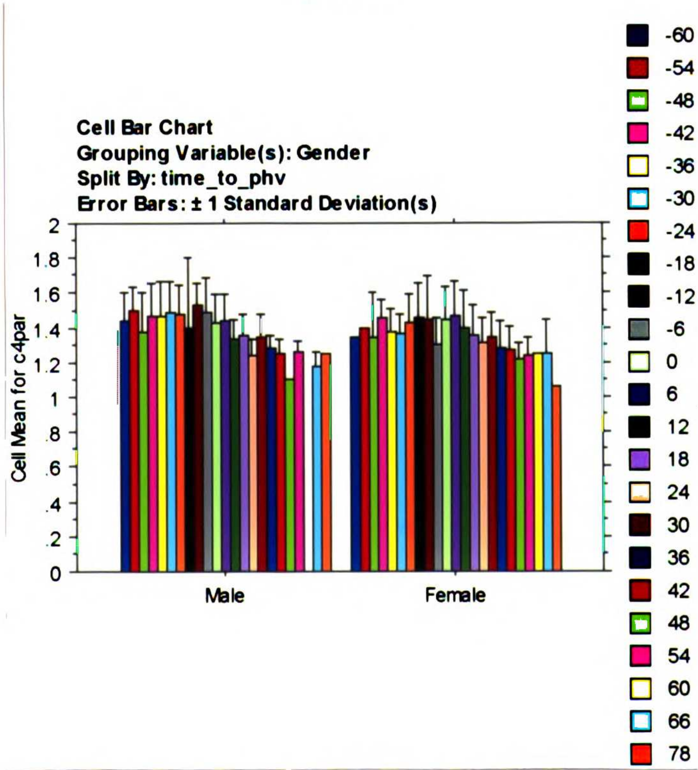


Figure 36

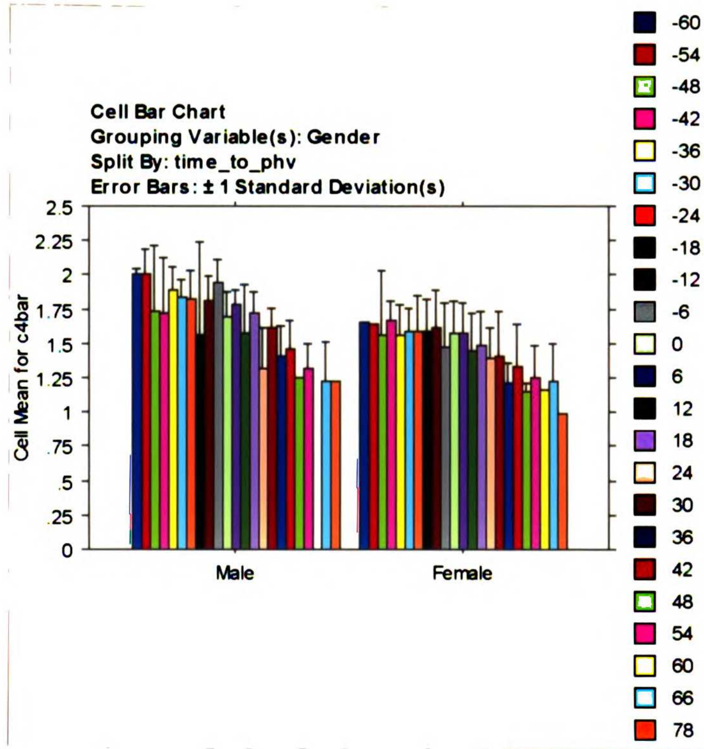

Cell Bar Chart
Grouping Variable(s): Gender
Split By: time_to_phv
Error Bars: ± 1 Standard Deviation(s)
Cell Mean for c4bar
2.5
2.25
2
1.75
1.5
1.25
1
.75
.5
.25
0
Male
Female
-60
-54
-48
-42
-36
-30
-24
-18
-12
-6
0
6
12
18
24
30
36
42
48
54
60
66
78

Figure 37