THE ASSOCIATION OF CONCUSSION HISTORY AND MENTAL HEALTH IN FORMER COLLEGIATE ATHLETES

Zachary Yukio Kerr

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Approved by:

Stephen Marshall

Kelly Evenson

Kevin Guskiewicz

Jason Mihali

Wayne Rosamond

ABSTRACT

ZACHARY YUKIO KERR: The association of concussion history and mental health in former collegiate athletes
(Under the direction of Stephen Marshall)

This dissertation aimed to: (1) estimate the association between recurrent concussion and mental health; and (2) compare athlete-recalled and clinically-documented concussion histories during college. Questionnaires were completed by 797 former collegiate athletes who played collegiate sport between 1987-2012. Athlete-recalled concussions from 130 former collegiate athletes were individually linked to previously collected clinical data that tracked medically-diagnosed concussions at the host institution between 1996 and 2012. In Aim 1, binomial regression estimated adjusted prevalence ratios (PR), with depression, impulsivity, and aggression as outcomes. Controlling for alcohol dependence and family history of depression, the prevalence of currently meeting diagnostic criteria for major depression among former collegiate athletes reporting three of more concussions was 2.6 times that of those reporting no concussions [95% Confidence Interval (CI): 1.1, 6.1]. No association was found for impulsivity. Controlling for alcohol dependence, sex, and relationship status, former collegiate athletes reporting three or more concussions had a higher prevalence of high levels of aggression, compared to those reporting no concussions (PR=1.2; 95% CI: 1.0, 1.5). In Aim 2, intraclass correlation coefficients (ICC) assessed agreement between athlete-recalled and clinically-documented concussion histories. Descriptive analyses assessed reasons for disagreement. Agreement between athlete-recalled

and clinically-documented concussion histories was low (ICC: 0.21; 95% CI: 0.05, 0.37), but higher for females (ICC=0.65; 95% CI: 0.44, 0.79) and those playing more recently (2005-2012: ICC=0.39; 95% CI: 0.01, 0.67). Of those sustaining college sports-related concussions (40.8%), 39.6% believed they had sustained concussions that went undiagnosed, and 20.8% admitted non-disclosure of suspected concussions. Common reasons for non-disclosure included: did not think injury was serious enough (90.9%); did not know it was a concussion (72.7%); and did not want to leave the game/practice (72.7%). In summary, former collegiate athletes reporting concussions may be at greater risk for major depression and higher levels of aggression. However, current sources of concussion history data apparently fail to capture large proportions of concussions. Methodological research is needed to improve the quality of concussion history assessment tools. The health and well-being of collegiate athletes should continue to be monitored even after transitioning out of collegiate sports.

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As a first year student entering college, I did not foresee working in public health. In response, I have jokingly told friends that I "accidentally" fell into research and the world of public health. However, as I look back over the past ten years, I realize my passion for and dedication to the field is serious. I aim to become part of the future of injury epidemiology, while mentoring the next generation of public health professionals.

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LIST OF ABBREVIATIONS

AT	Athletic Trainer
BPAQ	Buss-Perry Aggression Questionnaire
BPAQ-SF	12-item Short Form of the Buss-Perry Aggression Questionnaire
BIS-11	Barratt Impulsiveness Scale
BIS15	Short Form of the Barratt Impulsiveness Scale
BMI	Body Mass Index
BRFSS	Behavioral Risk Factor Surveillance System
CDC	Centers for Disease Control and Prevention
CI	Confidence Interval
CSRA	Center for the Study of Retired Athletes
CTE	Chronic Traumatic Encephalopathy
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, 4th edition
ED	Emergency Department
ICC	Intraclass Correlation Coefficient
NCAA	National Collegiate Athletic Association
NFL	National Football League
NFLPA	National Football League Players Association
PHQ-9	Patient Health Questionnaire for Depression
PD	Prevalence Difference
PR	Prevalence Ratio
SF-12	12-Item Short Form Health Survey
SF-36	Short Form 36 Measurement Model for Functional Assessment of Health and Well-Being

TBI	Traumatic Brain Injury
UNC	University of North Carolina at Chapel Hill
US	United States
VR-12	Veterans RAND 12 Item Health Survey
VR-36	Veterans RAND 36 Item Health Survey

CHAPTER 1

INTRODUCTION

Sports place high levels of mental and physical demands on athletes. Athletes undertake a long duration and high intensity of training, frequently specialize in their sport from an early age, experience high numbers of repetition of specific sport skills, and constantly seek to elevate the difficulty of the athletic skills they practice and possess.[1] The performance-oriented paradigm of sport encourages many athletes to constantly push their bodies in an effort to optimize performance, sometimes ignoring recovery demands and their bodies' warning signs of pain and overuse.[2] Severe injuries can disrupt athletes' quality of life in the short- and long-term, by negatively affecting their health and causing them to miss a large part, if not all, of their playing season.[3] Severe injuries are also more likely to require surgery and other advanced medical treatments.[3] As participation in organized sports at the youth, high school, and college levels continue to increase,[4-6] it is important to accurately characterize the burden of sports injury on athlete well-being and health.

Most findings related to the current health of former athletes originate from the Retired National Football League (NFL) Players Cohort, consisting of former professional football players that had played between 1930-2001. In comparison to the general American male population, retired NFL players had a higher prevalence and earlier onset of Alzheimer's disease and osteoarthritis.[7,8] In addition, recurrent concussion in retired NFL players was associated with a higher prevalence of significant memory problems, and self-

reported diagnoses of mild cognitive impairment and depression.[7,9,10] Another study of former NFL players found that 49% had experienced bodily pain and 15% currently met diagnostic criteria for major depression.[11] Furthermore, there is growing concern about the potential development of chronic traumatic encephalopathy (CTE),[12] as related neurodegeneration has been observed in former athletes from boxing, football, hockey, and soccer.[13-20] This dissertation explores the current health of former collegiate athletes, associated with a sports-related injury that has later-life consequences: concussion.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Concussion

Concussion, a common type of traumatic brain injury (TBI), is a highly-publicized injury.[21] Sports-related physical activity and motor vehicle crashes are responsible for the majority of concussions.[22] The Centers for Disease Control and Prevention (CDC) estimates that each year, up to 3.8 million sport-related concussions occur in the United States (US).[23] Of all reported injuries occurring in high school sports in 2008-2010, approximately 13.2% were concussions.[24] An additional study also found that within three seasons, 5.1% of high school and collegiate football players sustained concussions.[25]

Piland et al.[26] categorizes concussion symptomatology as: (1) cognitive (feeling "slowed down," feeling like one is "in a fog," difficulty concentrating, difficulty remembering); (2) neurobehavioral (sleeping more than usual, drowsiness, fatigue, nervousness); and (3) somatic (headache, nausea, sensitivity to light and noise, loss of balance). Post-concussion syndrome occurs when these symptoms persist for more than six months.[27] McCrea et al.[28] administered a series of cognitive assessments to 94 concussed National Collegiate Athletic Association (NCAA) Division I-III football players: immediately following injury; two to three hours after injury; and on post-injury days one, two, three, five, seven, and 90. Compared to 56 non-concussed controls, concussed players

exhibited more severe symptoms, cognitive impairment, and balance problems immediately after sustaining a concussion. However, these symptoms resolved within 3-7 days.

Recurrent concussion has also been found to have additional negative acute and cumulative effects.[25,29] A study of collegiate and high school football players found that approximately 15% of concussed players experienced a second concussion in the same season.[25] Compared to collegiate football players reporting no previous history of concussion, collegiate football players reporting three or more concussions before the study period were three times as likely to have sustained a concussion during the study period.[29] Furthermore, players with a previous concussion history that had sustained concussions during the study period had slower recovery from symptoms than players without a previous concussion history.[29]

Recurrent concussion also places athletes at risk for second impact syndrome, which occurs when a second concussion is sustained before the symptomatology from a previous concussion has resolved.[30-32] The cause of second impact syndrome is unknown, although it is hypothesized that the second concussion causes the brain's arterioles to lose control of cerebral blood flow, which causes cerebral edema.[31] Approximately 50% of known cases of second impact syndrome have resulted in mortality, partially because medical intervention to reverse complications occurs too late.[33] Examination of second impact syndrome is limited, although in 1980-1993, 35 cases of second impact syndrome were recorded.[31] It is widely assumed that better identification and monitoring of sports-related concussions can help to minimize the potential frequency of second impact syndrome and its substantial effects.

Although concussions are sustained in numerous sports,[24,34] concussion rates are higher in sports permitting more body contact, such as football, soccer, hockey, and

lacrosse.[24,35,36] In particular, the concussion rate in football exceeds that of all other sports.[24] Data from high school sports-related injury surveillance have reported football concussion rates of 0.47-0.64 per 1,000 athlete exposures (AEs) (i.e., one athlete's participation in one practice or one competition).[24,36] Similar concussion rates (0.61 per 1,000 AEs) have been reported in college football.[36] In the NFL, an average 0.41 concussions occur per game.[37] The National Center for Catastrophic Sport Injury Research examined football-related fatalities in 1931-2008 and found that brain trauma was the second-most common cause of fatalities (behind cardiac-related injuries and illnesses).[38]

2.2 Sex Differences Related to Concussions

There is also growing concern over sex differences related to concussions.[39,40] In a meta-analysis that included samples of individuals sustaining sports-, fall-, and motor vehicle crash-related concussions, females experienced worse concussion-related outcomes than males, such as a larger number of post concussive symptoms and a longer length of hospitalization.[39] In a pharmacological trial of patients aged 50 years and younger, females had a greater frequency of brain swelling and intracranial hypertension than did males.[40]

High school student-athlete surveillance data suggests that females have higher rates of reported concussions, and a larger proportion of reported injuries that were concussions than those males playing in the same sports.[24,36,41,42] Sex differences also exist with symptomatology, recovery time, and outcomes in neuropsychological testing.[24,41,43-45] For example, in a recent study of concussed high school athletes,[41] males reported more cognitive symptoms (e.g., amnesia, confusion/disorientation) whereas females reported more neurobehavioral (e.g., drowsiness) and somatic (sensitivity to light and noise) symptoms.

Multiple reasons may underlie the higher frequency of reported concussions in females than males (Table 2.1). Differences may be attributable to anatomical/neuromuscular differences. Girls may be at higher risk due to having less muscle strength in their necks or less mass in their neck and heads.[46] In sports with ball-contact, a smaller ball-to-head ratio may increase risk.[36] Social-environment factors also affect the diagnosis and reporting of concussions. Society may also be more protective of females than males, thereby making clinicians more likely to diagnose hard hits sustained by females as concussions. Females may also be more willing to disclose injuries more than males.[47] Alternatively, it is also possible that female athletes may play contact sports such as a soccer and basketball more aggressively, perhaps to over-compensate for traditional role model expectations that suggest that women should be physically non-assertive.[48] Last, equipment differences may confound the association between sex and concussion rates. For example, men's lacrosse requires protective headgear, whereas women's lacrosse does not (although it must be noted that this protective headgear is not intended to prevent concussions).

However, examining the reporting of concussions and their associated symptoms by sex is limited, with only two studies to our knowledge utilizing females in their sample.[49,50] More research regarding sex differences is warranted in order to justify recommendations that female athletes should be monitored more closely.[24,47]

Table 2.1. Theories explaining larger frequency of concussions in females than males
Anatomical/neuromuscular differences
Females have weaker necks
Females have less mass in heads/necks
In sports utilizing playing ball, females have smaller ball-to-head ratio than males
Social-environment factors
Society wanting to be more protective of women leads to more diagnosed concussions
Females disclose more injuries
Females play sports more aggressively
More protective equipment in certain males sports

2.3 The Association of Recurrent Concussion and Mental Health

The public health significance of concussion is further highlighted by findings that suggest recurrent concussion is associated with the onset of negative mental health outcomes, such as depression, mild cognitive impairment, and Alzheimer's disease.[7,9,10] Understanding the causes of negative mental health outcomes is important in public health terms. Depression and Alzheimer's disease are associated with significantly higher health care costs.[51,52] Depression can also affect one's ability to maintain self-care, relationships, and work productivity.[53] Mild cognitive impairment must also be monitored because it is an established diagnostic criterion for assessing risk for dementia and Alzheimer's disease in older individuals.[54-57] Given the large numbers of sports participants and concussed athletes, further exploration of how concussions contribute to the onset of such mental health outcomes will help sports organizations better enact policy that will protect the long-term health, safety, and well-being of current and former athletes.

2.3.1 Theories Related to the Association of Recurrent Concussion and Mental Health

A number of theories attempt to explain the association between concussion and mental health outcomes (Table 2.2). Recurrent concussions are of concern, in part due to

their apparent association with "tauopathies", aggregations of tau proteins in the brain that were identified on pathologic examination of deceased individuals with a history of head trauma.[13,15-18] Although tau proteins are integral in properly functioning cognition, an over-accumulation is potentially associated with cognitive decline and depressive tendencies.[18] Neurodegeneration related to one form of taupathy, chronic traumatic encephalopathy (CTE),[12] was first observed in the early 20th century, when many former boxers exhibited abnormalities related to cognition, behavior, and motor skills[13]. Evidence in the latter half of the 20th century also found CTE-related neurodegeneration among former athletes from other sports with high levels of player to player contact, such as football, hockey, and soccer.[14-20]

CTE is considered a form of tauopathy but is unique in that it targets particular areas of the brain, such as the superficial layers of the cerebral cortex.[18] CTE may also be associated with depression, impulsivity, and aggression.[18,58] Because CTE is also associated with severe neurological changes such as dementia, gait and speech abnormalities, and parkinsonism, it may be misdiagnosed as Alzheimer's disease.[13,59]

Other theories have attempted to explain the association of recurrent concussion and an increased risk for depression and Alzheimer's disease in later life. One hypothesis for such an accelerated onset is that the brain lesions caused by concussions may produce biochemical changes that increase the number of excitatory neurotransmitters, and result in neuron loss and cell death.[7,9,60] Such neuron loss may then serve as the mechanism for the onset of TBI-mediated depression. It is also suggested that individuals diagnosed with major depression have smaller hippocampal and amygdala volumes,[61,62] structural and morphological changes in the prefrontal[63] and orbitofrontal cortex,[64] and basal ganglia

structures.[65] These structures are interconnected and are believed to compose a "neuroanatomical circuit"[66] that plays a key role in mood regulation.

Genetics may also affect the brain's response to injury. The human ApoE gene has three allelic forms (ApoE e2, e3, e4). Having the e2 allele may be protective against Alzheimer's disease; however, having the e4 allele may increase the risk of Alzheimer's disease and negatively affect recovery from TBI.[56,67-70] Furthermore, cognitive impairment further increases when athletes carry the e4 allele and also sustain multiple concussions.[71,72] Exploration of genetic variations is of particular concern as it is estimated that 30% of the US population carries the e4 allele.[73] But, the exact mechanism by which the e4 allele increases risk is under investigated. It is suggested that the e4 allele is associated with the build-up of beta-amyloids, which have been found at high levels in the brains of patients with Alzheimer's Disease.[74] This is in contrast to other allelic forms of the human ApoE gene, which may be more apt to break down such beta-amyloid build-up.[74]

Table 2.2. Theories for association between concussion and mental health outcomes

Tauopathies (brain accumulates an excess of tau proteins)
Over-accumulation caused by repetitive head impacts may be associated with cognitive decline
Genetics
e4 allele may negatively affect recovery from traumatic brain injury
e4 allele associated with the build-up of beta-amyloids, which have been found at high levels in the brains of patients with Alzheimer's disease
Brain lesions caused by concussions
Produce biochemical changes that increase the number of excitatory neurotransmitters, and result in neuron loss, which serves as the mechanism for the onset of depression
Distinct "neuroanatomical circuit" in those diagnosed as depressed
Smaller hippocampal and amygdala volumes, structural and morphological changes in the prefrontal and orbitofrontal cortex, and basal ganglia structures

2.3.2 Findings Related to the Association of Recurrent Concussion and Mental Health

Despite these numerous theories, much is still unknown regarding recurrent concussion's impact on mental health outcomes. First, CTE cannot be diagnosed in living individuals at the current point in time. Despite profound limitations due to potential selection bias,[13] the existing brain autopsy studies of deceased athletes have contributed to increased public/media recognition and a better understanding of CTE. Omalu et al.[15-17] generated a case series of deceased retired NFL players diagnosed with CTE. Medical reports of all three cases noted: a long latent period between draft into the NFL and manifestation of symptoms; deterioration in social/cognitive functioning (e.g., loss of memory, language and coherence); exaggerated responses to stress (e.g., social phobias, anger and agitation over minor issues, mood swings); depression; suicidal thoughts; and headaches/body aches. Furthermore, all three autopsies confirmed the presence of cerebral taupathy.

Gavett et al.[13] examined the brains of 12 of the 321 former professional football players that had died between February 2008-June 2010. All 12 brains showed evidence of CTE. Gavett et al.[13] asserted:

> "If one assumes that all deceased players who did not come to autopsy did not have CTE and that the amount of head trauma in professional football has remained fairly constant over the past 5 decades, a prevalence of 3.7% [12 autopsied players / 321 total players] would result."

The findings from Omalu et al.[15-17] and Gavett et al.[13] suggest that individuals sustaining multiple concussions are at substantial risk for CTE.

Findings from living retired athletes and the general population suggest that recurrent concussions may also accelerate the onset long-term mental health outcomes, particularly depression and Alzheimer's disease.[29,70,75-87] At all playing levels, concussed athletes have been found to have greater neuropsychological deficits than non-concussed athletes.[7,88-92]

In 2001, the National Football League Players Association (NFLPA) provided funds to the University of North Carolina at Chapel Hill (UNC) Center for the Study of Retired Athletes (CSRA) to launch the Retired NFL Players' Cohort study, consisting of former professional football players that had played between 1930-2001. Compared to the general American male population, the cohort had a higher prevalence of and an earlier onset of Alzheimer's disease.[7] Also, compared to retired players reporting no concussions during their professional careers, retired players reporting three or more concussions had five times the prevalence of self-reported mild cognitive impairment diagnosis and three times the prevalence of reported significant memory problems.[7] In addition, after adjusting for confounders (i.e., age, number of years since retirement, number of years played, physical health status, and diagnosed comorbidities such as osteoarthritis, coronary heart disease, stroke, cancer, and diabetes), the prevalence of self-reported clinical diagnosis of depression was three times as high in retired players reporting three or more concussions during their professional careers, compared to those players reporting no concussions. In a subsequent study that utilized follow-up data collected in 2010,[10] a stronger dose-response relationship was found. The nine-year risk (between baseline and follow-up administrations) of self-reported clinical diagnosis of depression increased with more concussions self-reported at follow-up, ranging from 3.0% in those reporting no concussions, to 26.8% in those reporting 10 or more concussions.

Despite the building evidence and posited theories, additional studies have failed to find an association between recurrent concussion and mental health outcomes.[7,67-69,93-96] The lack of associations may be attributable to measurement error related to both concussion history and health outcomes. However, some studies may have lacked sufficient sample sizes and resulting statistical power to detect associations.[67,93,95] Additionally, the research to date has limited generalizability, as former athletes that are female or from sports with lower levels of intentional contact are rarely examined. Soccer, for example, has a high frequency of concussion at the high school, collegiate, and professional levels.[36,97,98] At the same time, the Retired NFL Players Cohort is comprised of an older population, making it difficult to ascertain outcomes that may affect individuals at a younger age. There is therefore a need for further research on this topic.

Furthermore, a large number of collegiate athletes never reach the professional level. In football, an estimated 1.6% of all NCAA senior student-athletes are drafted into professional leagues.[99] The proportion drafted also varies among other sports, ranging from 0.7% in men's soccer to 9.7% baseball.[99] With over 450,000 NCAA student-athletes in the 2011/12 school year,[6] former collegiate athletes are an important population of former athletes in need of further study.

Last, almost all studies have focused on concussions sustained during professional careers. Although moderate correlation was found between the number of concussions reported to have been sustained during one's professional and collegiate career,[100] it would be more appropriate to consider a complete concussion history that includes all sports-related and non-sports related concussions sustained in one's lifespan. Comprehensive concussion

data from a younger population of former athletes may contribute to a better understanding of how recurrent concussion affects mental health across the lifespan.

2.4 Measurement of Mental Health

In addition, health data in the study of the former NFL players has its limitations. First, diagnosis of a health outcome is dependent on the recall of retired athletes. For example, individuals with a depression diagnosis have been shown to demonstrate difficulties with retrieval of specific autobiographical memories.[101-104] Thus, findings may be limited to some extent by a recall bias. The method for each health outcome diagnosis for each retired player is also unknown. With depression, the utilization of different diagnosis procedures for depression (e.g., Hamilton Depression Scale; NIMH diagnostic interview) may have contributed to possible misclassification error. Also, cases involving single episodes of depression are often collapsed with cases involving recurrent episodes of depression. Such a collapse of data consequently prohibits further examination of depression, particularly recurrence or severity.

2.4.1 Usage of Scale Measures of Mental Health

The usage of validated scale measures may serve as an alternative method of measuring attributes of mental health associated with recurrent concussion and CTE.[58] Scale measures of depression are abundant but underutilized in studies of former athletes, with those existing predominantly sampling sampled retired NFL players. A sample of 3,377 retired members of the NFL Players Association completed the depression module (PHQ-9) of the Patient Health Questionnaire and were found to have levels of depression similar to

that of the general population, alongside a strong correlation between moderate/severe depression and having difficulty from pain.[11] A recent case-control study also found that compared to non-NFL participants, retired NFL players had higher depression symptom severity, as indicated by the Beck Depression Inventory II.[105] In addition, the number of lifetime concussions was associated with depression symptom severity.[105] The one study to our knowledge utilizing collegiate athletes found that scores on the Wakefield Depression Scale were higher for current collegiate athletes than for former collegiate athletes.[106]

Other scale measures of mental health have been utilized in the study of sports participation and may be useful in the study of the association of recurrent concussion and mental health. For example, previous research has explored impulsivity's association with participation in "explosive" sports such as tennis, hockey, and baseball,[107] and sports with high risk for injury.[107] Aggression has also been studied in athletes,[108-111] with results suggesting that aggression was associated with penalty minutes designated in ice hockey,[110] and that no difference in aggression levels existed between athletes and non-athletes.[111] However, research has yet to explore impulsivity and aggression in former athletes, particularly as related to recurrent concussions.

2.5 Measurement of Concussion History

Exploration of the association between recurrent concussions and mental health is also limited by the lack of a standardized protocol to identify concussions. Some studies have relied upon reporting criteria, such as those outlined from the American Academy of Neurology,[112,113] the National Athletic Trainers Association Position Statement[114] and the International Conference on Concussion in Sport.[115,116] In the Retired NFL Players Cohort,

the 2001 baseline and 2010 follow-up health surveys defined concussion as "an injury resulting from a blow to the head followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, seeing stars, feeling in a fog or slowed down, memory problems, poor concentration, nausea, or throwing-up."[10] Participants were also reminded that they did not need to be "knocked out" or unconscious to sustain a concussion. One fault of such a definition, however, is that concussions can occur without a direct blow to the head.

Furthermore, numerous studies do not define concussion with reporting criteria.[88,113,117,118] Surveillance systems such as The National High School Sports-Related Injury Surveillance System, High School RIO™ (Reporting Information Online) and the NCAA Injury Surveillance System rely upon the professional opinion of the reporting certified Athletic Trainer (AT) or trained sports medicine clinicians with board certification. The High School RIO™ surveillance system chose not to provide specific reporting criteria because: (1) it would not be feasible to ensure only those events meeting the specific criteria were being reported in such a large, geographically dispersed sample; and (2) research staff believed it was more important to capture what was actually happening in the high school setting rather than what would be happening if specific constraints were imposed (Comstock, personal communication, 2012). In addition, researchers may focus on methodological rigor, such as ensuring standardized acquisition of athlete-recalled concussion histories. For example, one study required that test administrators from four institutions attend a two-hour workshop related to proper data collection.[88]

Heterogeneity in the research methods used for the identification of concussion is a profound issue that limits the ability of researchers and clinicians to compare results among

various studies. This limitation is particularly exacerbated when reporting criteria for concussions are left completely undocumented in manuscripts.

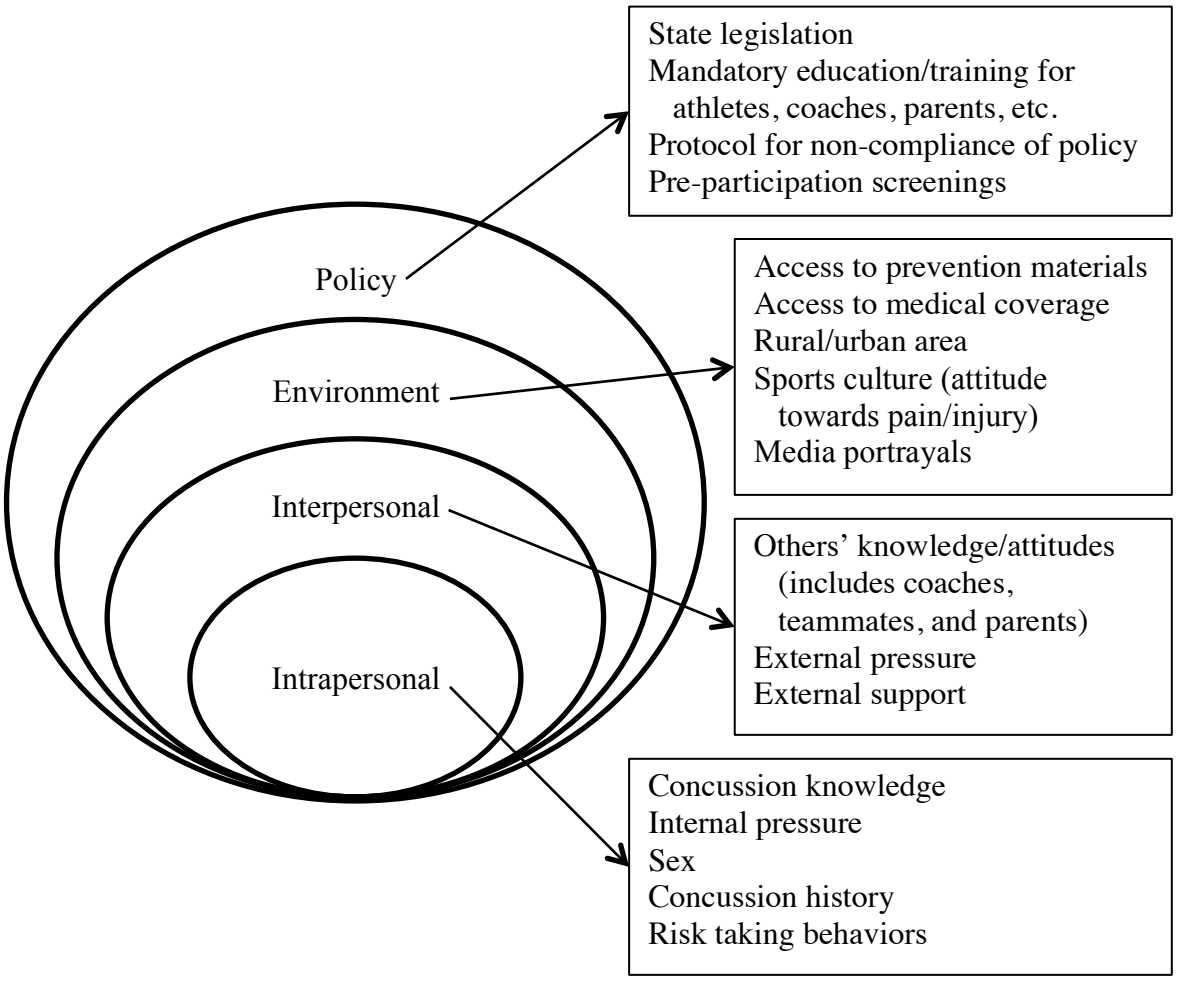
2.5.1 Athlete-Recalled Concussion History

Despite the limits of self-reported health data such as athlete-recalled concussion history, proponents note their many advantages. First, self-report data requires less labor and cost to collect. Literature has also reported selective preservation of older information in participants with Alzheimer's disease-related dementia, suggesting that recollection of all past injuries may be likely in former athletes.[119] On the other hand, athlete-recalled concussion history may be attenuated for those players who have been retired the longest. For example, retired NFL players that had played in the 1950s would have to recall sports-related concussions that occurred approximately 60 years ago, whereas those that had played in the 1990s would have to recall sports-related concussions that occurred approximately 20 years ago. Assessment of this type of recall decay is complicated by fact that our diagnostic assessment of concussion has evolved over time, particularly in recent years. Thus, former athletes may have had more undiagnosed concussions than current athletes. The effects of recall decay are intractably intertwined with the evolution of our diagnostic methods and criteria.

Athletes' recall of concussions is likely a function of numerous influences. The socio-ecological framework is a helpful means of grouping the factors that may influence recall[120] (Figure 2.1). On the policy level, required concussion education may help sports medicine professionals and athletes better detect concussions due to better knowledge of symptomatology. On the environmental level, social-environment factors such as media

coverage may influence athletes to better detect concussions, or even misclassify any previous hard hit with lasting symptoms as a concussion. At the same time, game culture may cause athletes to withhold disclosure of concussions for fear of being taken out of play. On the interpersonal level, teammates, coaches, and fans may also pressure athletes to withhold disclosure. Even if overt pressure is not present, the athlete's perception of the potential for pressure may be an important influence as well. On the intrapersonal level, increased concussion knowledge or a previous concussion history may help athletes become more apt to better detecting and recalling more recent concussions. As a result, all levels of influence must be considered in the examination of the evidence for validity of athlete-recalled concussion history.

Figure 2.1. Socio-ecological framework regarding athlete disclosure of concussions



2.5.1.1 Reliability of Athlete-Recalled Concussion History

Reliability is defined as "the extent to which an experiment, test, or any measuring procedure yields the same results on repeated trials."[121] The research on the reliability of athlete-recalled concussion history is limited. To our knowledge, only one study has examined reliability related to athlete-recalled concussion history. Kerr et al.[122] assessed the stability (i.e., the consistency of repeated measurements)[123] of athlete-recalled concussion history in retired NFL players. At the 2001 baseline and 2010 follow-up administrations of the Retired NFL Players Cohort study, retired players reported the number of concussions

they sustained during their professional playing careers. Overall agreement was moderate (weighted Cohen's Kappa=0.48).

However, 31.4% of the cohort reported more concussions at the follow-up administration.[122] Inherent issues related to any self-report injury data, such as imperfect recall, may have resulted in the change in recall over time. Kerr et al.[122] also speculated that "social cognitive theory," which suggests that individuals acquire knowledge through interactions with other individuals,[124] may have contributed to the increases in the number of concussions that were self-reported. Over the past decade, the presence of stories related to the safety of athletes in general (e.g., The New York Times) and sport-specific media (e.g., ESPN, Sports Illustrated) has greatly increased.[125] Increased media reporting of concussion injury may have sensitized the former athletes to the significance of concussion, increased their concussion knowledge, and thus, altered their recall of the injuries they sustained during their professional careers. This could create differential recall bias if it resulted in a more complete recall of concussion details in those who have worse mental health. Differential recall bias could also result from former players experiencing normal cognitive decay due to aging, which may prompt them – and their families – to dwell more on their health and as a result, spuriously result in increased attribution of life changes to concussions. However, Kerr et al.[122] did not have available data to ascertain exposure to media coverage.

2.5.1.2 Validity of Athlete-Recalled Concussion History

Validity examines the extent to which an experiment, test, or any measuring procedure yields an accurate inference of truth. The evidence for the validity of athlete-recalled concussion history has not been sufficiently examined. Currently, validity-focused

research pertaining to concussions is limited to concussion symptomatology and recovery,[126-130] as opposed to detection and diagnosis. Examinations of valid detection and diagnosis are warranted as 35.2-62.1% of athletes not reporting all sustained concussions to coaches and/or team medical staff.[49,50,131-133] As a result, it is essential to ensure that all factors contributing to imperfect recall are considered in any validation study pertaining to athlete-recalled concussion history.

First, inaccurate detection of concussion is exacerbated by players' lack of knowledge about concussions (Table 2.3). Despite recent concussion education programs such as the CDC's "Heads Up" intervention,[134] athletes may still not able to appropriately identify concussions and their less common symptoms, such as nausea.[67] Athletes may have also believed that injuries were not serious enough to warrant disclosure. A recent study[135] surveyed a sample of high school student-athletes on the number of "bell-ringers" they sustained alongside concussions. "Bell-ringers" were loosely defined as the events in which athletes had their "bell rung" or were "dinged." "Bell-ringers" typically are not seen as serious of injuries as concussions; however, the authors believed that athletes may misdiagnose concussions as "bell-ringers" because they did not perceive the injury to be as serious as they would expect a concussion to be. The study found that 40% of concussions and 13% of "bell-ringers" reported by athletes had been reported to ATs/coaches. The findings suggest that first, many concussions are unreported; and second, perceived severity of head injury and disclosure are associated.

Table 2.3. Study findings regarding reasons for non-disclosure of concussion among athletes

	Study				
Reason for non-disclosure	**Broglio et al. (2010)[133]**	**Kroshus et al. (2013)[131]**	**Llewellyn (in press)[49]**	**McCrea et al. (2004)[132]**	**Register-Mihalik et al. (2013)[50] a**
Did not think it was serious enough	94.4%	69.7%	42.1%	66.4%	70.2%
Did not want to leave the game/practice	66.7%	48.3%	42.1%	41.0%	50.0%[b]
Did not know it was a concussion	66.7%	50.6%	52.6%	36.1%	14.9%
Did not want to let down team	38.9%	32.6%	42.1%	22.1%	27.0%
Did not want to be pulled from future game/practice	X[c]	X	52.6%	X	X
Would have it was a less important game/practice	X	X	21.1%	X	X
Concussions are part of the game	88.9%	X	X	X	X
Did not want to let down coaches	X	X	X	X	23.0%

NOTE: Respondents could endorse multiple items, therefore items sum to more than 100%

[a]Percentages for non-disclosure also include "bell-ringer" events

[b]Sum of percentages of not wanting to be removed from game (36.5%) and not wanting to be removed from practice (13.5%)

[c]X = was not included in study's list of potential responses

Athletes may also choose to purposefully withhold disclosure of their concussion symptoms (Table 2.3). They may not want to be taken out of the game and may be concerned they will let down their coaches and teammates if they are removed.[49,131-133,136] Athletes may also feel pressured by cultural norms regarding playing through pain and choose to continue playing despite being injured or symptomatic.[137,138] There is a dearth of empirical information regarding the social and behavioral factors that may hinder or facilitate athlete disclosure of concussion symptoms. Better understanding these barriers to disclosure

will help drive the development of interventions designed to help athletes recognize concussion symptomology and understand the importance of disclosing concussions.

2.5.2 Comparing Athlete-Recalled and Clinically-Documented Concussion Data

The lack of evidence supporting the validity of athlete-recalled concussion history highlights the need to establish concurrent validity (i.e., the extent to which instruments are able to measure the same concept at the same time) with other sources of concussion history, such as clinical records. An appropriate "gold standard" of concussion frequency originating from clinical data is hard to define and potentially may not be readily available. Past clinically-documented concussion histories may be incomplete and thus insensitive to accurately detecting concussions.[112] Detecting and diagnosing concussion has also been limited due to the lack of a standard definition related to symptomatology, as well as a biologic marker to detect injury.

The clinical variability and evolving understanding of concussion symptomatology and care in the medical community also affects detection.[114,116,139]. Past concussions may have been undetected because these concussions did not exhibit symptoms that previously were deemed necessary for diagnosis, such as loss of consciousness and amnesia.[28] These symptoms are now considered predictors of subsequent recovery time and neuro-cognitive deficits.[140-143] Furthermore, even current concussion medical data is heavily influenced by the skill and knowledge of the clinician treating the concussed athlete. Without a clear understanding of guidelines related to symptomatology, the sensitivity and specificity of clinically-documented concussion histories may vary among studies.[36,126-129,144] A "gold-standard" originating from clinically-documented concussion history is possible if sports

medicine professionals with proper and up-to-date training on identifying and diagnosing concussions are on-site during any sports activity, and if athletes willingly disclose all concussions otherwise undetected. Unfortunately, such circumstances are infrequent.

2.6 Summary

The large number of NCAA student-athletes that never play in the professional level[99] warrants examination of the current health of former collegiate athletes. In addition, the association of recurrent concussion and mental health has been solely studied among former male athletes in high contact professional-level sports, as opposed to female athletes and non-football athletes. Furthermore, outcome measures utilized in previous studies are limited, mostly relying upon self-reported recall of clinical diagnosis. Validated scale measures of mental health (e.g., depression, impulsivity, aggression) are also underutilized.

Athletes' recall of concussions is associated with numerous influences that operate at multiple levels, as posited by the socio-ecological framework (Figure 2.1). However, research on the evidence for the validity of athlete-recalled concussion history is very limited. Without further examination, the literature on recurrent concussion's association with mental health will remain limited by its samples and usage of self-reported measures of concussion history.

Clinically-documented concussion history is also limited if sports medicine professionals lack an understanding of the symptomatology of concussions, and if athletes do not disclose all concussions. Identifying the reasons for which athletes with this clinical data did not disclose concussions will help drive the development of policy and interventions that

will encourage proper reporting of injuries, and consequently help develop a legitimate "gold-standard" of concussion history.

The proposed dissertation will examine the following general research questions:

RQ1: What is the association of recurrent concussion and mental health in former collegiate athletes?

RQ2: How do athlete-recalled and clinically-documented concussion histories differ?

This dissertation will utilize a cohort of former collegiate athletes that played in 1987-2012.

CHAPTER 3

STATEMENT OF SPECIFIC AIMS

This dissertation, the first study to examine the health of former collegiate athletes, addresses three specific aims (Tables 3.1 to 3.2).

Aim 1: Estimate the association between recurrent concussion and mental health in former collegiate athletes (Table 3.1)

Aim 1a: Estimate the association between recurrent concussion and current levels of depression, impulsivity, and aggression in former collegiate athletes

Aim 1b: Compare effect estimates of the association between recurrent concussion and current levels mental health that utilize a total concussion history with a college and professional sports concussion history

Hypotheses:

H1: Recurrent concussion will be associated with higher levels of depression, impulsivity, and aggression in former collegiate athletes.

H2: Effect estimates that utilize a total concussion history will vary from effect estimates that utilize a college and professional sports concussion history

Rationale: Previous research regarding the association of recurrent concussion and mental health is limited by utilizing a small segment of former athletes: older male athletes in

high contact sports. As a result, these findings may not be generalizable to former athletes that are female or from sports with lower contact levels, such as soccer and basketball. Our sample included former athletes, both male and female, that had played in 27 sports during college.

At the same time, previous measurements of health outcomes are limited by utilizing self-reported recall of diagnoses of conditions, which are prone to recall bias. Outcomes, such as Alzheimer's disease are also more likely to affect older individuals. However, CTE may often be misdiagnosed as Alzheimer's disease.[13,59] As a result, it may be better to examine mental health outcomes such as depression, impulsivity, and aggression[18,58] that may be associated with CTE and more prevalent in younger populations.

In addition, in studies, only concussions sustained during professional careers were considered in analyses. Consequently, a proportion of the "non-exposed" athletes (i.e., no professional sport concussions) in previous studies may have sustained concussions in other sports and non-sports settings. It may be more appropriate to consider a complete concussion history that includes all sports-related and non-sports related concussions sustained across the lifespan.

Data: We collected questionnaire data from a cohort of former collegiate athletes, male and female, that had played from 1987 to 2012 (n=797).

Table 3.1. Summary of Aim 1 for Dissertation

#	Aim	Data	Analysis
1	**Estimate the association between recurrent concussion and mental health in former collegiate athletes**		
1a	Estimate the association between recurrent concussion and current levels of depression, impulsivity, and aggression in former collegiate athletes	Questionnaire data from 797 former collegiate athletes	(1) Binomial regression and linear risk regression estimating prevalence ratios and prevalence differences of levels of mental health
1b	Compare effect estimates of the association between recurrent concussion and current levels mental health that utilize a total concussion history with a college and professional sports concussion history		(1) Rerun analyses utilizing a concussion history consisting only of college and professional sports-related concussions

Aim 2: Compare athlete-recalled and clinically-documented concussion histories in former collegiate athletes (Table 3.2)

Aim 2a: Estimate the level of agreement between athlete-recalled and clinically-documented concussion histories

Aim 2b: Examine whether sex- or sport contact level- specific variations exist in the level of agreement between athlete-recalled and clinically-documented concussion histories

Aim 2c: Explore the reasons for which athlete-recalled and clinically-documented concussion histories may differ

Hypotheses:

H1: The number of athlete-recalled concussions will be higher than the number of clinically-documented concussions in former collegiate athletes.

H2: Factors such as sex- and sport contact level-specific variations affects the level of agreement between athlete-recalled and clinically-documented concussion histories in former collegiate athletes.

H3: Former collegiate athletes will indicate reasons for which athlete-recalled concussions were not reported by clinically-documented concussions.

Rationale: Understanding the detection capabilities of athlete-recalled concussion history against clinically-documented concussion history will help yield more accurate estimates of concussion history in future research. Unfortunately, medical records from professional sports, such as the NFL, are inconsistent, hard to access, or nonexistent. The literature also suggests sex differences in the reporting of concussion, which has yet to be further explored.

Data: We identified 130 former UNC athletes that had completed an online questionnaire and also had clinical data from their collegiate sports careers available.

Table 3.2. Summary of Aim 2 for Dissertation

#	Aim	Data	Analysis
2	**Compare athlete-recalled and clinically-documented concussion histories in former collegiate athletes**		
2a	Estimate the level of agreement between athlete-recalled and clinically-documented concussion histories	Clinical data from 130 former UNC athletes that underwent clinical observation at UNC during 1996-2012 SEX: Males: n=82; Females: n=48 RACE/ETHNICITY: Non-Hispanic Whites: n=109; Nonwhite/Hispanic: n=21 CONTACT LEVEL: Collision sports (i.e., football, wrestling): n=42; High contact sports (i.e., basketball, field hockey, lacrosse, soccer): n=79; Low/Non-contact sports (i.e., cheerleading, diving, track and field pole vault): n=9 TIME: Started college sports career before 1996: n=25; 1996-2000: n=49; 2001-2004: n=28; 2005 and after: n=28	(1) Compute ICC coefficient and % agreement between concussion histories
2b	Examine whether sex- or sport contact level- specific variations exist in the level of agreement between athlete-recalled and clinically-documented concussion histories		(1) Repeat analyses from Aim 2a within each stratum (2) Compare ICC scores and % agreement by stratification levels
2c	Explore the reasons for which athlete-recalled and clinically-documented concussion histories may differ		(1) Descriptive analyses

CHAPTER 4

METHODS

4.1 Former Collegiate Athlete Cohort

Our eligible study population was comprised of former collegiate athletes that played at least one season of a collegiate sport at UNC between 1987-2012. We contacted the UNC Alumni Association, who provided the names and graduation years of 5,153 former athletes, 3,657 of whom had valid email addresses.

4.1.1 Data Collection of Former Collegiate Athlete Cohort

The target sample was emailed an invitation to participate in the research study with the URL to the online questionnaire. The inclusion criteria for eligibility into the study cohort were: (1) played at least one season of a collegiate sport between 1987 and 2012; (2) aged 18 years or older; (3) had a working email address provided by the university alumni association; and (4) able to read and understand English. Upon clicking the link and consenting to participate, respondents completed the online questionnaire, which was hosted on Qualtrics through the UNC Odum Institute (see Appendix). Non-respondents received up to six reminder emails over the course of the three-month data collection window (April to June 2013).

4.1.2 Online Questionnaire

The online questionnaire was based upon the Retired NFL Athletes Cohort health survey.[10] It collected information on sports history and health status (Table 4.1). The questionnaire was piloted in a convenience sample of four former Division I student-athletes and eight ATs from one university that provided care to collegiate athletes. The questionnaire was then revised based on their feedback prior to deployment.

We received data from 808 former UNC student-athletes. Of those, 11 did not complete the online questionnaire, leaving 797 available for analysis. In addition, ten members of the target population informed us that they were student managers as opposed to student-athletes. This led a completion rate of 21.9% [797/(3657-10)]. Respondents came from 27 collegiate sports (Table 4.2). Compared to the 2013/14 UNC athlete roster, sport distributions in the former collegiate athlete cohort were similar. However, within the former collegiate athlete cohort, there were larger proportions of athletes from women's rowing (+4.0%), women's fencing (+3.5%), men's fencing (+3.2%), and smaller proportions of athletes from men's football (-6.4%), and equestrian (-2.4%). Also, respondents graduated slightly earlier (Mean: 1999) than non-respondents (Mean: 2000) ($P<0.001$). Specific information collected from the online questionnaire is described in the following sections.

Table 4.1. Content of former collegiate athlete cohort online questionnaire		
Section	**Title**	**Item**
1	**Sports history**	Primary collegiate sport
		Primary position played
		Other collegiate sports played
		Age and grade began playing primary sport
		Years began and ended college sports
		Weight and height during last year of collegiate sports
		Played professional sports? (If yes, which sport(s), and years began and ended professional career)
		Sustained career-ending injury? (If yes, type of injury, year of injury)
2	**Concussion history**	# sports-related concussions (high school, college, professional)
		# concussions evaluated at least once by medical staff
		# times returned to practice/competition same day due to resolved symptoms
		# times returned to practice/competition same day despite still having symptoms
		# concussions with prolonged symptoms (>1 week)
		Sport played, year in school, time in season, during practice/competition for college sports-related concussions
		Year in school for non-sports-related concussions during college
		Reasons for undiagnosed concussions (including non-disclosure)
3	**Health status**	12-item Short Form of the Buss-Perry Aggression Questionnaire (BPAQ-SF)
		Short Form of the Barratt Impulsiveness Scale (BIS15)
		Patient Health Questionnaire (PHQ-9)
		Alcohol dependence and other compulsive behaviors
4	**Medical history**	Diagnosis of conditions (if yes, has the problem occurred within the past three months, receiving medicine or treatment for the condition, does condition limit activities)
		Family history of conditions
5	**Demographics**	Sex
		Age
		Weight and height
		Marital status
		Education level
		Work status
		Race/Ethnicity
		Disability status

Table 4.2. Distributions of former collegiate cohort and 2013/14 school year athlete roster, by sport

	Former collegiate athlete cohort		2013/14 Roster	
Sport	**n**	**%**	**n**	**%**
Men's Baseball	31	3.9	34	4.4
Men's Basketball	22	2.8	16	2.1
Men's Cross Country	8	1.0	20	2.6
Men's Fencing	54	6.8	28	3.6
Men's Football	75	9.4	122	15.8
Men's Lacrosse	35	4.4	43	5.6
Men's Soccer	22	2.8	31	4.0
Men's Swimming and Diving	44	5.4	32	4.2
Men's Tennis	13	1.6	14	1.8
Men's Track and Field	34	4.3	48	6.2
Men's Wrestling	27	3.4	35	4.5
Women's Basketball	14	1.8	13	1.7
Women's Cross Country	14	1.8	15	1.9
Women's Fencing	48	6.0	19	2.5
Women's Field Hockey	29	3.6	25	3.2
Women's Golf	16	2.0	8	1.0
Women's Gymnastics	21	2.6	13	1.7
Women's Lacrosse	25	3.1	33	4.3
Women's Rowing	66	8.3	33	4.3
Women's Soccer	30	3.8	36	4.7
Women's Softball	30	3.8	22	2.9
Women's Swimming and Diving	45	5.6	33	4.3
Women's Tennis	11	1.4	8	1.0
Women's Track and Field	52	6.5	38	4.9
Women's Volleyball	27	3.4	18	2.3
Cheerleading	3	0.4	15	1.9
Equestrian	1	0.1	19	2.5
Total	**797**	**100.0**	**771**	**100.0**

4.1.2.1 Athlete-Recalled Concussion History

Respondents reported the number of concussions they sustained during sports participation, including at high school, college, and professional (if applicable) levels. Respondents also reported the number of non-sports related concussions (e.g., from a car crash, fall, or violence). We reminded respondents that these non-sports related concussions may also include any childhood injuries that they had been told about, but may not

remember. Concussions were defined as: "occurring typically, but not necessarily, from a blow to the head followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, 'seeing stars', feeling in a fog, or slowed down, memory problems, poor concentration, nausea, or throwing-up. Getting 'knocked out' or being unconscious does not always occur with a concussion." This definition was modified from the Retired NFL Athletes Cohort health survey[10] to indicate that concussions need not result from direct impacts to the head.

For sports-related concussions, respondents reported the number of concussions that: (1) were evaluated at least once by a physician or AT; (2) resulted in being returned to practice/ competition on same day because symptoms resolved; (3) resulted to being returned to practice/ competition on same day despite still experiencing symptoms; and (4) resulted in prolonged symptoms (more than one week). For non-sports related concussions, respondents were also asked to reported the number of concussions that were: (1) evaluated at least once by a physician; and (2) resulted in prolonged symptoms (more than one week).

Because we were interested in matching concussions that were athlete-recalled to those that were clinically-documented, we asked specific information about the time and circumstances of sport- and non-sport-related concussions that were sustained during college. For each concussion, respondents identified the month, day, and year of injury, as well as the year in school (i.e., Freshman, Sophomore, Junior, Senior, 5th Year Senior, Grad School). In addition, respondents also provided qualitative information that specified the circumstances around injury (e.g., injury of mechanism, specific competition at which injury occurred) in case respondents incorrectly remembered the time of injury.

Next, respondents were asked about “any other hard hits, bell-ringers, or dings” that were sustained during participation in college sports and should have been diagnosed by team medical staff as concussions, but were not. Respondents then answered why they thought these concussions went undiagnosed, as well as the sources of information that helped them subsequently understand that these “hard hits, bell-ringers, or dings” may have been undiagnosed concussions. All respondents who reported that they did not disclose all college sports-related concussions were asked the reason for non-disclosure, using a closed-response list originating from McCrea et al.[132]

4.1.2.2 Patient Health Questionnaire for Depression

The Patient Health Questionnaire (PHQ) is the self-administered version of the PRIME-MD diagnostic tool that is used to screen and diagnose health disorders. The depression module (PHQ-9) (α=0.85) consists of the nine criteria from the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV) that were scored from "0" (not at all) to "3" (nearly every day). The PHQ-9 has been found to be a reliable and valid scale,[145] with psychometrics comparable to that of the Beck Depression Inventory (which is not a public domain scale as is the PHQ-9).[146] Usage of the scale in former athletes is limited to the study of retired NFL players.[11,105]

4.1.2.3 Short Form of the Barratt Impulsiveness Scale

The Barratt Impulsiveness scale (BIS-11) consists of 30-items answered on a four-point scale (1=”rarely/never”; 4=”almost always”). On the basis of factor analyses,[147] items in the BIS-11 can be separated into three subscales: attentional (8 items); motor (11 items);

and non-planning (11 items). Internal consistency has validated the measure in various populations.[147] The Short Form of the Barratt Impulsiveness scale (BIS15) (α=0.84) was created using a convenience sample of 700 non-institutionalized adults.[148] The 15 items that had the highest loadings on the three factors of the scale comprised the BIS15. The BIS15 was also found to have strong correlations with The Frontal Systems Behavior Scale, which measures neurobehavioral traits associated with prefrontal systems, and linked to impulsivity.[148] The BIS-11 and the BIS15 have yet to be used in the study of former athletes.

4.1.2.4 12-item Short Form of the Buss-Perry Aggression Questionnaire

The Buss-Perry Aggression Questionnaire (BPAQ) consists of 29-items answered on a five-point scale (1="extremely uncharacteristic of me"; 5=" extremely characteristic of me"). On the basis of factor analyses,[149] items in the BPAQ can be separated into four subscales: physical aggression (9 items); verbal aggression (5 items); anger (7 items), and hostility (8 items). Test-retest reliability had been previously established for all four subscales.[149] The measure has been previously utilized in samples of athletes.[109-111] The 12-item Short Form of the Buss-Perry Aggression Questionnaire (BPAQ-SF) (α=0.89) was created by omitting items with low loadings or multiple loadings based on principal components analysis and excluding items with reverse-scored wording. The resulting 12-item measure retained the four subscales and yielded acceptable goodness of fit.[150] The BPAQ-SF has yielded strong construct and discriminant validity across American, British, and Canadian samples.[150] Although one study[108] has noted the BPAQ (and thus the BPAQ-SF) may not be appropriate for measuring aggression during sports play, our study rather intends to capture current aggression levels in former athletes.

4.1.2.5 Alcohol Dependence and Other Compulsive Behaviors

The CAGE questionnaire is a four-item questionnaire used to screen for alcohol dependence.[151] Scores of 3 and 4 (3-4 of questions answered "yes") have good positive predictive value (i.e., individuals with these scores are likely to actually suffer from alcohol dependence).[152] The measure has been validated in multiple clinical and research settings with samples of both men and women.[152,153]

Respondents also identified if they ever felt that they had problems with other behaviors that they could not control, such as gambling, substance use other than alcohol (e.g., illicit drugs, prescription drugs), and uncontrolled eating (i.e., binge eating, purging).

4.1.2.6 Medical History

Questions related to medical history were modified from the Retired NFL Players Cohort health survey. This original survey was limited in that it only considered medical conditions that had been diagnosed by a physician or health professional. We speculated that respondents: (1) may not have access to healthcare; (2) may opt not to seek medical care for these conditions; and (3) may have a family history related to these conditions. As a result, we asked respondents if they felt that they had any of the listed conditions, and whether anyone related to them by blood had been diagnosed or treated with any of the listed conditions. Respondents noting that they had any of the listed conditions were then asked whether they: (1) had ever been diagnosed by a physician or health professional with the condition; (2) had received medicine or treatment for the condition; (3) currently have symptoms or had symptoms within the last three months from the condition; and (4) have

had daily activities (e.g., housework, exercise, or social activities) limited due to the condition.

A number of conditions listed on Retired NFL Players Cohort health survey were included on the questionnaire (e.g., depression; sleep apnea; coronary heart disease/heart attack; learning disability). However, because we expected a younger population of respondents, we excluded medical conditions that generally have a later onset (e.g., Alzheimer's disease; dementia). In addition, we included additional medical conditions (e.g., diabetes; anxiety; attention deficit disorder, with or without hyperactivity; bipolar disorder; impulse control disorder/conduct disorder).

4.1.2.7 Sports History

Sports history included measures related to: sports played in college and primary positions or events (defined as the positions or events that respondents played the most during their college sports careers); the year in which respondents began and ended their college sports careers; and weight and height during the final year of respondents' college sports careers. Respondents also noted the age and grade in which they began playing their primary sport (defined as the one sport in which they were most invested during college) and if they played at the professional level (and if so, which sports, and in what years). Finally, respondents indicated if they had sustained a career ending injury, including the type of injury and when the injury occurred.

4.1.2.8 Demographics

Questions capturing information on demographics (sex; age; weight; height; marital status; education level; work status; race/ethnicity; and disability status) originated from the

Retired NFL Players Cohort health survey,[10] and the Behavioral Risk Factor Surveillance Survey (BFRSS) questionnaire.[154]

4.1.3 Clinical Data

Beginning in 2001, UNC required preseason baseline testing as part of an ongoing clinical program for sports including basketball, cheerleading, diving, field hockey, football, lacrosse, soccer, track and field pole vault, and wrestling. Data from pilot testing of procedures (prior to mandate) was also available for some former athletes from these sports that played from 1996-2000. Baseline testing included a clinical evaluation, athlete-recalled symptom checklist, postural control assessment, and neurocognitive testing.[114,115] These tests were repeated after athletes sustained a concussion (sports- and non-sport-related) in order to track recovery progress and help inform return-to-play decision-making. Clinical data also included qualitative information that specified the circumstances around injury (e.g., mechanism of injury, specific competition at which injury occurred).

For the purposes of this clinical program, concussion was diagnosed by a physician according to previously published standards identified by the National Athletic Trainers Association Position Statement[114] and the International Conference on Concussion in Sport.[115,116] This widely accepted clinical definition of concussion has remained relatively unchanged since the 1990s, and incorporates the five following clinical, pathological, and biomechanical constructs: "(1) Concussion may be caused either by a direct blow to the head, face, or neck or by a blow elsewhere on the body with an "impulsive" force transmitted to the head; (2) Concussion typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously; (3) Concussion may result in neuropathologic changes, but the acute clinical symptoms largely reflect a functional

disturbance rather than a structural injury; (4) Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course; however, it is important to note that in a small percentage of cases, postconcussive symptoms may be prolonged; and (5) No abnormality on standard structural neuroimaging studies is seen in concussion."[115] Other post concussive symptoms may include loss of consciousness, post-traumatic amnesia, and blurred vision.

The primary purpose of this clinical dataset was to track neurological recovery from concussions sustained during participation in collegiate sports. However, this dataset also provides credible clinically-documented concussion histories that utilize: (1) a uniform and widely-accepted definition of concussion; (2) data management from accomplished and well-respected experts in concussions; and (3) insight from sports medicine professionals that have received extensive up-to-date training on recognizing and treating concussions.

From this clinical data, we collected clinically-documented concussion histories from 130 athletes in total. Additional data related to the ascertainment of clinically-documented concussions and matching online questionnaire and clinical data can be found in Sections 6.3.3 and 6.3.4.

4.2 Statistical Analysis

Level of significance for all analyses were set a priori at $P<0.05$. All analyses were conducted with SAS version 9.3 (SAS Institute, Cary, NC); Stata version 13 (Stata Corp., College Station, TX), and SPSS version 21 (SPSS, Chicago, IL). The study obtained

approval from the Institutional Review Board at UNC; all respondents provided informed consent.

4.2.1 Analysis for Aim 1

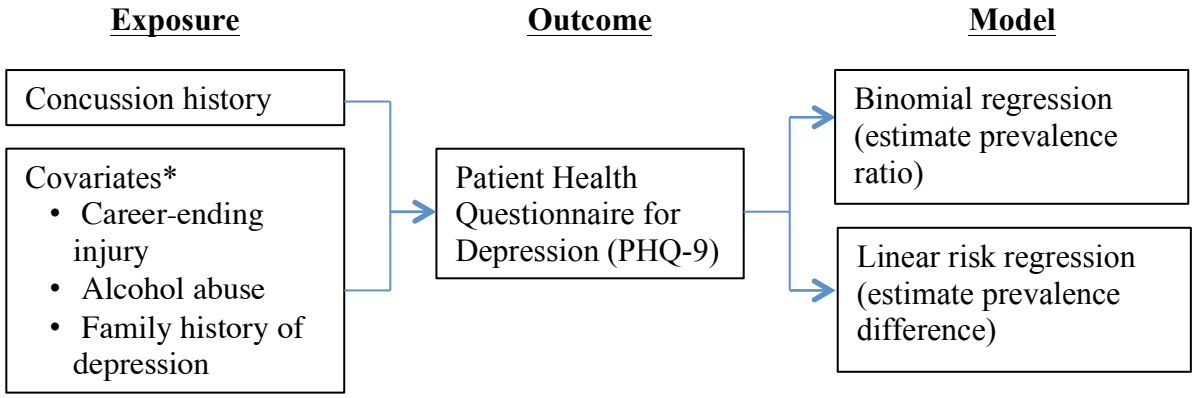
Our study estimated the association between recurrent concussion and current levels of depression, impulsivity, and aggression, in a sample of 797 former collegiate athletes. PHQ-9 scores are typically categorized into four levels of depression: Minimal (score of 0-4); Mild (score of 5-9); Moderate (score of 10-14); Moderately severe (15-19); and Severe (score of 20-27).[145] However, within the former collegiate athlete cohort, such categorization would have resulted in insufficient cell sample sizes. PHQ-9 scores ≥10 suggests currently meeting diagnostic criteria for major depression.[145] Kroenke and Spitzer[145] found that 88% of patients with no depressive disorder had PHQ-9 scores <10, and 88% of patients with major depression had scores ≥10. Thus, we categorized those with PHQ-9 scores <10 as not meeting diagnostic criteria for major depression (n=759). PHQ-9 is not able to account for those individuals that may score low due to being treated for depression so we excluded those respondents with PHQ-9 scores <10 that were currently being treated/medicated for depression (n=28). Because validated diagnostic cutpoints for impulsivity and aggression do not exist, we explored various methods for categorizing BIS15 and BPAQ-SF scores before deciding to utilize a median split for both measures. We considered modeling the outcomes continuously and with other dichotomous forms based upon natural breaks within the data. However, results did not considerably change from those we present in Section 5.4.

Crude prevalence ratios (PR) and prevalence differences (PD) were obtained with classical tabular methods. Adjusted PR and PD were estimated using binomial regression and linear risk regression,[155] respectively (Figures 4.1 to 4.3). Fitting algorithms for binomial and linear risk regression models were stabilized using Poisson residual and robust variance estimation.[155-157] Each model was run with total concussion history (i.e., all sport- and non-sport-related concussions) as the main exposure. We stratified total concussion history data into three categories: zero (referent), one to two, and three or more concussions.

Other covariates considered for all models included but were not limited to: sex (male/female), current age (continuous), current BMI (continuous); relationship status (single vs. in a relationship); education level (obtained graduate degree vs. did not obtain graduate degree); work status (currently employed at least part time vs. not currently employed at least part time); disability status (disabled vs. non-disabled); race/ethnicity (Non-Hispanic White vs. all other race/ethnicity combinations); primary college sport played (categorized by level of playing contact: collision, high contact; low/non-contact); number of years since played college sports (continuous); and played professional sports (yes/no). Specific covariates were also added to each model based on covariate-outcome associations found in previous research.[158-162] For models predicting depression, we also considered: alcohol dependence (continuous); sustaining a career-ending injury (yes/no); and having a blood relative that had been diagnosed or treated for depression (yes/no) (Figure 4.1). For models predicting impulsivity, we considered: alcohol dependence (continuous); and having a blood relative that had been diagnosed or treated for anxiety (yes/no) (Figure 4.2). For models predicting aggression, we considered alcohol dependence (continuous) (Figure 4.3). Additional information regarding the model building process for Aim 1 can be found in Section 5.3.4.

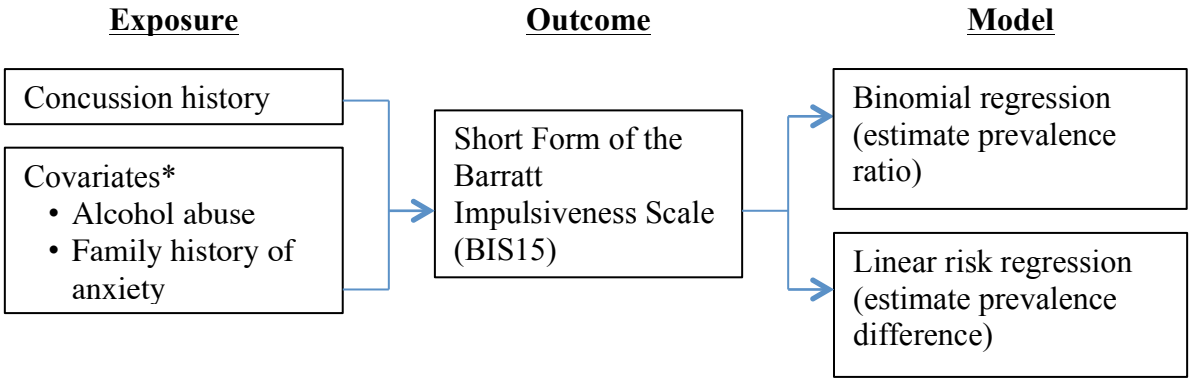
We then reran all analyses utilizing a concussion history that considered college and professional sports-related concussion history to determine how effect estimates may change. It is important to note that individuals in the referent category of zero college and professional sports-related concussions may not be "non-exposed" due to having sustained concussions in other sports and non-sports settings. Instead, this analysis will determine the usefulness of utilizing a segment of total concussion history as a proxy. Additional analyses are described in Section 5.3.4.

Figure 4.1. Statistical model for Aim 1a (Estimate the association between recurrent concussion and severity of depression, impulsivity, and aggression in former collegiate athletes): Depression outcome



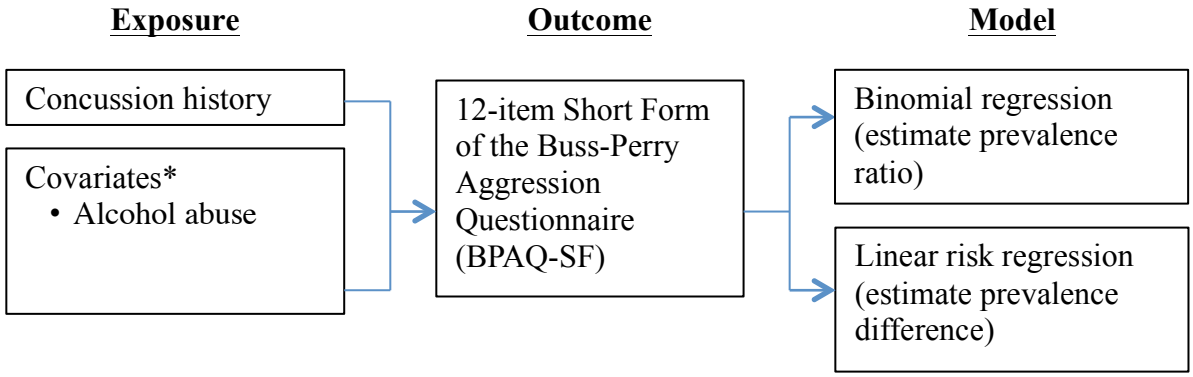
*Other covariates considered: sex; age; body mass index; relationship status; education; work status; disability status; race/ethnicity; primary college sport played (by level of playing contact: collision; high contact; low/non-contact); number of years since played college sports; and whether respondents played professional sports.

Figure 4.2. Statistical model for Aim 1a (Estimate the association between recurrent concussion and severity of depression, impulsivity, and aggression in former collegiate athletes): Impulsivity outcome



*Other covariates considered: sex; age; body mass index; relationship status; education; work status; disability status; race/ethnicity; primary college sport played (by level of playing contact: collision; high contact; low/non-contact); number of years since played college sports; and whether respondents played professional sports.

Figure 4.3. Statistical model for Aim 1a (Estimate the association between recurrent concussion and severity of depression, impulsivity, and aggression in former collegiate athletes): Aggression outcome



*Other covariates considered: sex; age; body mass index; relationship status; education; work status; disability status; race/ethnicity; primary college sport played (by level of playing contact: collision; high contact; low/non-contact); number of years since played college sports; and whether respondents played professional sports.

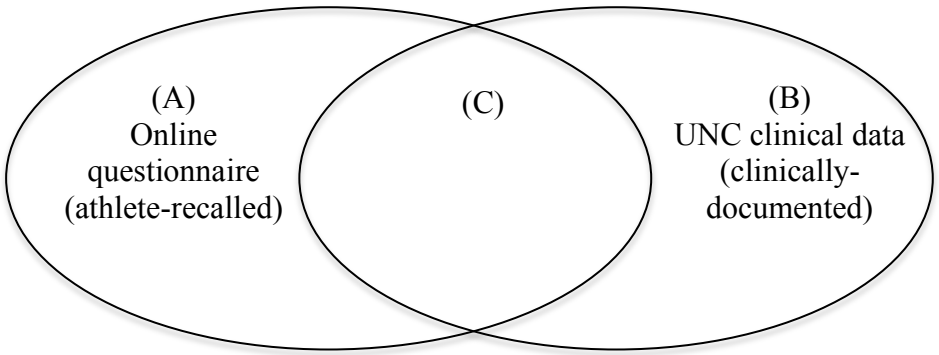
4.2.2 Analysis for Aim 2

Our study assessed the comparability between athlete-recalled and clinically-documented concussion histories. Athlete-recalled concussions were provided by 130 former collegiate athletes using the online questionnaire and individually linked to previously-collected clinical data that tracked medically-diagnosed concussions at UNC between 1996 and 2012.

Intraclass correlation coefficients (ICC)[163] assessed agreement between athlete-recalled and clinically-documented concussion histories. A value of 1.00 indicated perfect agreement; values between 0.81 and 0.99 suggested almost perfect agreement; values between 0.61 and 0.80 suggested substantial agreement; values between 0.41 and 0.60 suggested moderate agreement; values between 0.21 and 0.40 suggested fair agreement; and values between 0.00 and 0.20 suggested slight agreement.[164]

We also categorized concussions by those reported: (1) only by athlete-recalled concussion history data; (2) only by clinically-documented concussion history data; and (3) by both athlete-recalled and clinically-documented concussion history data (Figure 4.4).

Figure 4.4. Comparing concussions reported by online questionnaire and UNC clinical dataset



C/(A+C) = proportion of all concussions reported by online questionnaire that were also reported by clinical data
C/(B+C) = proportion of all concussions reported by clinical data that were also reported by online questionnaire

Section 6.3.5 includes additional information regarding: the calculation of percent agreement between athlete-recalled and clinically-documented concussion histories, overall and by strata; and descriptive analyses related to undiagnosed and undisclosed concussions, and sources of information for concussion knowledge**.**

CHAPTER 5

RESULTS FOR AIM 1: Association between recurrent concussion and current mental health in former collegiate athletes

5.1 Introduction

The Centers for Disease Control and Prevention (CDC) estimates that each year, up to 3.8 million sport-related concussions occur in the United States (US).[23] Sport-related physical activity is responsible for a large proportion of concussions,[22] thereby placing many athletes at risk of concussion and its long-term consequences.[24,34] Concussion rates are higher in sports permitting body contact such as football, soccer, hockey, and lacrosse than in low/non-contact sports such volleyball, and swimming.[24,35,36]

Recurrent concussions are of particular concern, given findings from living retired athletes suggesting that recurrent concussion may also accelerate long-term negative mental health outcomes, particularly depression, mild cognitive impairment, and Alzheimer's disease.[7,9,10,75,76,105] More recently, research has also examined head trauma's association with chronic traumatic encephalopathy (CTE), a progressive neurodegenerative disorder predominantly observed in professional athletes in high contact sports (e.g., football, boxing, ice hockey, professional wrestling) that have sustained repetitive head trauma.[13-15,18] It has been suggested that CTE may be associated with symptoms of mental health disorders such as depression, impulsivity, and aggression.[18,58]

However, the existing research is largely limited to samples of former professional athletes and has a number of methodological concerns. First, these studies typically utilized

male-only samples that had played collision sports such as football and ice hockey.[7,9,10,75,76,105] Thus, it is difficult to generalize findings to former athletes that are younger, female, and from sports with lower levels of contact. Second, with the exception of a few recent studies,[11,105,106] prior research has relied on single-item questions and has made limited use of validated scales to assess mental health outcomes. Third, in many cases, only concussions sustained during professional careers were considered in analyses. However, some of the "non-exposed" athletes (i.e., no professional sport concussions) in previous studies may have sustained concussions in other sport-related and non-sport-related settings. This could lead to biased effect estimates. A moderate correlation was found between the reported number of concussions sustained during one's professional and collegiate career;[100] however, it would be more appropriate to consider a complete concussion history that includes all sport-related and non-sports related concussions sustained across the lifespan. Researchers have limited concussion history to those concussions sustained during college and professional sports because former athletes probably have better recall of these concussions than earlier concussions due to memory decay effects. In addition, on-site clinical coverage during college and professional sports may have led to better detection and diagnoses of college and professional sport-related concussions. Finally, although depression has been previously studied in relation to recurrent concussion, there has been limited research to date on other mental health outcomes that have been speculatively linked to concussion, such as impulsivity and aggression.

The purpose of this study was to estimate the association between recurrent concussion and current levels of depression, impulsivity, and aggression in a cohort of former collegiate athletes. We also examined how use of a concussion history measure that

considered only college and professional sport-related concussions would influence effect estimates, relative to a concussion history that considered all sport-related and non-sport-related concussions. Compared to previous studies,[7,9,10,75,76,105] our cohort consisted of a younger population of former athletes, most of whom had not played professionally. Our sample drew from a diverse range of collegiate sports in order to include females and individuals that played sports with little or no body contact, but still were at risk of sustaining head injuries.

5.2 Methods

The study utilized a cross-sectional design. We received the email addresses of 3,657 former collegiate athletes from an alumni association of a Division I university in the southern US. These former collegiate athletes received an invitation to complete an online self-administered questionnaire. The questionnaire included a detailed concussion history, and previously-utilized multi-item scales for assessing depression, impulsivity, and aggression.

The inclusion criteria for eligibility into the study cohort were: played at least one season of a collegiate sport at the host university between 1987 and 2012; aged 18 years or older; had a working email address provided by the university alumni association; and able to read and understand English. Ten respondents informed us that they did not fit the eligibility criteria and were excluded. Reminder emails were sent every other week throughout the three-month data collection window (April to June 2013).

The online Qualtrics questionnaire, based on the Retired National Football League (NFL) Players cohort health,[10] collected information on sports history, concussion history,

current physical and mental health, and sociodemographics. An initial version of the questionnaire was pilot-tested on a group of 12 former student-athletes and certified athletic trainers providing care to collegiate athletes. The Institutional Review Board at (name removed for blinded review) approved all aspects of this study; all respondents provided informed consent.

5.2.1 Self-reported concussion history

Respondents reported the number of concussions they sustained during participation in sports, including at the high school, college, and (if applicable) professional levels. In addition, respondents reported the number of non-sports related concussions (e.g., from a car crash, fall, or violence). We reminded respondents that these non-sports related concussions may also include any childhood injuries that they had been told about, but may not remember. Concussions were defined as: "occurring typically**,** but not necessarily, from a blow to the head followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, 'seeing stars', feeling in a fog, or slowed down, memory problems, poor concentration, nausea, or throwing-up." Participants were reminded that "getting 'knocked out' or being unconscious does not always occur with a concussion."

5.2.2 Outcome measures of depression, impulsivity, and aggression

To assess depression, we used the depression module from the Patient Health Questionnaire (PHQ), a self-administered version of the PRIME-MD diagnostic tool that is in the public domain and has been used to screen and diagnose health disorders. The

depression module (PHQ-9) (α=0.85) consists of the nine criteria, scored from "0" (not at all) to "3" (nearly every day), that were provided by the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV). To assess impulsivity, respondents completed The Short Form of the Barratt Impulsiveness scale (BIS15) (α=0.84), an abbreviated version of the Barratt Impulsiveness scale (BIS-11).[148] The BIS15 consists of 15 items answered on a four-point scale (1="rarely/never"; 4="almost always"). Questions focused on: task-focus (attentional); acting without thinking (motor); and not thinking about the future (non-planning). To assess aggression, we used the 12-item Short Form of the Buss-Perry Aggression Questionnaire (BPAQ-SF) (α=0.89) is an abbreviated version of The Buss-Perry Aggression Questionnaire (BPAQ) that utilizes a five-point scale (1="extremely uncharacteristic of me"; 5=" extremely characteristic of me").[150] Questions focused on physical aggression, verbal aggression, anger, and hostility.

5.2.3 Covariates

In order to explore for potential confounding effects from other behavioral outcomes, we collected data on medical history. Respondents were asked whether they had any medical conditions (e.g., depression) and whether any blood relative had been diagnosed or treated with any of these conditions. Respondents noting any of the listed conditions were asked whether they were receiving medicine or treatment for the condition. We also assessed alcohol dependence using the CAGE questionnaire.[151]

Respondents provided a recalled sports history, including: sports played in college; the years in which participants began and ended their college sports careers; and whether participants sustained a career ending injury. Respondents that played more than one sport in

college were asked to identify the primary sport in which they were most invested. Last, we collected data on sex, current age, weight, height, relationship status, education level, work status, race/ethnicity, and disability status. From weight and height, we calculated respondents' body mass index (BMI).

5.2.4 Statistical analyses

Outcome measures were analyzed dichotomously. PHQ-9 scores ≥10 were classified as meeting diagnostic criteria for major depression.[145] Kroenke and Spitzer[145] found that 88% of patients without major depression had PHQ-9 scores <10, and 88% of patients with major depression had scores ≥10. Thus, we categorized those with PHQ-9 scores <10 as not meeting diagnostic criteria for major depression (n=759). PHQ-9 is not able to account for those individuals that may score low due to being treated for depression so we excluded those respondents with PHQ-9 scores <10 that were currently being treated/medicated for depression (n=28). Because validated diagnostic cutpoints for impulsivity and aggression do not exist, we explored various methods for categorizing BIS15 and BPAQ-SF scores before deciding to utilize a median split for both measures. Results utilizing these other forms did not considerably change from those presented in the results section below.

Crude prevalence ratios (PR) and prevalence differences (PD) were obtained with classical tabular methods. Adjusted PR and 95% confidence intervals (CI) were estimated using binomial regression. Adjusted PD and 95% CI were estimated using linear risk regression.[155] Fitting algorithms for binomial regression and linear risk regression models were stabilized using Poisson residual and robust variance estimation.[155-157] Each model was run with total concussion history (i.e., all sport- and non-sport-related concussions) as the

main exposure. We stratified total concussion history data into three categories: zero (referent), one to two, and three or more concussions.

Covariates considered for all models included the previously described sociodemographic and sports history variables: sex (male/female), current age (continuous), current BMI (continuous); relationship status (single vs. in a relationship); education level (obtained graduate degree vs. did not obtain graduate degree); work status (currently employed at least part time vs. not currently employed at least part time); disability status (disabled vs. non-disabled); race/ethnicity (Non-Hispanic White vs. all other race/ethnicity combinations); primary college sport played (categorized by level of playing contact: collision, high contact; low/non-contact); number of years since played college sports (continuous); and played professional sports (yes/no). Specific covariates were also added to each model based on previous research suggesting associations with outcomes.[158-162] For models predicting depression, we also considered: alcohol dependence (continuous); sustaining a career-ending injury (yes/no); and having a blood relative that had been diagnosed or treated for depression (yes/no). For models predicting impulsivity, we considered: alcohol dependence (continuous); and having a blood relative that had been diagnosed or treated for anxiety (yes/no). For models predicting aggression, we considered alcohol dependence (continuous).

Model building for all three outcomes was performed with binomial regression utilizing total concussion history. Effect measure modification was assessed between concussion history and covariates. Due to a small number of events, models predicting depression utilized forward selection model building, in which each covariate was added one at a time to a model that initially comprised the main exposure only. Chi-square test statistics

compared the models with and without the added covariate. The predictor yielding the smallest p-value was included. Due to the small number of events (i.e., PHQ-9 scores ≥ 10), the process was repeated until the model contained four predictors, or nine events per predictor variable. Models predicting impulsivity and aggression utilized backward selection model building, in which all covariates were initially included with the main exposure. For each covariate, chi-square test statistics compared the whole model with the reduced model that excluded the covariate. The predictor with the largest p-value was excluded. The process was repeated until no covariate yielded a p-value above 0.10. To ensure consistency, the covariates retained for the binomial regression models were also utilized for linear risk regression models.

The model-building strategy described above was implemented in a set of models that treated total concussion history as the main exposure. We also conducted additionally analyses using a concussion history that considered only college and professional sport-related concussions to determine how effect estimates changed relative to a total concussion history. As previously noted, the limitation of a concussion history that considers only college and professional sport-related concussions is that that individuals in the referent category of zero college and professional sport-related concussions may not be truly "non-exposed" had they sustained concussions in other sport-related and non-sport-related settings. This analysis sought to examine the effect on the estimated measures of effect of utilizing a partial concussion history based on more recent concussions. We also reran this analysis, restricted to include only those former collegiate athletes that sustained concussions solely during college and professional sports. We examined a more nuanced exposure variable in which on-sports-related and sports-related concussion history were treated as distinct types of

exposure. Due to the small number of former collegiate athletes with more than one non-sports-related concussion, non-sports-concussion history utilized a dichotomous split (zero, one or more). Aside from the noted level of significance for model-building, level of significance for all other analyses was set a priori at $P<0.05$.

5.3 Results

We received complete data from 797 (21.9%) former collegiate athletes. Respondents from 27 different collegiate sports were included, with a majority playing in men's football, followed by women's rowing, men's and women's fencing, and women's track and field (Table 5.1). The sport distribution was similar to the to the 2013/14 athlete roster at the host university that our sample had attended. The mean time since respondents' last year of participating in collegiate sport was 14.5 years [Standard Deviation (SD)=7.4], with 29.4% playing within the past ten years ago (Table 5.1). On average, respondents played their last year of collegiate sports slightly longer ago than non-respondents ($P<0.001$). Among respondents, 86.1% were non-Hispanic White; 70.2% were in a relationship; 48.1% obtained a post-graduate degree; and 87.7% were currently employed at least part-time. In addition, 11.5% played their primary sport professionally. Of all respondents, 16.2% had sustained a career-ending injury, and 0.8% were on disability.

Concussions (sport- and non-sport-related) were reported by 38.8% of respondents. Five respondents did not provide information on non-sport-related concussions and were excluded from analyses with total concussion history. Among those reporting no concussions during collegiate and professional sports (n=684), 28.6% reported sustaining at least one concussion elsewhere (e.g., high school sports, non-sport-related activities).

Agreement between total concussions and concussions sustained during college and professional sport-related was moderate (weighted Cohen's Kappa=0.47; 95% CI: 0.41, 0.53).

Among respondents, 4.7% had PHQ-9 scores ≥10, indicating that they currently meet diagnostic criteria for major depression (Table 5.2). Crude associations were observed between recurrent concussion and depression (Table 5.3). In multivariate binomial regression models controlling for covariates, the association was attenuated but still present. Controlling for alcohol dependence and family history of depression, the prevalence of currently meeting diagnostic criteria for major depression among former collegiate athletes reporting three of more concussions in total was 2.4 times that of former collegiate athletes reporting zero concussions (95% CI: 1.0, 5.7).

Average BIS15 scores for impulsivity were 26.0 (SD=6.0) (Table 5.2). Modest crude associations were observed between recurrent concussion and impulsivity (Table 5.3). However, in both binomial regression and linear risk regression models, estimates were attenuated following adjustment for covariates. Results were suggestive but not definitive. For example, controlling for covariates (alcohol dependence, family history of anxiety, relationship status, obtaining a post-graduate degree, played primary college sport professionally), former collegiate athletes reporting three or more concussions in total had an increased prevalence of higher levels of impulsivity, compared to those reporting no concussions (PD=0.09; 95% CI: -0.03, 0.20). We caution that PR may understate the strength of association for impulsivity since the prevalence of this outcome was approximately 50% (due to the use of a median split).

BPAQ-SF subscale scores for aggression (overall score mean: 18.7, SD=7.4) varied, with the highest score being verbal aggression (5.5, SD=2.6) and the lowest score being physical aggression (3.7, SD=1.7) (Table 5.2). Modest crude associations were observed between recurrent concussion and aggression (Table 5.3). In both binomial regression and linear risk regression models, estimates were attenuated following adjustment for covariates, but still present. As with impulsivity, we caution that PR may understate the strength of association for aggression since the prevalence of this outcome was approximately 50%. Controlling for alcohol dependence, sex, and relationship status, former collegiate athletes reporting three or more concussions in total had an increased prevalence of higher levels of aggression, compared to those reporting no concussions (PD=0.12; 95% CI: 0.01, 0.23).

We repeated analyses with a concussion history that considered only college and professional sport-related concussions. Effect estimates tended to be approximately similar to those obtained utilizing total concussion history, but varied for depression for the "one to two concussions" group (Table 5.4). In addition, due to the lower cell sizes for individuals sustaining college and professional sport-related concussions, effect estimates were less precise. Furthermore, lower precision was more evident when restricted to only those former collegiate athletes that sustained concussions only during college and professional sports (Table 5.5). At the same time, there was no evidence to suggest that the effect of sports-related concussion history differed from non-sports-related concussion history (Table 5.6).

5.4 Discussion

This study extends previous studies that examined the association between recurrent concussion and mental health.[7,9,10,75,76,105] This is the first study to examine these

associations in a cohort of former collegiate (rather than professional) athletes. The study cohort is the most diverse sample studied to date in terms of the sports studied. It is also the first such study to include both males and females, and extends prior work by exploring impulsivity and aggression as outcomes.

Our cohort of former collegiate athletes had a lower prevalence of meeting diagnostic criteria for major depression, compared to a sample of former NFL players (4.7% vs. 14.7%).[11] Nevertheless, the findings contribute to a growing body of evidence that links the risk of depression to self-reported concussion history in former athletes. Cross-sectional data[9] indicated that compared to retired NFL players that reported zero concussions during their professional football career, those reporting three or more concussions were three times as likely (95% CI: 2.3, 4.1) to report that they were diagnosed with depression. A follow-up study,[10] which incorporated longitudinal data and examined incidence of depression, found larger effect estimates and a stronger dose-response relationship between concussion history and the nine-year risk of depression diagnosis. A recent case-control study[105] also found a strong association between the number of lifetime concussions and depressive symptom severity, particularly cognitive symptoms such as feelings of sadness, guilt, and critical self-evaluation.

Compared to former collegiate athletes reporting sustaining zero concussions, former collegiate athletes reporting three or more concussions had a higher prevalence of high aggression. However, we caution interpretation of these results. There are currently no validated scales that allow for retrospective recall of these outcomes. Therefore, we had no means of assessing whether aggression (as well as depression and impulsivity) were manifested in participants prior to the onset of concussion. Subjects with high levels of

aggression in this study may have had the same aggression levels prior to their concussions, and outcomes such as aggression and impulsivity may have influenced the probability of exposure (e.g., aggressive playing behavior may have increased the risk of concussion). Our outcome measures are also unable to account for those that were depressed, impulsive, and aggressive, yet reported lower levels on the scale measures because they are currently being treated or medicated. To manage this with the PHQ-9, we excluded those respondents that did not currently meet diagnostic criteria for major depression, but were being treated/medicated for depression. We were unable to impose the same restriction for impulsivity and aggression. Future longitudinal studies that examine athlete cohorts and mental health outcomes longitudinally, while incorporating treatment/medication as time-varying covariates, will provide stronger assessments of these causal relationships.

Our main exposure, concussion history, may be prone to measurement and recall bias.[122] However, self-reported concussion history is easier to obtain than medical reports and also may be more complete. Recent findings have suggested a history of underreporting of concussion in clinical records, with between 35% and 62% of athletes not reporting all sustained concussions to coaches and/or team medical staff.[49,50,131-133] Our main exposure also accounts for the number of concussions sustained, but is unable to account for variations in the time since injury and the time between multiple concussions.

We also caution that concussion effects for some mental health outcomes, such as impulsivity, may not be apparent in our cohort due to their young age, particularly in comparison to the Retired NFL Players Cohort,[7,9,10] and the relatively short time (mean of 14.5 years) since they played collegiate sport. Adverse outcomes may take some time to develop and occur at a later age. Continued research with former athletes of all ages will

help determine a more precise age range at which the onset of negative mental health outcomes occurs.

Last, our findings illustrated that when solely considering college and professional sport-related concussions, as opposed to all sports- and non-sport-related concussions, effect estimates became less precise and in some cases, changed considerably. Previous research on retired professional football players[7,9,10] opted to utilize professional sport-related concussion history for multiple reasons. First, it was considered that professional sport-related concussion history could be more reliably assessed than total concussion history. Second, moderate correlation was found between the reported number of concussions sustained during former NFL players' professional and collegiate careers.[100] However, in this cohort of former collegiate athletes that included sports with low levels of contact, 28.6% of those reporting no concussions during collegiate and professional sports had sustained at least one concussion elsewhere (e.g., high school sports, non-sport-related activities). A complete concussion history may provide more valid estimates of the effects of sustaining concussions than a sport-related concussion history.

5.4.1 Limitations

Although repeated efforts were made to contact our target sample of 3,657 former collegiate athletes, our completion rate among eligible respondents was low (21.9%). The sample originated from one university and was restricted to those that had played at least one season in 1987-2012. Thus, our findings may not be generalizable to non-respondents, former athletes not in contact with the university alumni association, and former athletes from other universities, playing eras, or playing levels. Nonetheless, this study provides

estimates from a diverse population of former athletes. The study was cross-sectional, although findings highlight the need for longitudinal examinations of former athletes, particularly those that incorporate treatment/medication as time-varying covariates. As previously mentioned, information bias related to the exposure and outcomes may have resulted in biased effect estimates. Last, differential recall bias could also result from former players experiencing normal cognitive decay due to aging, which may prompt them to dwell more on their health and as a result, spuriously result in increased attribution of life changes to concussions.

5.4.2 Conclusion

Former collegiate athletes reporting a history of concussions may be at greater risk for prevalent major depression and higher prevalent levels of aggression, compared to those without a concussion history. There was insufficient evidence that impulsivity was associated with concussion history, although results were suggestive of a relationship. Additional prospective studies that better address causality are needed. In particular, studies should better ascertain a valid lifetime concussion history, as well as medical histories regarding diagnosis, treatment, and management of mental health issues. Nevertheless, current findings highlight the need to provide appropriate access to mental health care for former and current athletes.

Table 5.1. Sociodemographics and sports history of former collegiate athlete cohort (n=797)

Sociodemographics/ Sports history	n	%
Sex		
Male	376	47.2
Female	421	52.8
Age (in years)		
Less than 29	212	26.6
30 to 34	139	17.4
35 to 39	158	19.8
40 to 44	167	21.0
45 and over	121	15.2
Years since playing college sports		
Less than 5	78	10.0
5 to 9	152	19.4
10 to 14	170	21.7
15 to 19	143	18.3
20 to 24	149	19.1
25 or more	90	11.5
Missing	15	
College body mass index [a]		
Underweight/Normal	585	73.7
Overweight	159	20.0
Obese	50	6.3
Missing	3	
Current body mass index [a]		
Underweight/Normal	427	55.4
Overweight	264	33.2
Obese	90	11.3
Missing	3	
Total concussion history		
Zero	485	61.2
One or two	213	26.9
Three or more	94	11.9
Missing	5	
Highest education level		
High school/GED	6	0.7
Bachelor's degree	377	47.4
Post-graduate degree	413	51.9

Sociodemographics/ Sports history	n	%
Primary sport played		
Men's Baseball	31	3.9
Men's Basketball	22	2.8
Men's Cross Country	8	1.0
Men's Diving	6	0.8
Men's Fencing	54	6.8
Men's Football	75	9.4
Men's Lacrosse	35	4.4
Men's Soccer	22	2.8
Men's Swimming	38	4.8
Men's Tennis	13	1.6
Men's Track and Field	34	4.3
Men's Wrestling	27	3.4
Women's Basketball	14	1.8
Women's Cross Country	14	1.8
Women's Diving	8	1.0
Women's Fencing	48	6.0
Women's Field Hockey	29	3.6
Women's Golf	16	2.0
Women's Gymnastics	21	2.6
Women's Lacrosse	25	3.1
Women's Rowing	66	8.3
Women's Soccer	30	3.8
Women's Softball	30	3.8
Women's Swimming	37	4.6
Women's Tennis	11	1.4
Women's Track and Field	52	6.5
Women's Volleyball	27	3.4
Cheerleading	3	0.4
Equestrian	1	0.1
Level of contact		
Low/no contact	518	65.0
High contact	177	22.2
Collision	102	12.8
Race/ethnicity		
Non-Hispanic White	686	86.1
Non-Hispanic Black	71	8.9
Non-Hispanic Asian/PI [b]	11	1.4
Hispanic White	8	1
Hispanic Black	1	0.1

Missing	1	Mixed race	20	2.5

[a]WHO classifications: Underweight/Normal (<25.0kg/m^2); Overweight (25.0 – 29.9kg/m^2); Obese (≥30.0kg/m^2)
[b]PI=Pacific Islander

Table 5.2. Distribution and mean values of mental health outcomes, by self-reported total concussion history

Mental health outcome	Number of total concussions[a]			Total
	0	1-2	3+	
Depression (PHQ-9)[b]				
Mean (SD)	2.5 (3.0)	3.4 (4.0)	4.5 (5.0)	3.0 (3.7)
Categories, n (%)				
Minimal (0-4)	370 (79.9)	153 (73.2)	57 (63.3)	580 (76.1)
Mild (5-9)	80 (17.3)	41 (19.6)	25 (27.8)	146 (19.2)
Moderate (10-14)	9 (2.0)	9 (4.3)	4 (4.4)	22 (2.9)
Moderately Severe (15-19)	3 (0.7)	4 (1.9)	1 (1.1)	8 (1.0)
Severe (20-27)	1 (0.2)	2 (1.0)	3 (3.3)	6 (0.8)
% ≥10[c]	2.8%	7.2%	8.8%	4.7%
Impulsivity (BIS15)				
Mean (SD)	25.1 (5.2)	27.5 (6.6)	27.7 (7.4)	26.0 (6.0)
Subscale Mean (SD)				
Attentional	8.5 (2.4)	9.7 (2.9)	9.9 (3.3)	9.0 (2.7)
Motor	8.1 (2.1)	8.8 (2.5)	8.6 (2.5)	8.4 (2.3)
Non-planning	8.4 (2.6)	9.0 (2.8)	9.2 (3.2)	8.7 (2.7)
% over median	43.9%	57.4%	58.7%	49.4%
Aggression (BPAQ-SF)				
Mean (SD)	18.0 (6.3)	19.4 (7.8)	22.4 (10.0)	18.7 (7.4)
Subscale Mean (SD)				
Physical aggression	3.5 (1.3)	3.8 (1.9)	4.5 (2.7)	3.7 (1.7)
Verbal aggression	5.3 (2.4)	5.6 (2.6)	6.6 (3.1)	5.5 (2.6)
Anger	4.7 (2.2)	5.2 (2.7)	5.7 (2.9)	5.0 (2.5)
Hostility	4.5 (2.2)	4.7 (2.5)	5.6 (3.3)	4.7 (2.5)
% over median	45.5%	51.0%	66.0%	49.4%

NOTE: PHQ-9=Patient Health Questionnaire for Depression; BIS15=Short Form of the Barratt Impulsiveness scale; BPAQ-SF=12-item Short Form of the Buss-Perry Aggression Questionnaire; SD=Standard deviation; Sum of number of concussions may not equal 797 due to missing data for non-sport concussions and mental health outcomes

[a]Total concussions includes all sport- and non-sport-related concussions

[b]Excludes respondents with PHQ-9 scores <10 that were currently being treated/medicated for depression (n=28)

[c]PHQ-9 score ≥10 indicates currently meets diagnostic criteria for major depression

Table 5.3. Prevalence ratios and prevalence differences of mental health outcomes, by self-reported total concussion history[a]

Total concussions	n	PR (95% CI)		PD (95% CI)	
		Crude	Adjusted	Crude	Adjusted
Depression (PHQ-9)[b, c, d]					
0	463	1	1	0	0
1-2	209	2.6 (1.2, 5.3)	1.9 (0.9, 4.0)	0.04 (0.01, 0.08)	0.01 (-0.02, 0.03)
3+	90	3.2 (1.4, 7.4)	2.4 (1.0, 5.7)	0.06 (0.00, 0.12)	0.04 (-0.02, 0.09)
Impulsivity (BIS15)[e, f]					
0	476	1	1	0	0
1-2	209	1.3 (1.1, 1.5)	1.2 (1.0, 1.4)	0.14 (0.04, 0.26)	0.06 (-0.02, 0.14)
3+	92	1.4 (1.1, 1.6)	1.2 (1.0, 1.4)	0.15 (0.05, 0.22)	0.09 (-0.03, 0.20)
Aggression (BPAQ-SF)[e, g]					
0	477	1	1	0	0
1-2	210	1.1 (0.9, 1.3)	1.0 (0.9, 1.2)	0.05 (-0.03, 0.14)	0.00 (-0.08, 0.09)
3+	94	1.5 (1.2, 1.7)	1.2 (1.0, 1.5)	0.20 (0.10, 0.31)	0.12 (0.01, 0.23)

NOTE: PHQ-9=Patient Health Questionnaire for Depression; BIS15=Short Form of the Barratt Impulsiveness scale; BPAQ-SF=12-item Short Form of the Buss-Perry Aggression Questionnaire; PR=Prevalence ratio; CI=Confidence interval; PD=Prevalence difference;

[a]Total concussions includes all sport- and non-sport-related concussions

[b]Excludes respondents with PHQ-9 scores <10 that were currently being treated/medicated for depression (n=28)

[c]Model predicting PRs utilizes split where 0=<10 on PHQ-9, 1=≥10 on PHQ-9 (score ≥10 indicates currently meets diagnostic criteria for major depression)

[d]Adjusted models control for alcohol dependence and family history of depression

[e]Model predicting PRs utilizes median split where 0=median and below, 1=above median

[f]Adjusted models control for alcohol dependence, family history of anxiety, relationship status, education (obtained post-graduate degree), played primary college sport professionally

[g]Adjusted models control for alcohol dependence, sex, relationship status

Table 5.4. Prevalence ratios and prevalence differences of mental health outcomes, by self-reported college and professional sport concussion history

Sport-related high school and college concussions[a]	n	PR (95% CI)		PD (95% CI)	
		Crude	Adjusted	Crude	Adjusted
Depression (PHQ-9)[b, c, d]					
0	655	1	1	0	0
1-2	65	0.7 (0.2, 2.8)	0.6 (0.2, 2.5)	-0.01 (-0.06, 0.03)	-0.01 (-0.09, 0.06)
3+	47	2.4 (1.0, 5.9)	2.5 (1.1, 5.7)	0.06 (-0.02, 0.15)	0.05 (-0.05, 0.16)
Impulsivity (BIS15)[e, f]					
0	669	1	1	0	0
1-2	65	1.3 (1.1, 1.6)	1.1 (0.9, 1.4)	0.14 (0.02, 0.27)	0.06 (-0.07, 0.19)
3+	48	1.3 (1.0, 2.7)	1.3 (1.0, 1.6)	0.15 (0.01, 0.29)	0.13 (-0.02, 0.28)
Aggression (BPAQ-SF)[e, g]					
0	672	1	1	0	0
1-2	66	1.2 (0.9, 1.5)	1.1 (0.9, 1.3)	0.08 (-0.04, 0.21)	0.01 (-0.11, 0.14)
3+	48	1.3 (1.0, 1.6)	1.1 (0.9, 1.4)	0.13 (-0.02, 0.27)	0.05 (-0.09, 0.20)

NOTE: PHQ-9=Patient Health Questionnaire for Depression; BIS15=Short Form of the Barratt Impulsiveness scale; BPAQ-SF=12-item Short Form of the Buss-Perry Aggression Questionnaire; PR=Prevalence ratio; CI=Confidence interval; PD=Prevalence difference

[a]College and professional sport-related concussions only

[b]Excludes respondents with PHQ-9 scores <10 that were currently being treated/medicated for depression (n=28)

[c]Model predicting PRs utilizes split where 0=<10 on PHQ-9, 1=≥10 on PHQ-9 (score ≥10 indicates currently meets diagnostic criteria for major depression)

[d]Adjusted models control for alcohol dependence and family history of depression

[e]Model predicting PRs utilizes median split where 0=median and below, 1=above median

[f]Adjusted models control for alcohol dependence, family history of anxiety, relationship status, education (obtained post-graduate degree), played primary college sport professionally

[g]Adjusted models control for alcohol dependence, sex, relationship status

Table 5.5. Prevalence ratios and prevalence differences of mental health outcomes, by self-reported college and professional sport concussion history

		PR (95% CI)		PD (95% CI)	
Concussions[a]	**n**	**Crude**	**Adjusted[c]**	**Crude**	**Adjusted[c]**
Outcome=Depression (PHQ-9)[b, c]					
0	463	1	1	0	0
1-2	32	1.1 (0.2, 8.2)	0.9 (0.2, 4.5)	0.00 (-0.06, 0.07)	-0.02 (-0.10, 0.05)
3+	9	4.0 (0.6, 27.1)	3.8 (0.6, 24.3)	0.08 (-0.12, 0.29)	0.06 (-0.14, 0.27)
Outcome=Impulsivity (BIS15)[d, e]					
0	476	1	1	0	0
1-2	32	1.4 (1.0, 1.8)	1.2 (0.9, 1.6)	0.15 (-0.02, 0.33)	0.06 (-0.12, 0.24)
3+	9	1.0 (0.5, 2.1)	0.9 (0.5, 1.6)	0.01 (-0.32, 0.33)	-0.15 (-0.38, 0.07)
Outcome=Aggression (BPAQ-SF)[d, f]					
0	477	1	1	0	0
1-2	32	1.0 (0.6, 1.4)	0.9 (0.6, 1.3)	-0.02 (-0.29, 0.16)	-0.09 (-0.26, 0.08)
3+	9	1.5 (0.9, 2.4)	1.3 (0.8, 2.1)	0.21 (-0.10, 0.52)	0.15 (-0.16, 0.46)

NOTE: PHQ-9=Patient Health Questionnaire for Depression; BIS15=Short Form of the Barratt Impulsiveness scale; BPAQ-SF=12-item Short Form of the Buss-Perry Aggression Questionnaire; PR=Prevalence ratio; CI=Confidence interval; PD=Prevalence difference; *p-value <0.05

[a]Includes college and professional sports-related concussions; restricted to those former collegiate athletes sustaining concussions solely during college and professional sports

[b]Model predicting PRs utilizes split where 0=<10 on PHQ-9, 1=≥10 on PHQ-9 (score ≥10 indicates currently meets diagnostic criteria for major depression)

[c]Adjusted models control for alcohol dependence and family history of depression

[d]Model predicting PRs utilizes median split where 0=median and below, 1=above median

[e]Adjusted models control for alcohol dependence, family history of anxiety, relationship status, education (post-grad degree or not), played primary college sport professionally

[f]Adjusted models control for alcohol dependence, sex, relationship status

Table 5.6. Prevalence ratios of mental health outcomes, by self-reported sports- and non-sports-related concussion history[a]

Non-sports-related concussions	Sports-related concussions	PR (95% CI)	
		Crude	Adjusted
Outcome=Depression (PHQ-9)[b, c, d]			
0	0	1	1
	1-2	1.9 (0.7, 5.3)	1.8 (0.7, 4.8)
	3+	3.5 (1.2, 10.4)	2.9 (1.0, 8.5)
1+	0	2.7 (1.1, 6.6)	1.9 (0.7, 4.9)
	1-2	3.7 (1.4, 9.9)	2.2 (0.8, 6.6)
	3+	3.7 (0.9, 15.4)	2.6 (0.7, 8.9)
P-value for interaction[e]		0.60	0.70
Outcome=Impulsivity (BIS15)[f, g]			
0	0	1	1
	1-2	1.3 (1.0, 1.6)	1.1 (0.9, 1.3)
	3+	1.2 (0.9, 1.6)	1.1 (0.9, 1.5)
1+	0	1.3 (1.0, 1.6)	1.1 (0.9, 1.4)
	1-2	1.6 (1.3, 2.0)	1.5 (1.2, 1.8)
	3+	1.4 (1.0, 2.0)	1.1 (0.7, 1.7)
P-value for interaction		0.96	0.44
Outcome=Aggression (BPAQ-SF)[f, h]			
0	0	1	1
	1-2	1.2 (1.0, 1.5)	1.1 (0.9, 1.3)
	3+	1.3 (1.0, 1.7)	1.1 (0.9, 1.5)
1+	0	1.0 (0.8, 1.3)	0.9 (0.7, 1.2)
	1-2	1.5 (1.2, 1.8)	1.3 (1.1, 1.7)
	3+	1.5 (1.1, 2.0)	1.2 (0.8, 1.7)
P-value for interaction		0.70	0.30

NOTE: PHQ-9=Patient Health Questionnaire for Depression; BIS15=Short Form of the Barratt Impulsiveness scale; BPAQ-SF=12-item Short Form of the Buss-Perry Aggression Questionnaire; PR=Prevalence ratio; CI=Confidence interval; *p-value <0.05

[a]Total concussions includes all sport- and non-sport-related concussions

[b]Excludes respondents with PHQ-9 scores <10 that were currently being treated/medicated for depression (n=28)

[c]Model utilizes split where 0=<10 on PHQ-9, 1=≥10 on PHQ-9 (score ≥10 indicates currently meets diagnostic criteria for major depression)

[d]Adjusted models control for alcohol dependence and family history of depression

[e]Interaction for sports- and non-sports-related concussion histories

[f]Model utilizes median split where 0=median and below, 1=above median

[g]Adjusted models control for alcohol dependence, family history of anxiety, relationship status, education (post-grad degree or not), played primary college sport professionally

[h]Adjusted models control for alcohol dependence, sex, relationship status

CHAPTER 6

RESULTS FOR AIM 2: Agreement between athlete-recalled and clinically-documented concussion histories in a cohort of former collegiate athletes

6.1 Introduction

Participation in organized sports is at its highest ever recorded levels, particularly in youth.[5] Thus, it is important to accurately characterize the burden of sports injury on athlete well-being and health. Concussion is a serious injury in sports, with estimates of up to 3.8 million occurring in sports in the United States (US) annually.[23] Approximately 13.2% of all reported injuries occurring in high school sports in 2008-2010 were concussions.[24] Studies of current and former athletes suggest that recurrent concussion is associated with diverse adverse health effects, including: cognitive, neurobehavioral, and somatic symptomatology; slower recovery from concussion symptomatology; and earlier onset of negative mental health outcomes such as depression, mild cognitive impairment, and Alzheimer's disease.[7,9,10,26,29] Of note, chronic traumatic encephalopathy (CTE), a neuro-degenerative condition characterized by accumulation of tau proteins within certain brain structures, may be associated with recurrent head trauma.[58]

A methodological weakness of the evidence base on the long-term effects of concussions in former athletes is the dependence on athlete-recalled data and clinical records to compile concussion histories. There are no studies of the comparative validity of these two methods in athletes. Clinically-documented concussion reports from athletes' playing careers may be incomplete due to undisclosed or undiagnosed concussions (particularly

concussions that are not related to sports), and thus may be insensitive for a complete concussion history.[112] Variability in the clinical and research community in assessment methods for concussion also impacts detection sensitivity.[114,116,139] Concepts of what constitutes a concussion have evolved over time.[114] Past concussions may have been undetected because these concussions did not exhibit symptoms that previously were mistakenly deemed necessary for diagnosis, such as loss of consciousness and amnesia.[28] Furthermore, current concussion identification is likely influenced by the skill and knowledge of the clinicians treating concussed athletes.

Athlete recall is also far from perfect. Athlete-recalled histories are subject to memory decay and other subjective recall effects and typically lack clinical confirmation. Recent findings also suggest that 35.2-62.1% of athletes under-report concussions to coaches and/or team medical staff.[49,50,131-133] Athletes may be unable to appropriately identify concussions, or may believe that concussive impacts were not serious enough to warrant disclosure. Athletes may also choose to purposefully withhold disclose of concussions in order to avoid being taken out of games or letting down their coaches and teammates.[16-19,37,37] In addition, athletes pressured by self-imposed expectations and/or external cultural norms about "playing through pain" may choose to continue playing despite experiencing concussion symptoms.[137,138]

Even in the general (non-athlete) population, the validity of methods for obtaining determining a history of traumatic brain injury (TBI) is infrequently studied, in part because of the difficulty of obtaining a "gold standard" measure of TBI. Schofield et al.[165] compared the self-recalled TBI histories of prisoners with hospital medical records. Of the 112 self-recalled TBIs that resulted in treatment at an emergency department (ED), 70% had medical

records that verified the diagnosis. However, most TBIs (almost two-thirds of TBIs reported by prisoners) did not result in treatment at an ED. The limitations of clinical records for assessing TBI in a general ED population were underscored by Powell et al.,[166] who compared the level of agreement in concussion diagnoses between ED medical staff (through ED records) and research staff (through ED records, as well as emergency medical service records, and interviews with witnesses or the patient). Of the research staff-identified TBI cases, only 56% were identified as TBI cases by ED medical staff.

An improved understanding of the detection capabilities of athlete-recalled and clinically-documented concussion histories is needed to help develop more accurate estimates of concussion history for future research of former athletes and for clinical use with current athletes. The purpose of this study was to compare athlete-recalled and clinically-documented concussion histories in a group of former collegiate athletes. Our specific aims were to: (1) estimate the level of agreement between athlete-recalled and clinically-documented concussion histories that occurred during college; and (2) explore the potential reasons why athlete-recalled and clinically-documented concussion histories may differ.

6.2 Methods

The study utilized data from a cohort of former collegiate athletes at <*name removed for blinded review*> [a Division I National Collegiate Athletic Association (NCAA) university in the southern US]. Athlete-recalled concussion history was obtained via online self-administered questionnaire and individually linked to existing previously-collected clinical data for the same athletes for their complete collegiate playing career at<*name removed for blinded review*>. The Institutional Review Board at <*name removed for*

blinded review> approved all aspects of this study; all respondents provided informed consent.

6.2.1 Cohort definition and contact

To contact this cohort (n=3,657), we accessed current email addresses from our institution's alumni directory, maintained by the Department of Athletics. The inclusion criteria for eligibility into the study cohort were: (1) played at least one season of a collegiate sport between 1987 and 2012; (2) aged 18 years or older; (3) had an email address provided by the university alumni association; and (4) able to speak and understand English.

6.2.2 Athlete-recalled concussion history

The self-administered online Qualtrics questionnaire was based upon the Retired National Football League (NFL) Players cohort health survey[10] and collected information on sports history, concussion history, current physical and mental health, and demographics.

Respondents reported the number of concussions they sustained during participation in high school, college, and professional (if applicable) sports. In addition, respondents also reported the number of non-sports related concussions (e.g., from a car crash, fall, or violence). Concussions were defined as: "occurring typically, but not necessarily, from a blow to the head followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, 'seeing stars', feeling in a fog, or slowed down, memory problems, poor concentration, nausea, or throwing-up." Respondents were informed that "getting 'knocked out' or being unconscious does not always occur with a concussion." Respondents were reminded that these non-sport-related concussions may also

include any childhood injuries that they had been told about, but may not remember. For sport-related and non-sport-related concussions sustained during college, respondents identified the date in which each injury occurred. Because it may be unrealistic for respondents to remember precise concussion dates, the year in school at the time of injury was also requested. Respondents also provided qualitative information that specified the circumstances around injury (e.g., mechanism of injury, specific competition at which injury occurred).

Respondents were asked about impacts (i.e., "any other hard hits, bell-ringers, or dings") that were sustained during participation in college sports and should have been diagnosed by team medical staff as concussions, but were not. Respondents then answered why they thought these concussions went undiagnosed, as well as the sources of information that helped them subsequently understand that these impacts may have been undiagnosed concussions. All respondents who reported that they did not disclose all college sports-related concussions were asked the reason for non-disclosure, using a closed-response list originating from McCrea et al.[132]

The online questionnaire was piloted-tested and revised prior to data collection. A link to the online self-administered questionnaire was sent to the email addresses of the 3,657 former collegiate athletes. Reminder emails were sent every other week throughout a three-month data collection window. We received data from 808 former collegiate athletes, of which 11 were excluded for incomplete data, leaving 797 for analysis. In addition, ten members of the target population contacted us to inform us that they were former student managers as opposed to former athletes. This resulted in a completion rate of 21.9%.

6.2.3 Clinically-documented concussions

Beginning in 2001, our university required preseason baseline testing as part of an ongoing clinical program for sports including basketball, cheerleading, diving, field hockey, football, lacrosse, soccer, track and field pole vault, and wrestling. Data from pilot-testing of procedures (prior to mandate) was also available for some former athletes from these sports that played from 1996-2000. Baseline testing included a clinical evaluation, athlete-recalled symptom checklist, postural control assessment, and neurocognitive testing.[114,115] These tests were repeated after athletes sustained a concussion (sport-related and non-sport-related) in order to track recovery progress and help inform return-to-play decision-making. Clinical data also included qualitative information that specified the circumstances around injury (e.g., injury of mechanism, specific competition at which injury occurred).

We limited assessment of clinically-documented concussions (incident during playing career) to former athletes who completed pre-season concussion assessment procedures. Of the 797 respondents with complete questionnaire data, we identified 67 that played at a time in which preseason testing was required for their sport. Of these 67 former collegiate athletes, we obtained complete clinical data for 54 (81%). The remaining 19% were likely not available due to a combination of factors, including late report to school, presence of current injuries, miscommunication between clinical staff and team officials, and loss of clinical records. In addition, we obtained clinical data from 76 athletes with pilot testing of preseason clinical procedures prior to 2001. Thus, 130 athletes in total had preseason clinical data available (Figure 6.1).

6.2.4 Linking questionnaire and clinical data

We linked the two sources of concussion history - athlete-recalled and clinical records - using name, sport, birthdate, and approximate date of injury. We used two levels of matching criteria, which we refer to as "hard" and "soft". A match between the questionnaire data (i.e., athlete-recalled concussion) and clinical data (i.e., clinically-documented concussion) was defined as "hard" when: (1) the date in which a respondent athlete-recalled sustaining the concussion was within six months from the date reported by the clinical data; or (2) the school year that a respondent reported sustaining the concussion (i.e., Freshman, Sophomore, Junior, Senior, 5th Year Senior, Grad School) matched the school year reported by the clinical data. "Soft" matches were the same as "hard" matches except that discrepancies between sources on the date of injury were allowable if there was agreement about the circumstances of injury (injury of mechanism and the specific competition at which the injury occurred). Thus, for a "soft" match, reported/recorded year of injury could be discrepant between athlete recall and clinical records, if there was agreement on the injury of mechanism and/or the specific competition at which the injury occurred.

6.2.5 Statistical analysis

Intraclass correlation coefficients (ICC)[163] assessed agreement between athlete-recalled and clinically-documented concussion histories. We also categorized concussions by those reported: (1) only by athlete-recalled concussion history data; (2) only by clinically-documented concussion history data; and (3) by both athlete-recalled and clinically-

documented concussion history data. Percent agreement of clinically-reported concussions with athlete-recalled concussions was defined as:

$$\frac{\text{number of concussions reported by both data}}{\text{number of concussions reported by questionnaire data}}$$

Percent agreement of athlete-recalled concussions with clinically-reported concussions was defined as:

$$\frac{\text{number of concussions reported by both data}}{\text{number of concussions reported by clinical data}}$$

Results were also stratified by sex, race/ethnicity, and level of contact. We categorized level of contact as: collision sports (i.e., football, wrestling) (n=42); high contact sports (i.e., basketball, field hockey, lacrosse, soccer) (n=79); and low/non-contact sports (i.e., baseball, cheerleading, diving, rowing, track and field) (n=9).

Since changes in concussion reporting/awareness and diagnostic trends over time influence recall of concussions, we stratified results by the era in which athletes began playing collegiate sports: before 1996 (n=25); 1996 to 2000 (n=49); 2001 to 2004 (n=28); and 2005 and after (n=28). Because clinical data was only available starting in the 1996-97 school year, we excluded any concussions that respondents reported prior to the 1996-97 school year (n=2).

Finally, we tabulated counts of the items endorsed as the reasons that respondents believed college sports-related concussions went undiagnosed and undisclosed (based on the list of potential reasons we provided), and sources of information for concussion knowledge) based on a list of potential sources we provided, such as media, peers, and family/friends). Write-in responses for both questions were also tabulated.

6.3 Results

The majority of the 130 former collegiate athletes with clinical data available were male (63.1%, n=82), and played prior to 2001 (57.7%, n=75). Most were Non-Hispanic White (83.8%, n=109), followed by Non-Hispanic Black (13.1%, n=17) and Mixed race (3.1%, n=4). Mean age was 30.9 years (SD=4.4). A diverse range of sports was included (Table 1). Mean time since last year of collegiate play was 9.5 years [Standard Deviation (SD)=4.2].

6.3.1 Agreement between athlete-recalled and clinically-documented concussions

The average number of athlete-recalled concussions (mean=0.79, SD=1.27) was nearly three times the average number of clinically-documented concussions (mean=0.28, SD=0.57). Athlete-recalled concussion history indicated that 43.8% (n=57) had sustained one or more concussions during college, of which 53 (40.8%) sustained concussions during participation in collegiate sports. In contrast, clinically-documented concussion history indicated that 22.3% (n=29) had sustained one or more concussions during college.

Agreement between the number of athlete-recalled concussions and clinically-documented concussions was low (ICC=0.21, 95% CI: 0.05, 0.37) (Table 2). There were 21 "hard" matches, accounting for 58.3% of the 36 clinically-documented concussions, and 20.4% of the 103 athlete-recalled concussions (Table 3). In other words, based on "hard" matches alone, athletes failed to recall 41.7% of those concussions that were clinically-documented; and there were no clinical data associated with 79.6% of athlete-recalled concussions. In addition, four "soft matches" were generated from circumstances of injury information (obtained from both respondents and clinical data); three noted the same

competition at which the injury occurred, and one noted the same mechanism of injury. Inclusion of the "soft matches" increased number of matches to 25, accounting for 69.4% of clinically-documented concussions and 23.4% of athlete-recalled concussions. In other words, after including the "soft" matches, athletes failed to recall 31.6% of those concussions that were clinically-documented; and there were no clinical data associated with 76.6% of athlete-recalled concussions.

Findings were stratified by sex, race/ethnicity, level of contact in sport, and time. In all strata, the average number of athlete-recalled concussions was higher than that of clinically-documented concussions (Table 2). The ICC for females (0.65, 95% CI: 0.44, 0.79) was higher than that for males (0.13, 95% CI: -0.06, 0.31). Compared to females (36.8%), males had a larger percentage of clinically-documented concussions that were athlete-recalled (82.4%) (Table 3). In addition, the perentage of athlete-recalled concussions that were clinically-documented was highest among Hispanic Nonwhite athletes (33.3%) and those whose collegiate sports careers began in 2005 and after (32.0%).

6.3.2 Reported reasons for non-disclosure and sources of information on concussion

Of the 53 former collegiate athletes reporting college sport-related concussions, 21 (39.6%) reported that they believed they had college sport-related concussions that went undiagnosed. Common self-reported reasons for non-diagnosis were that respondents did not tell team medical staff (n=11), and no team medical staff was present (n=4). The 11 respondents that did not disclose all their sports-related concussions to team medical staff provided numerous reasons for non-disclosure, including: did not think it was serious enough (90.9%, n=10); did not know it was a concussion (72,7%, n=10); did not want to leave the

game/practice (72.7%, n=10); did not want to let the team down (63.6%, n=7); and did not want to pulled from future game/practice (54.5%, n=6). All 21 respondents noted in text responses that recent concussion knowledge helped them realize that these impacts were undiagnosed concussions. Sources of knowledge included: friends (23.8%, n=5); continuing education (23.8, n=5); and the media (85.7%, n=18), particularly ESPN (42.9%, n=9), other television shows (28.6%, n=6), and research articles (14.3%, n=3).

6.4 Discussion

Obtaining accurate concussion histories from former athletes is an important measurement issue in studies of associations between recurrent concussion and negative health outcomes such as depression and mild-cognitive impairment.[7,9,10,105] Clinically-documented concussion histories are limited because medical records are inconsistent, hard to access, or nonexistent. Athlete-recalled concussion histories are prone to potential recall effects and other subjective information that lacks clinical validation. This is the first study to compare athlete-recalled concussion histories with clinically-documented concussion history data in an attempt to study whether the two methods yield comparable results.

The discrepancies between the two methods were striking. Athlete-recalled and clinically-documented concussion histories had low agreement (ICC=0.21). The number of concussions during college self-recalled by collegiate athletes was nearly three times the number recorded in clinical records. Four of five athlete-recalled concussions were not recorded by clinical data. It is important to consider that our sample of former collegiate athletes with questionnaire and clinical data was small (n=130) and we were also unable to obtain pre-season clinical records for 19% (n=13) of individuals. Nevertheless, the minimal

overlap between the two methods for assessing concussion history suggests that neither athlete recall nor clinical documentation currently serve as a suitable "gold standard."

Each source of concussion history data failed to account for large proportions of concussions identified by the other data source. The only exception was clinically-documented concussions from 2005 and onwards; these were all recalled by the former athletes. Although better agreement was found between athlete-recalled and clinically-documented concussion histories in athletes from 2005 onwards (ICC=0.39), it is unclear if this was due to improved clinical detection in this era, reduced memory decay for more recent concussions, or a combination of both.

A fundamentally different paradigm may be needed to develop more accurate methods for assessing concussion history. Our method for obtaining athlete-recalled concussion history was an online self-administered questionnaire. However, results may have differed had we utilized a more in-depth methodology. For example, with a face-to-face interview, we could create a history of former athletes' careers in their sports. Methodological research utilizing cognitive psychology is required develop and test concussion instruments. Social cognitive theory suggests that it may be important to utilize this history in addition to memory prompts not limited to medical records, such as team win/loss records, film records, interviews with former teammates, family, and peers, and possibly even life events unrelated to sports.[124] These could serve as cognitive anchors to facilitate better recall of concussive symptoms. Additionally, education about the symptoms of concussion and their duration may be required in order for some respondents to provide an accurate history. However, providing educational information within a concussion history instrument has the potential to create over-reporting. At the same time, we cannot verify that

athlete-recalled concussions met the clinical definition of concussion. It is possible that athletes may have perceived subconcussive impacts to be concussions. Concussions may present with symptoms similar to other injuries, which may lead to misdiagnosis by athletes.[167] Because of the complex nature of concussion and concussion symptomology, it is essential that sports medicine professionals better communicate to patients when they have been concussed in order for them to generate more valid self-reported medical histories.

Agreement between athlete-recalled and clinically-documented concussion histories also varied by sex, with concussions histories for females having better agreement than for males. Previous findings have noted that males were more likely to not report concussion symptoms to coaches or athletic training staff,[136] and impacts sustained by females may be more likely diagnosed as concussions.[47] This would explain the higher average number of clinically-documented concussions for females compared to males. However, a previous study[49] found no differences in concussion disclosure between males and females. As concussion knowledge increases, and athletes are alerted about the potential negative consequences of not disclosing concussions, there is potential for better exploration of sex differences related to the incidence and reporting of concussions.

Nearly half of the respondents believed that they had sustained impacts that should have been diagnosed as concussions at the time of injury. Previous research[165,166] indicated that medical staff may not be effectively able to detect and identify all TBIs that occur within their clinical setting. However, our sample did not indicate that their undiagnosed concussions were due to their collegiate medical staff's lack of knowledge. Possible reasons for non-disclosure noted in the current and previous studies suggest that non-disclosure typically originates both from a lack of personal knowledge (e.g., did not think concussion

was serious enough, did not know it was a concussion), and from external norms and internal expectations (e.g., did not want to leave game/practice, did not want to be pulled from future game/practice, did not want to let down teammates/coaches).[49,50,131-133] Pre-season educational and social norming interventions that address non-disclosure will help sports organizations more effectively detect, treat, and manage concussions sustained by their athletes. Because of their potential positive impacts on disclosure, there is an urgent need to develop and evaluate such interventions.

Respondents also reported that undiagnosed concussions occurred due to team medical staff not being present at the time of injury. Other studies have noted the lack of medical staff presence at sports settings,[168] even when they were on staff.[169] A high level of staffing at the collegiate level is critical to the health and safety of scholastic and collegiate student-athletes.

These former collegiate athletes reported that information from peers and the media may have increased their concussion and concussion symptomatology knowledge, allowing them to retrospectively reconsider previously-sustained impacts. Thus, our results are further complicated by the fact that media reporting may influence the change in the recall of previously-sustained concussions.[122] Such changes in perception are consistent with social cognitive theory, which states that individuals acquire knowledge through the observation of others via social contexts, media, and other modes of communication.[124]

6.4.1 Limitations

As previously mentioned, our athlete-recalled concussions were based on responses from an online questionnaire that did not utilize cognitive event anchors. Such anchors could

have improved recall. In addition, although the concussion definition utilized at <*name removed for blinded review*> may have remained constant through the study period, we are unable to account for variations in clinical staff's detection and diagnoses among athletes' clinically-documented concussions.

Only 21.9% of all eligible former collegiate athletes provided complete responses to our online instruments, and only 130 had clinical data available. Our sample was recruited from one university and was restricted to those that had played at least one season in 1987-2012. Thus, our findings may not be generalizable to populations of former athletes from other universities, playing eras, or playing levels (e.g., high school). Last, no "gold standard" of concussion history currently exists to compare current methods of acquiring accurate estimates of concussion frequency.

6.4.2 Conclusion

Our findings suggest that agreement between athlete-recalled and clinically-documented concussion histories is low. Each source of concussion history data failed to account for large proportions of concussions identified by the other data source. However, higher agreement among former athletes that played collegiate sports more recently may suggest improved clinical detection over time. Moreover, external influences such as peers and the media are influential in former athletes' reporting of concussion histories. Future studies with former athletes must consider the strengths and limitations of each data source. At the same time, significant methodological innovation is recommended to improve the quality of concussion reporting questionnaires and documentation in medical records.

Table 6.1. Former collegiate athletes with clinical data, by sport (n=130)	
Sports	**n**
Men's basketball	5
Men's cheerleading	2
Men’s diving	1
Men's football	32
Men's lacrosse	19
Men's soccer	11
Men's track and field pole vault	2
Men's wrestling	10
Women's basketball	4
Women's field hockey	8
Women's lacrosse	23
Women’s soccer	9
Women's track and field pole vault	4
TOTAL	130

Table 6.2. Average number of athlete-recalled and clinically-documented concussions in former collegiate athletes (n=130), by sex, race/ethnicity, level of contact in sport, and time

	n	Average number of athlete-recalled concussions[a] (SD)	Average number of clinically-documented concussions[b] (SD)	ICC (95% CI)
Total	130	0.79 (1.27)	0.28 (0.57)	0.21 (0.05, 0.37)
Sex				
Male	82	0.90 (1.47)	0.21 (0.49)	0.13 (-0.06, 0.31)
Female	48	0.58 (0.79)	0.40 (0.68)	0.65 (0.44, 0.79)
Race/ethnicity				
Non-Hispanic White	109	0.80 (1.31)	0.27 (0.57)	0.21 (0.03, 0.37)
Hispanic Nonwhite	21	0.71 (1.06)	0.33 (0.58)	0.26 (-0.14, 0.60)
Level of contact in sport				
Low/no contact	9	0.22 (0.67)	0.00 (0.00)	0.00 (-0.63, 0.63)
High contact	79	0.85 (1.31)	0.39 (0.67)	0.28 (0.07, 0.47)
Collision	42	0.79 (1.28)	0.12 (0.33)	0.05 (-0.19, 0.30)
Time period[c]				
Before 1996	25	1.04 (1.77)	0.16 (0.47)	0.08 (-0.23, 0.42)
1996 to 2000	49	0.71 (1.31)	0.31 (0.51)	0.24 (-0.02, 0.48)
2001 to 2004	28	0.57 (0.84)	0.32 (0.77)	0.33 (-0.03, 0.62)
2005 and after	28	0.89 (1.03)	0.29 (0.53)	0.39 (0.01, 0.67)

NOTE: SD=Standard deviation; ICC=Intraclass correlation coefficient; CI=Confidence interval

[a]Athlete-recalled concussion history originated from online questionnaire

[b]Clinically-documented concussion history originated from clinical data

[c]Time period indicates the year in which respondent began playing collegiate sports

Table 6.3. Distribution of concussions that were athlete-recalled and clinically-documented in former collegiate athletes (n=130), by sex, race/ethnicity, level of contact in sport, and time

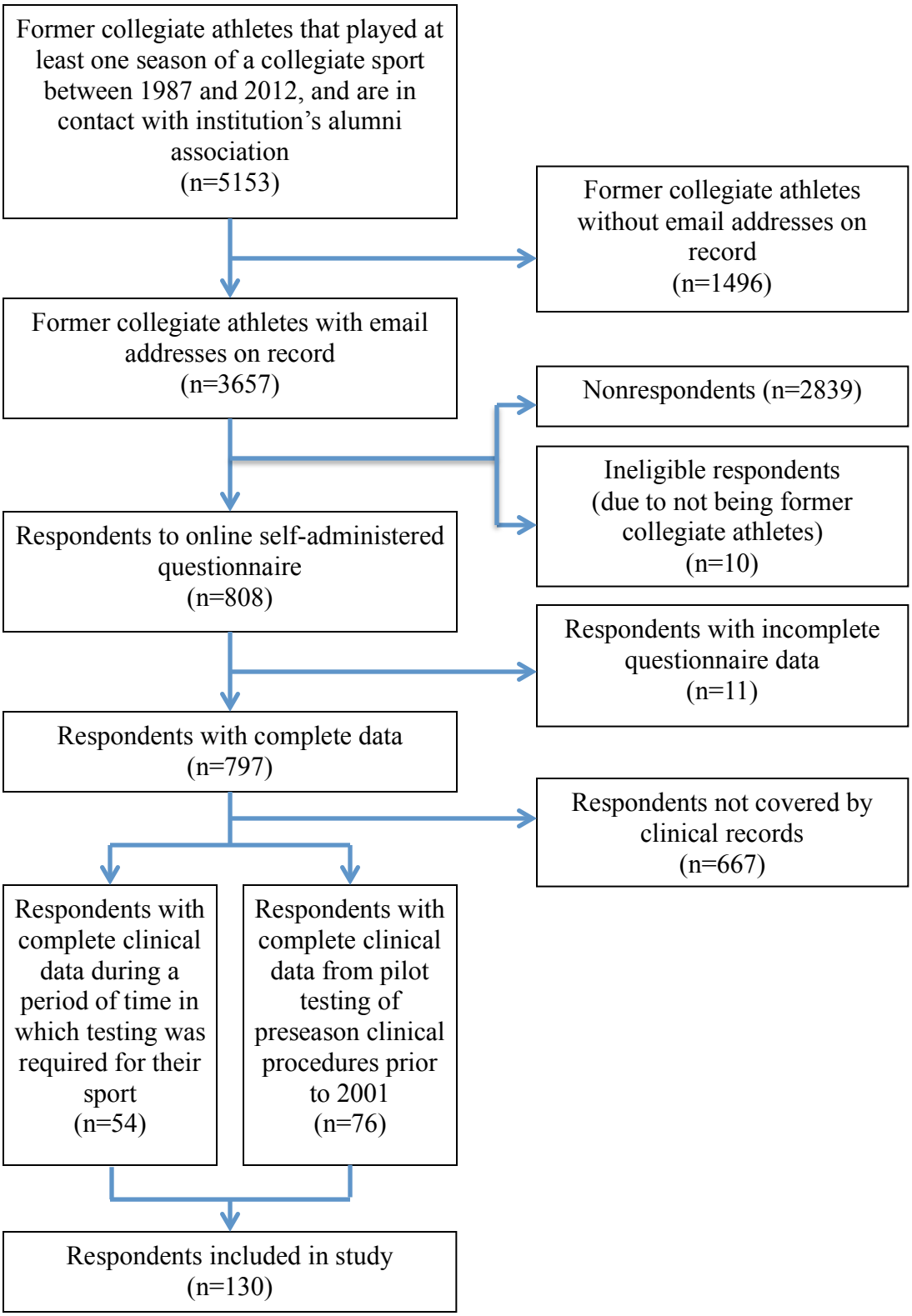
	# concussions both athlete-recalled and clinically-documented[a]	# concussions athlete-recalled but not clinically-documented	# concussions clinically-documented but not athlete-recalled	% athlete-recalled concussions that were clinically-documented		% clinically-documented concussions that were athlete-recalled	
				"Hard" matches only	With "soft" matches[b]	"Hard" matches only	With "soft" matches
Total	21	82	15	20.4	23.4	58.3	69.4
Sex							
Male	14	59	3	19.2	19.2	82.4	82.4
Female	7	23	12	23.3	32.4	36.8	57.9
Race/ethnicity							
Non-Hispanic White	16	72	13	18.2	20.9	55.2	65.5
Hispanic Nonwhite	5	10	2	33.3	37.5	71.4	85.7
Level of contact in sport							
Low/no contact	0	5	0	0.0	0.0	-	-
High contact	16	51	15	23.9	28.2	51.6	64.5
Collision	5	26	0	16.1	16.1	100.0	100.0
Time period[d]							
Before 1996	2	22	3	8.3	12.0	40.0	60.0
1996 to 2000	8	29	6	21.6	23.7	57.1	64.3
2001 to 2004	3	13	6	18.8	27.8	33.3	55.6
2005 and after	8	17	0	32.0	32.0	100.0	100.0

[a]Athlete-recalled concussion history originated from questionnaire data; clinically-documented concussion history originated from clinical data

[b]Matches were "hard" (n=21) when: (1) the date in which a respondent athlete-recalled sustaining the concussion was within six months from the date reported by the clinical data; or (2) the school year that a respondent reported sustaining the concussion

matched the school year reported by the clinical data.
[c]"Soft" matches (n=4) did not adhere to criteria for matching athlete-recalled and clinically-documented concussions, but still could be possible matches, given additional qualitative information provided by respondents and clinical data about the circumstances of injury to plausibly link records (e.g., mechanism of injury, specific competition at which injury occurred).
[d]Time period indicates the year in which respondents began playing collegiate sports

Figure 6.1. Ascertainment of data



CHAPTER 7

DISCUSSION

7.1 Summary of findings

Findings related to CTE and negative mental health outcomes in former athletes emphasize the need to further the study of the benefits and burden of sports participation.[7,9,10,13,15-17,75,76,105] As part of this effort, we must conduct methods research so that we can accurately characterize recurrent concussion's potential effects on athlete well-being and health.

Currently, most findings related to the current health of former athletes originate from research on retired NFL players.[7-11,105] This dissertation built upon previous research by examining a diverse cohort of former collegiate athletes from one university that had played in 27 sports between 1987-2012. Although our cohort of former collegiate athletes had a lower prevalence of major depression than a sample of retired NFL players (4.5% vs. 14.7%), the association between recurrent concussion and depression that had been previously reported in retired NFL players was also observed in the collegiate cohort.[9,10,105] Former collegiate athletes reporting a history of concussions also reported higher levels of aggression, compared to those without a concussion history.

Obtaining accurate concussion history is important, as misclassification error may lead to biased effect estimates of the association between recurrent concussion and negative health. However, little has been done to determine the validity of an athlete-reported

personal history of concussion. This dissertation examined this issue by compared the self-reported history of the former collegiate players to their clinical records at the host institution. Agreement between both data sources was low (ICC=0.21), with the number of concussions during college self-recalled by collegiate athletes being nearly three times the number recorded in clinical records. Four of five athlete-recalled concussions were not recorded by clinical data. However, agreement was higher for athletes who played more recently (2005-2012: ICC=0.39; 95% CI: 0.01, 0.67). Given the media attention and the increased knowledge and education regarding concussions, current measures of athlete-recalled concussion history may provide a more valid measure of concussion history than the older medical reports.

The discrepancy between athlete-recalled and clinically-documented concussion histories is partially attributable to concussions going undiagnosed at the time of injury. Among the cohort of former collegiate athletes, non-disclosure accounted for a large proportion of undiagnosed concussions, with common reported reasons including a lack of concussion knowledge and self-imposed pressure to continue playing despite being injured. Former athletes also reported that they are exposed to numerous sources of information that have increased their concussion-related knowledge related to identifying symptoms and understanding severity of injury. Increased knowledge of the long-term effects of concussion, generated by recent widespread media exposure, is an important influence on former athletes' recollections of prior concussion-like events. Neither of the measures used in this dissertation (clinical records and athlete-recalled history from a self-administered questionnaire) can be considered a "gold standard" for concussion history. However, the results from this research suggest for methodological opportunities for improved assessment

of concussion history in research studies.

7.2 Strengths

This dissertation extends previous studies that examined the association between recurrent concussion and mental health in retired NFL players,[7,9,10,75,76,105] This is the first study to utilize a cohort of former collegiate (rather than professional) athletes. It is also the most diverse sample in terms of the sports studied. It is also the first to include both males and females, thus contributing to the discussion regarding the generalizability of the findings associated with retired NFL players.[7,9,10,76,105] In addition, alongside depression, we examined impulsivity and aggression as outcomes. These outcomes have not previously been examined in relation to concussion history in athletes.

This dissertation was also the first study to compare athlete-recalled and clinically-documented concussion history data. All previous studies examining the association between recurrent concussion and mental health have utilized athlete-recalled concussion histories, and as a result have been criticized for recall bias.[170] Determining the proportion of concussions that are undetected by the self-recalled method will assist in yielding more valid estimates of concussion frequency in future research, and consequently, more facilitate accurate estimates of the association between concussion history and mental health outcomes.

7.3 Limitations

The current study has several limitations. First, although repeated efforts were made to contact our target sample of 3,657 former collegiate athletes, our completion rate among

eligible respondents was low (21.9%). The sample originated from one university and was restricted to those that had played at least one season in 1987-2012. Thus, our findings may not be generalizable to: non-respondents; former athletes without email addresses within the university alumni association records; former athletes not in contact with the university alumni association; and former athletes from other universities, playing eras, or playing levels. Future research examining former athletes from multiple sports organizations of varying competition levels (i.e., high school, college, and professional) will help present a broader perspective on the health of former athletes.

Our study was also cross-sectional, and the findings highlight the need for longitudinal examinations of former collegiate athletes. In addition, our outcome measures of current mental health are unable to account for those who are depressed, impulsive, and aggressive, yet reported lower levels on the scale measures because they are currently being treated through medication. Future longitudinal studies should incorporate the treatment/medication as covariates to better understand how it changes levels of mental health outcomes over time.

Our main exposure, concussion history, is not an objectively documented exposure history and may be prone to measurement and recall bias.[122] However, athlete-recalled concussion history is easier to obtain than medical reports and may be more complete. Our findings, coupled with previous studies, suggest a history of underreporting of concussion in clinical records, with 35.2-62.1% of athletes not reporting all sustained concussions to coaches and/or team medical staff.[49,50,131-133] Our main exposure also accounts solely for the number of concussions sustained, and not the variations in times since injury and times between multiple concussions. Significant methodologic innovation is required improve the

quality of concussion-reporting questionnaires.

In addition, our sample of former collegiate athletes with questionnaire and clinical data was small (n=130) and we were also unable to obtain pre-season clinical records for 19% (n=13) individuals. At the same time, we cannot verify that athlete-recalled concussions met the clinical definition of concussion, and it is possible that athletes may have misidentified subconcussive impacts or non-concussion ailments as concussions. Continued exploration of the concurrent validity of athlete-recalled and clinically-documented concussion histories will help to better understand the detection capabilities of both data sources. In-depth methods, such as face-to-face interviews with memory prompts that serve as cognitive anchors, may potentially assist in better recall of concussion history in future studies.

7.4 Public health implications

Although much emphasis has been placed on the post-retirement health of professional athletes,[10,171] research is also needed on those athletes that compete in elite level amateur sports, but never reach the professional level. The NCAA estimates that the number of NCAA senior student-athletes that are drafted into professional sports is low, ranging from 0.7% in men's soccer to 9.7% baseball.[99] With over 450,000 current NCAA student-athletes,[6] former collegiate athletes are a large and important population of former athletes and their post-retirement health needs are largely under-studied.

7.4.1 Concern regarding concussions and sports participation

Although this dissertation focused primarily on concussions, it is important to

consider this serious injury in the context of these athletes' overall playing careers. College sport-related concussions were self-recalled by 14.2% of our cohort of former collegiate athletes from a diverse range of sports. At the same time, an additional 12.5% reported no college sport-related concussions, but reported sport-related concussions in other settings (e.g., high school, professional sports); an additional 12.1% reported non-sport-related concussions (e.g., from falls or motor vehicle crashes). Although the risk of concussion during sports is significant, such concern about concussions should not be limited to collegiate sports only.

Media reports suggest a growing concern among parents regarding having their children participate in collision and high-contact sports.[172-175] Parents' concerns are not unwarranted, especially given a sports culture that increasingly encourages young athletes to constantly push their bodies, even at a young age, to maximize their performance potential. However, concern about injury, although legitimate, should be placed in the context of the many benefits of sports participation and physical activity, including: promotion of social interactions; an increased quality of life; supporting future adherence to an active lifestyle; and a reduced risk of mortality, cardiovascular disease, and diabetes.[176,177]

Because society places a high value on the safety of youth athletes, there has recently been an extensive effort to formulate and implement state-level policy on concussion management in order to improve recognition and response of concussions during sports. These policies typically include providing sports-related concussion information to athletes and their families, training coaches to recognize concussions, and requiring immediate removal of athletes that are suspected to be concussed from sports participation until they are cleared to return to play by a physician. As of April 2013, all but one state passed legislation

addressing concussions in high school athletes.[178] This dissertation aimed to acquire a better understanding of the impact of collegiate sports participation on health and well-being to provide information for those who develop policies and programs to better serve athletes during and after their collegiate careers.

7.4.2 Provision of care to former collegiate athletes

Despite the limitations of current methods for the ascertainment of concussion history (as documented in this dissertation and elsewhere), there is a growing body of evidence linking the risk of depression to athlete-recalled concussion history. As a result, it is important that first, current athletes disclose any suspected concussions to coaching and team medical staff; and second, former athletes have access to treatment and care to attend to any suspected long-term effects of sports participation.

Developing, implementing, and evaluating policy and interventions that positively influence health and well-being is a necessity. Currently, the NFLPA offers health insurance to retired NFL players. As a result, the question arises as to whether the NCAA should offer something similar to former collegiate athletes. On one hand, findings that suggest an association between recurrent concussion and mental health in former collegiate athletes support the need for such a program. On the other hand, such programming may be arduous to implement given the far greater number of former collegiate athletes than NFL players. This is further exacerbated by the difference in revenue between the NCAA ($871.6 million in 2011/12 for all sports)[179] and the NFL ($9.5 billion in 2011/12).[180] At the same time, it is also essential to consider these former athletes' access to healthcare. Starting in 2014, former collegiate athletes can acquire universal health care, or choose to remain on their parents'

insurance plans until the age of 26. However, they may still require assistance in paying premiums and accessing local healthcare professionals. Thus, adoption of such policy should be preceded by feasibility studies that evaluate need, demand, and cost.

Former athletes may also benefit from continued social support from other former athletes. Although social support models exist for current student-athletes[181] and athletes beginning their transition into retirement,[182] no model exists for athletes that have not participated in sports for an extended period of time. Incorporating previously-utilized social support strategies for current athletes and the general population may enhance social support in former collegiate athletes as well (Table 7.1).[181-183]

Table 7.1 Strategies to enhance social support among former collegiate athletes

- Encourage the maintenance of positive relationships with university and sports program
- Organize social events through local alumni associations that encourage communication among former athletes
- Arrange opportunities for former athletes to meet with their former university's sport psychologist to discuss emotional support
- Encourage inter-team connectedness and emotional support by suggesting former athletes from various sports and teams show support for each other, in order to expand each former athlete's pool of emotional support providers

Our findings also highlight the need to focus on maximizing disclosure of potential concussion events during participation in sports. The socio-ecologic framework is helpful in stressing that factors at multiple levels of influence can affect athletes' decision-making regarding the disclosure of concussions (Figure 1). The framework highlights the need to target interventions at more than just one level, since in general, multilevel interventions are more likely to be successful.

7.5 Future research

Table 7.2 summarizes the current knowledge related to the measurement of concussion history and its association with mental health, and provides recommendations for future research. Interventions that utilize multiple forms of support to help positively influence health and well-being need to be developed, implemented, and evaluated. Pre-season educational and social norming interventions that address non-disclosure will help sports organizations more effectively detect, treat, and manage concussions sustained by their athletes. Interventions that challenge sports culture norms and media influences such as 'win at all costs' must be developed and implemented to help athletes understand the importance of reporting concussions and other serious injuries. For example, former athletes could serve as "role models" that advocate the benefits of disclosure.

In addition, research that highlights media, particularly online and broadcast sports commentary may be important in altering norms about invincibility to injury. There is concern that similes involving machinery or animals ("he's a machine", "he's an ox") devalue the thousands of hours of training, conditioning, and skills acquisition of elite athletes, and may potentially promote dehumanization of the athlete, and reinforce false notion of invincibility. Likewise, the role of video games, video-based websites such as YouTube, and major television networks in popularizing misplaced notions of athlete invincibility to injury may be influential in setting athlete norm and creating self-imposed performance expectations for athletes. These influences need to be understood in order to better develop and evaluate interventions that address concussion norms.

In addition, significant methodological innovation is also required improve the quality of concussion reporting. As discussed earlier in this chapter, the minimal overlap

between athlete-recalled and clinically-documented concussion histories suggests that neither data source currently serves as a suitable "gold standard." A fundamentally different paradigm, may be needed if we are to develop accurate methods for assessing concussion history. For example, social cognitive theory suggests that it may be helpful to utilize memory prompts that are not limited to medical records, such as team win/loss records, film records, interviews with former teammates, family, and peers, and possibly even life events unrelated to sports. These events may serve as cognitive anchors that may facilitate better recall of concussive symptoms. Additionally, education about the symptoms of concussion and their duration may be required in order for some respondents to provide an accurate history. In view of this, it seems likely that interview-assisted instruments may be more accurate than self-administered questionnaires. Methodologic research utilizing cognitive psychology is required to develop and test concussion instruments.

The development of interventions that help increase disclosure of concussions, coupled with more methodologically rigorous assessments of concussion history will help develop a legitimate "gold-standard" of concussion history that can better estimate the association of concussion history and mental health. Future prospective studies must also examine athlete cohorts and mental health outcomes longitudinally to obtain stronger evidence of a causal relationship. Continued research with former athletes of all ages will help determine a more precise age range at which the onset of negative mental health outcomes occurs.

Table 7.2 Current knowledge and recommendations for future research related to the measurement of concussion history and its association with mental health

	Measurement of concussion history	Association of recurrent concussion and mental health
Current knowledge	- Athlete-recalled and medically-documented concussions have low agreement - Factors at multiple levels of influence can affect athletes' decision-making regarding the disclosure of concussions - Ascertainment of clinically-documented concussions is influenced by the skill and Knowledge level of the clinicians making the diagnoses	- Recurrent concussion in retired NFL players may be linked to depression and mild-cognitive impairment - Recurrent concussion in former collegiate athletes may be linked to depression and aggression - Brain autopsies of former professional football players show evidence of CTE
Recommendations for future research	- Effects of multi-level interventions at increasing disclosure of concussions, thus yielding more valid concussion history estimates - Continued evaluation of the concurrent validity of various data sources of concussion history - Methodological research to improve the quality of concussion reporting - Methodological research utilizing cognitive psychology to develop and test concussion instruments	- Future prospective studies to examine athlete cohorts and mental health outcomes longitudinally in order to obtain stronger evidence of a causal relationship - Effectiveness of social support systems among former collegiate athletes - Feasibility of the need, demand, and cost of offering health insurance to former collegiate athletes

APPENDIX

You are being asked to participate in a research study titled, "Current health status and college sports history of former college athletes" (UNC IRB Study # 13-1249).

This research study is being conducted by researchers at the University of North Carolina. The researchers involved are:

- Zachary Y. Kerr, Department of Epidemiology, University of North Carolina
- Stephen W. Marshall, Department of Epidemiology, University of North Carolina
- Kevin Guskiewicz, Department of Exercise and Sports Sciences, University of North Carolina
- Jason Mihalik, Department of Exercise and Sports Sciences, University of North Carolina

Why was I contacted?
You are being asked to be in the study because you are a former UNC athlete.

What is the research study about?
The purpose of this research study is to learn more about potential medical risks of playing college sports.

How many people will take part in this study?
There will be approximately 4,500 people invited to take part in this research study.

How long will your part in this study last?
We will ask you to answer questions regarding your college sports career. The questionnaire should not take longer than 20-25 minutes. One or more questions may be skipped.

What will happen if I take part in the study?
You will be asked to complete the questionnaire. We will also use data from a previous study in which all UNC student-athletes from 1996-present completed preseason baseline testing as part of a mandatory ongoing clinical program. Consenting to this study will allow us to match your information from the previous study (if applicable) to your information from this study.

How will information about me be protected?

No participants will be identified in any report or publication, and research records will be kept **confidential** to the maximum possible extent.

- All study data will only be seen by the research team
- Any paper files will be kept in a locked file cabinet in the Matthew Gfeller Sport Related Traumatic Brain Research Center in the Stallings Evans Sports Medicine Center on UNC's campus.
- The computers and file servers used to enter, store, and analyze the data will also be stored in secure, locked rooms and will be password-protected.
- Personal names will not be stored on the electronic data files used for analysis.

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You will not benefit personally from being in this research study.

What are the possible risks or discomforts involved from being in this study?

This is a onetime survey that would be completed at your convenience. There may be uncommon or previously unknown risks. You should report any problems to the researcher. If you choose not to participate in this research study, your status with UNC or the Alumni Association will not be impacted.

What if we learn about new findings or information during the study?

You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

Will you receive anything for being in this study?

There is no direct benefit for participation. You will not be paid to be in this research study. However, your participation will help us learn more about potential medical risks of playing college sports. It will not cost you anything to be in this study.

Whom should I call if I have questions or problems?

If you have questions about this study, you may contact the Principal Investigator, Zachary Kerr, at zkerr@email.unc.edu, or (919) 962-0409 (Monday-Friday, between 9am-5pm Eastern Time), or Dr. Steve Marshall, at smarshall@unc.edu, or(919) 923-5905 (Monday-Friday, between 9am – 5pm Eastern Time).

If you have questions, concerns, or complaints about the research, questions about your rights as a research volunteer, cannot reach the Principal Investigator, or want to call someone else, please call the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

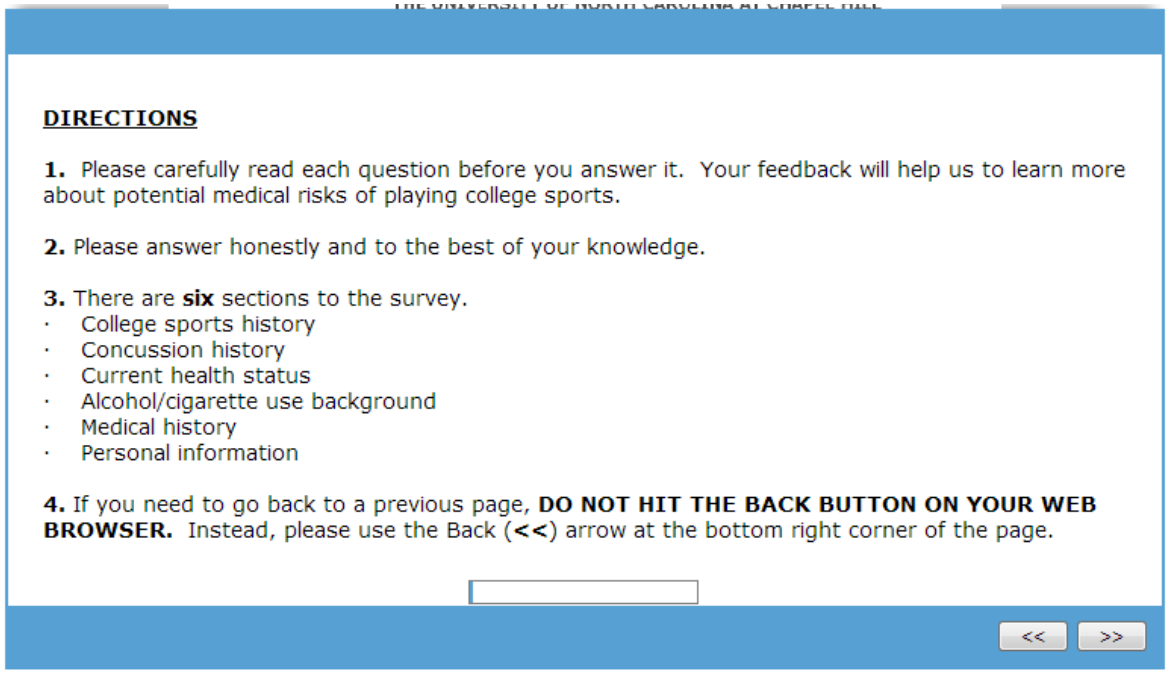
I have read the above consent form and understand the desire of my own free will to participate in this study. If I choose to do so, I have printed a copy of this consent form for my personal records.

If I do not wish to participate, I have the option to e-mail the researchers my e-mail address in order stop receiving follow-up emails regarding participation in this research study.

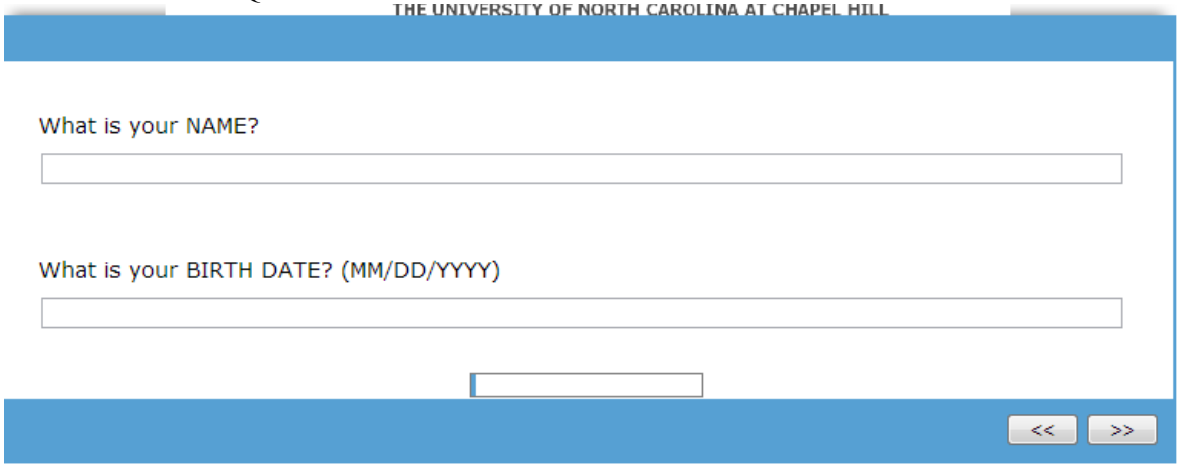
( ) Yes, I wish to participate

>>

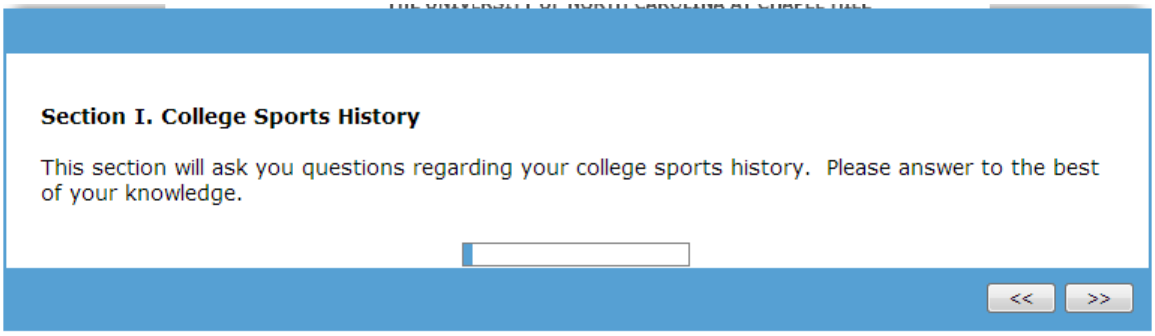
DIRECTIONS



BEGINNING OF QUESTIONNAIRE



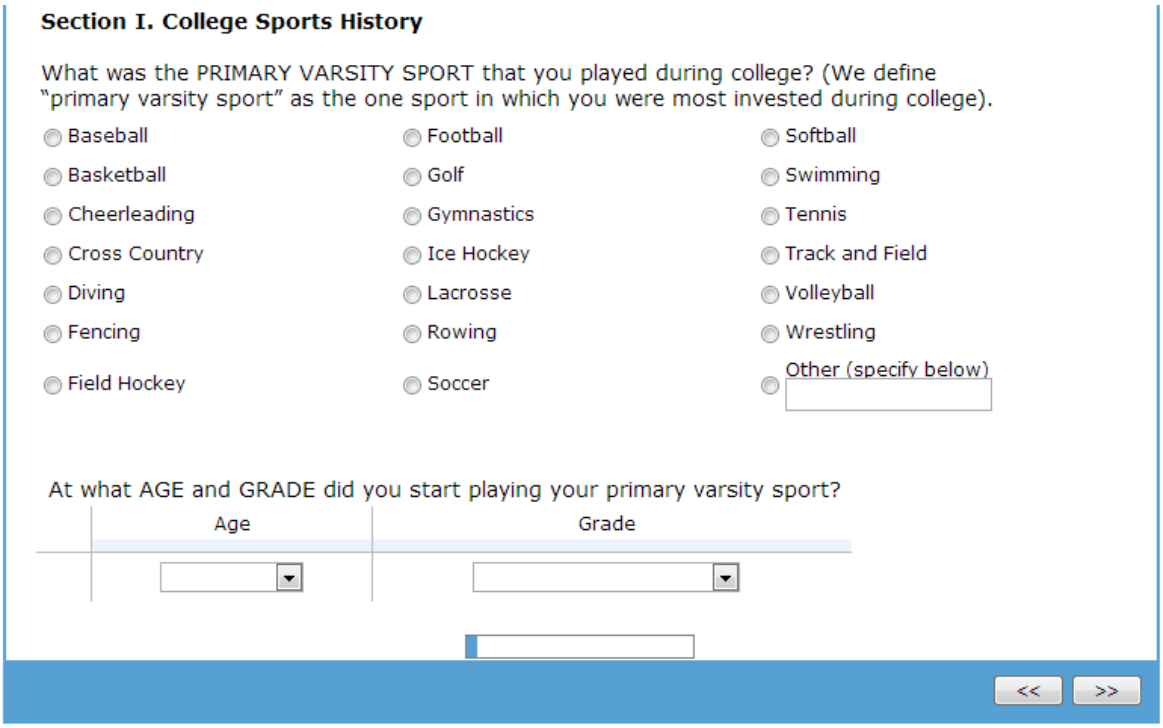
SECTION I



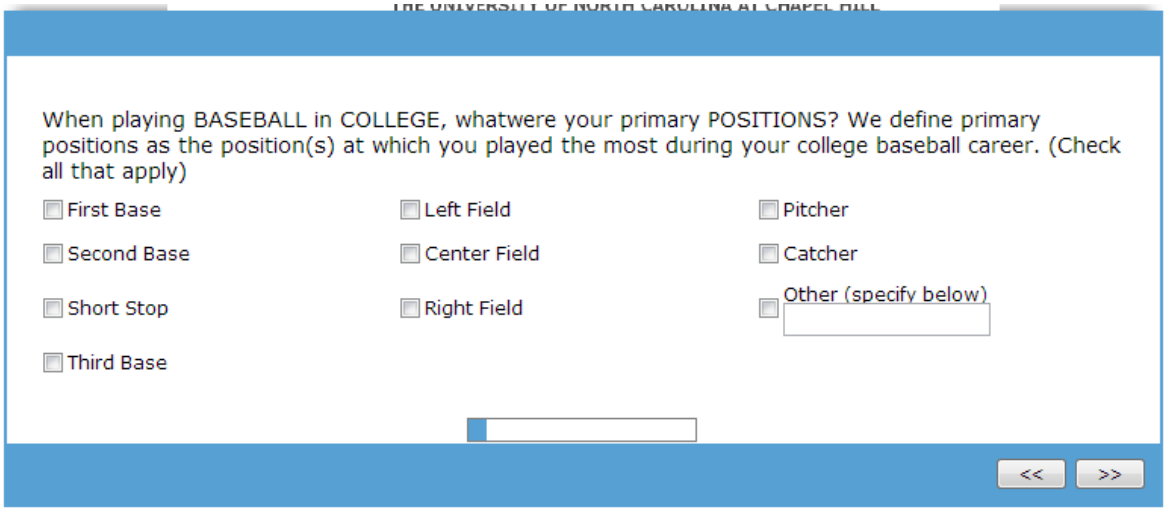
PRIMARY COLLEGIATE SPORT

AGE BEGAN PLAYING PRIMARY SPORT
Range (3 and under, 3,4,5….19,20,21, over 21)

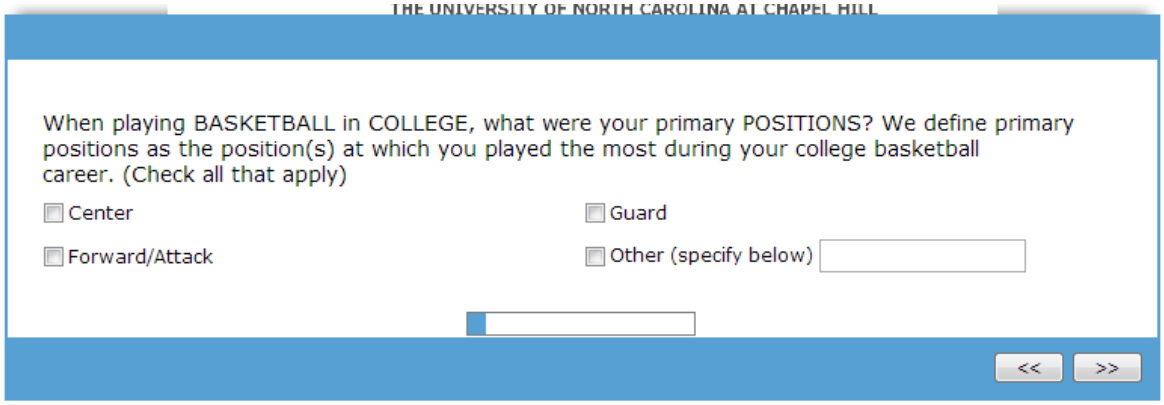
GRADE BEGAN PLAYING PRIMARY SPORT
Range (Before preschool, preschool, Kindergarten, 1st, 2nd, 3rd…10th, 11th, 12th, Freshman Year- College…Senior year – College, After Senior year- College)



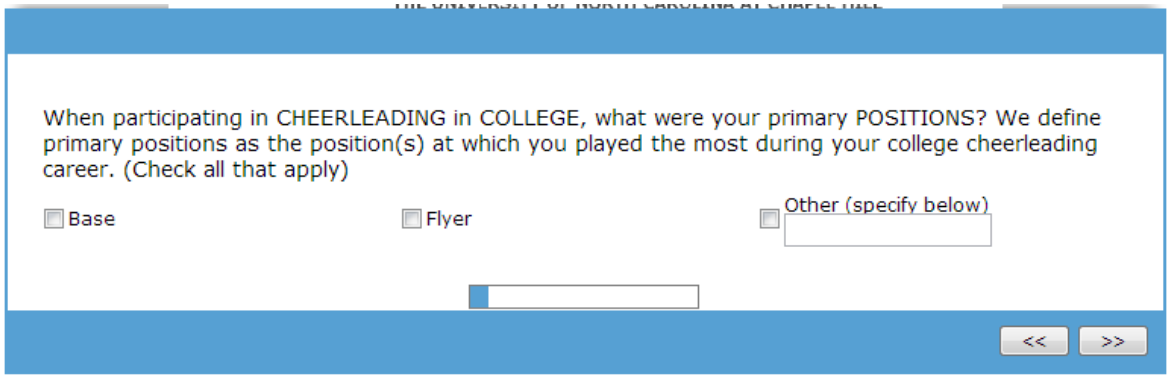
IF PRIMARY SPORT = BASEBALL



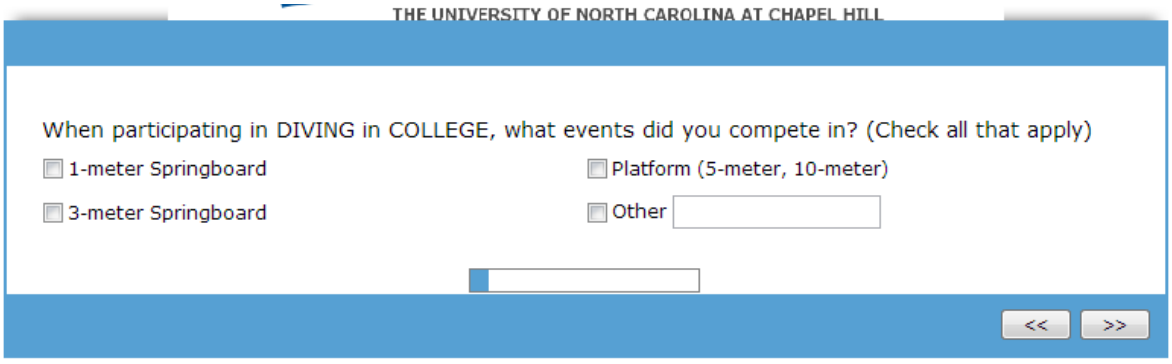
IF PRIMARY SPORT=BASKETBALL



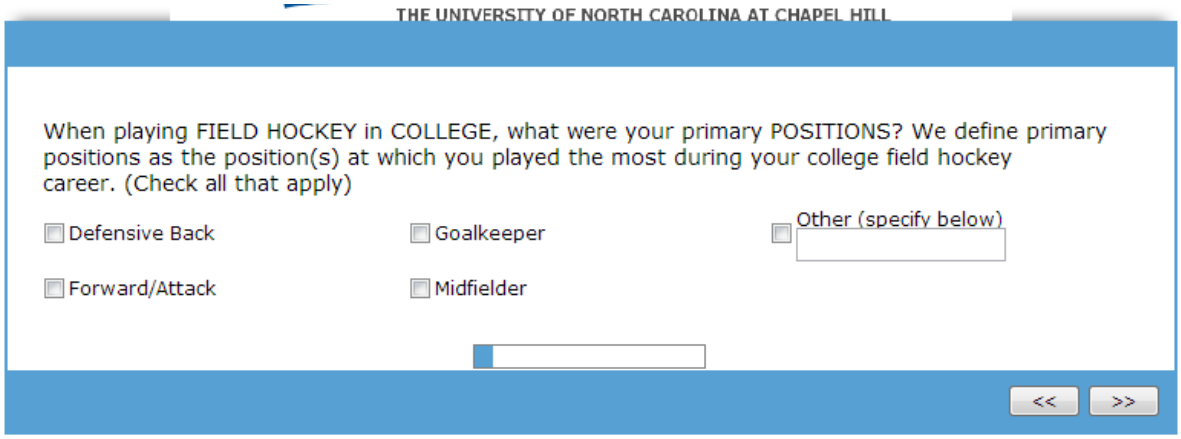
IF PRIMARY SPORT=CHEER



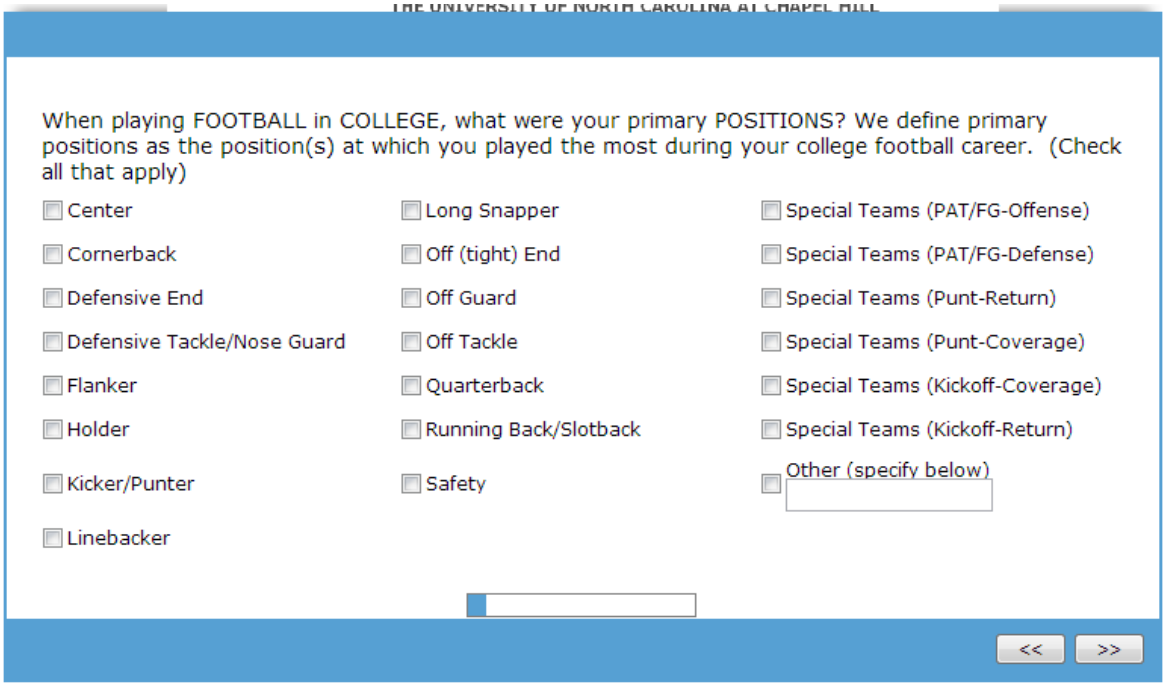
IF PRIMARY SPORT=DIVING



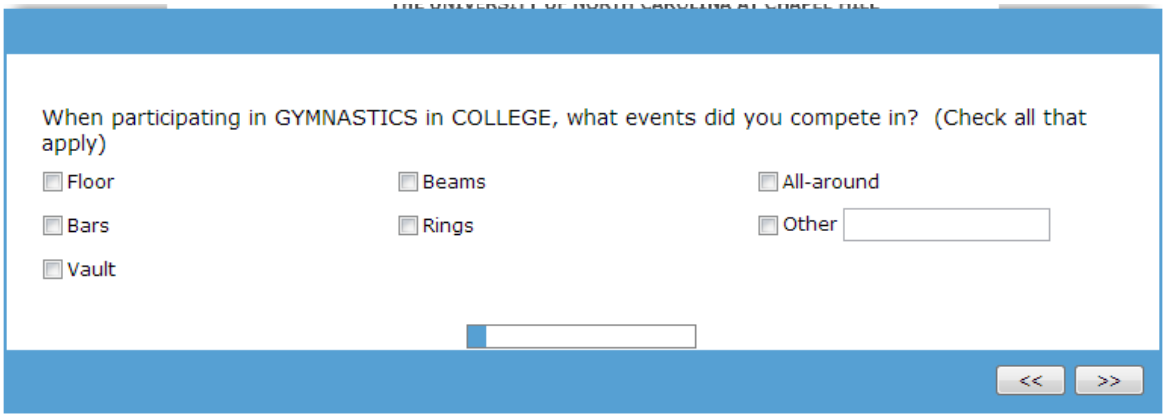
IF PRIMARY SPORT=FIELD HOCKEY



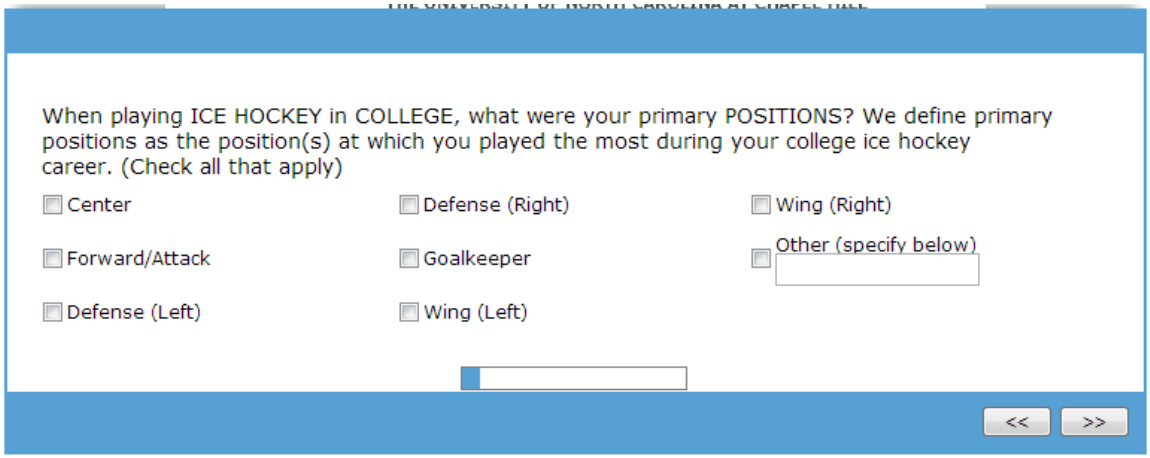
IF PRIMARY SPORT=FOOTBALL



IF PRIMARY SPORT=GYMNASTICS

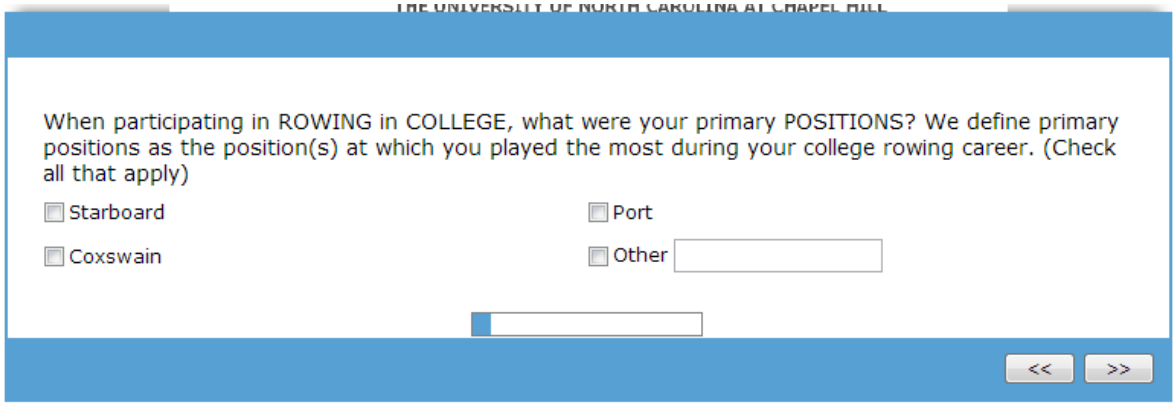


IF PRIMARY SPORT=ICE HOCKEY

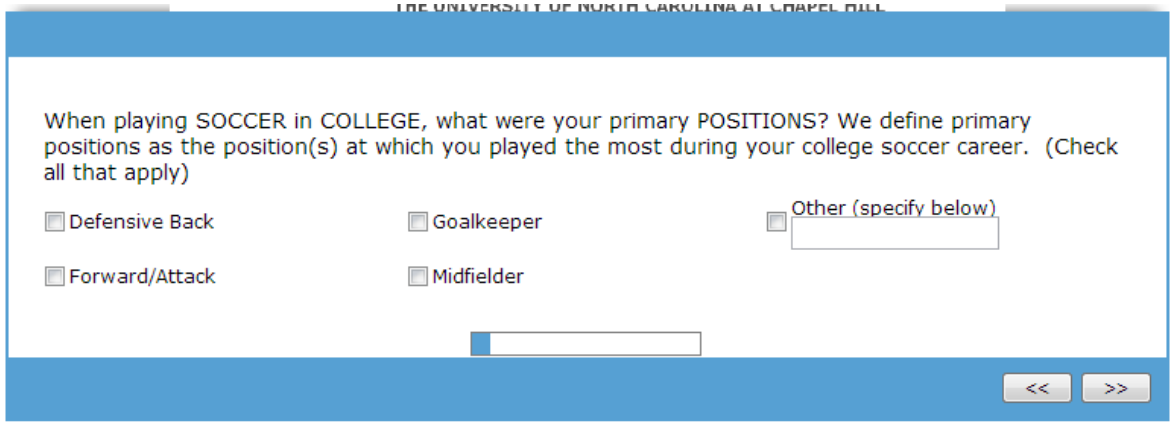


IF PRIMARY SPORT=LACROSSE

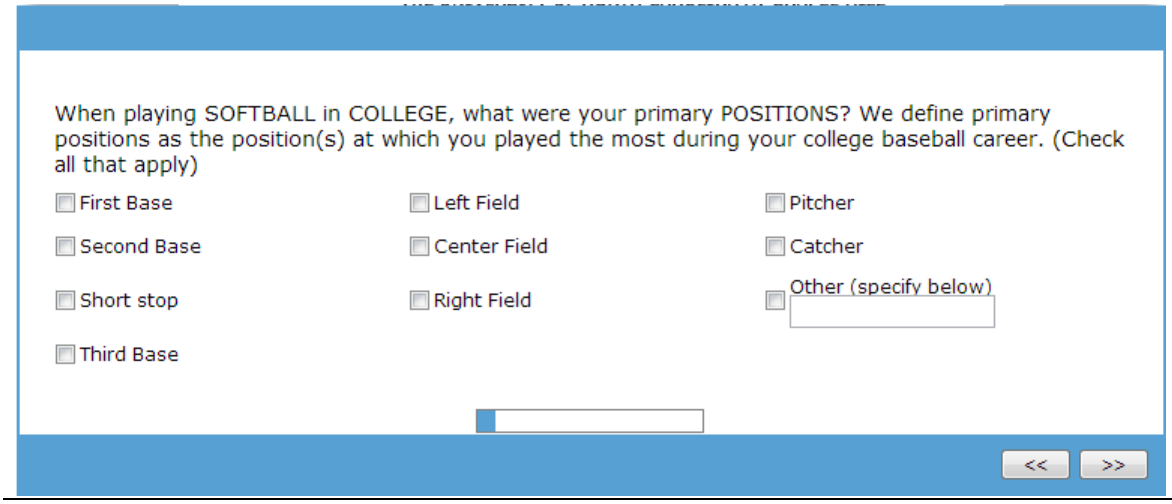
IF PRIMARY SPORT=ROWING



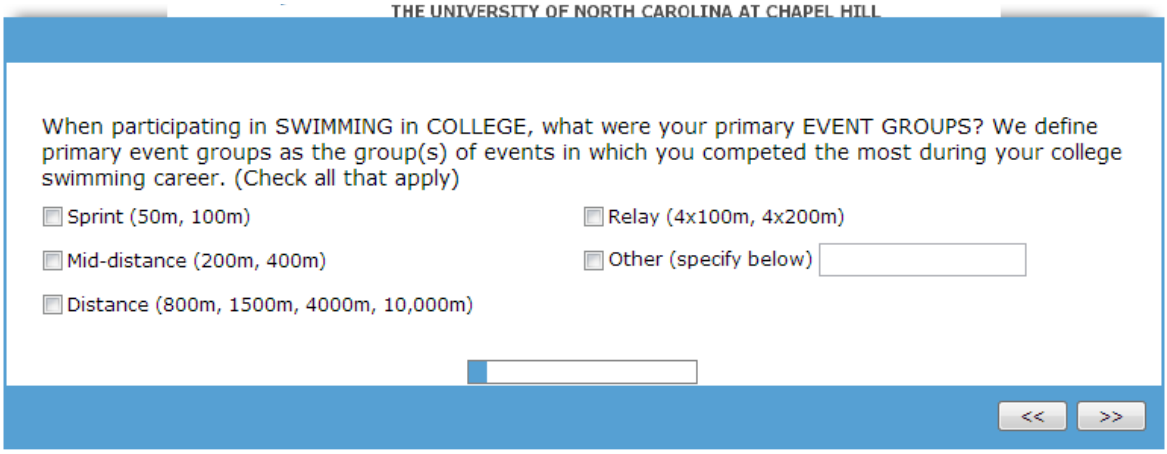
IF PRIMARY SPORT=SOCCER



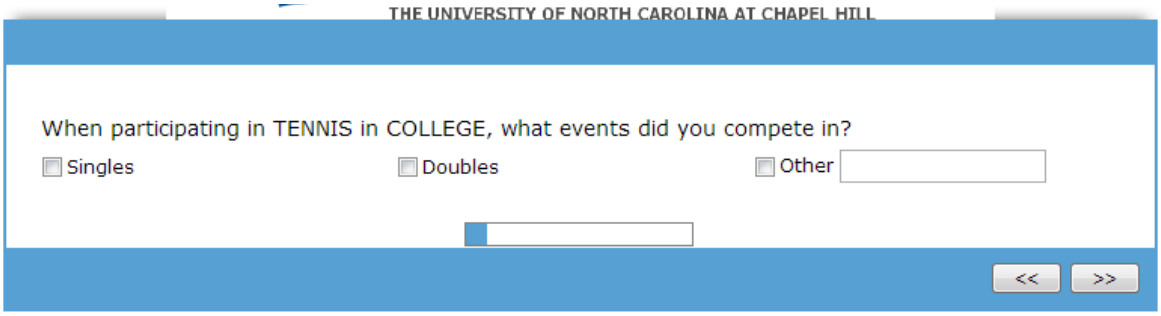
IF PRIMARY SPORT=SOFTBALL



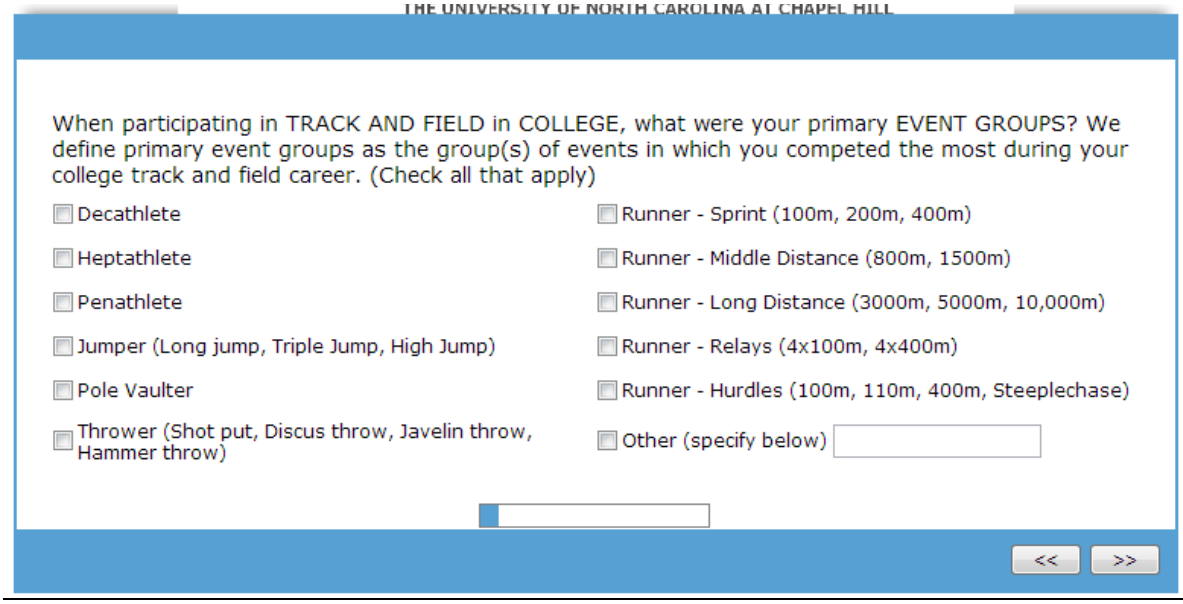
IF PRIMARY SPORT=SWIMMING



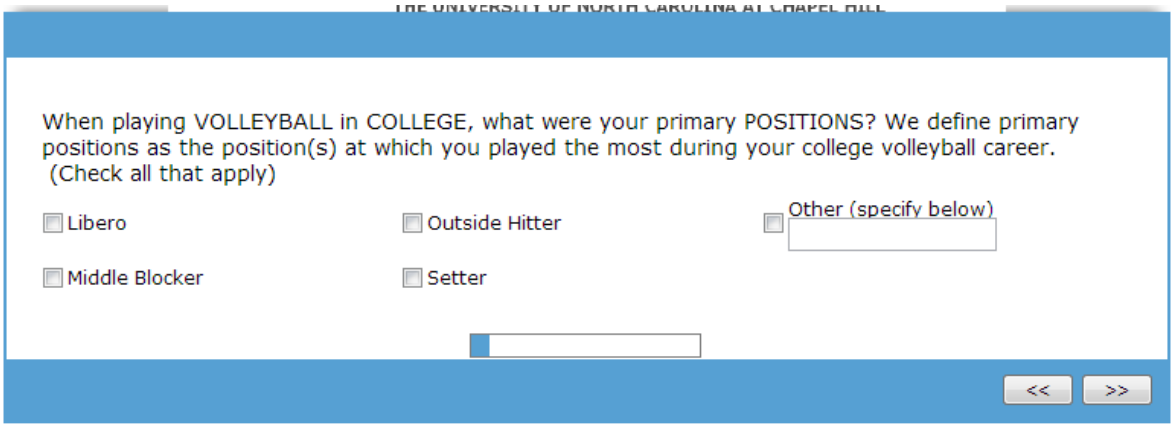
IF PRIMARY SPORT=TENNIS



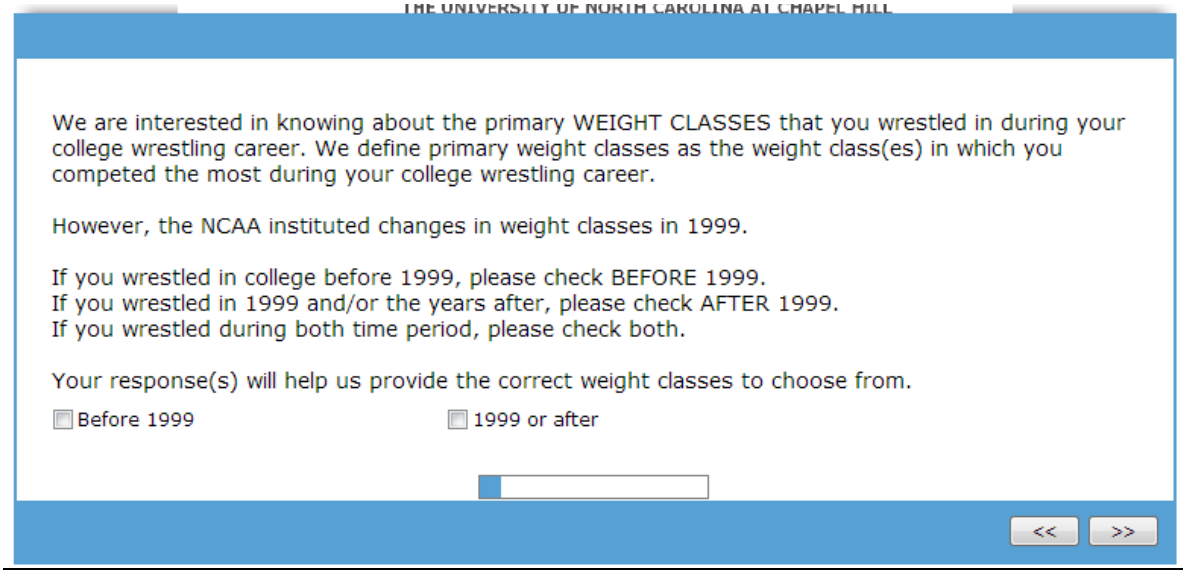
IF PRIMARY SPORT=TRACK AND FIELD



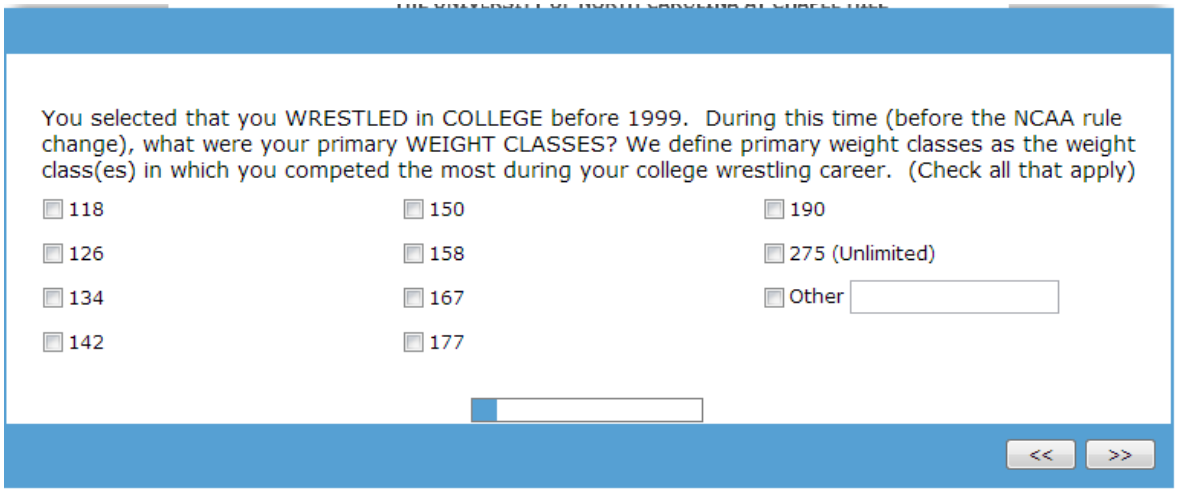
IF PRIMARY SPORT=VOLLEYBALL



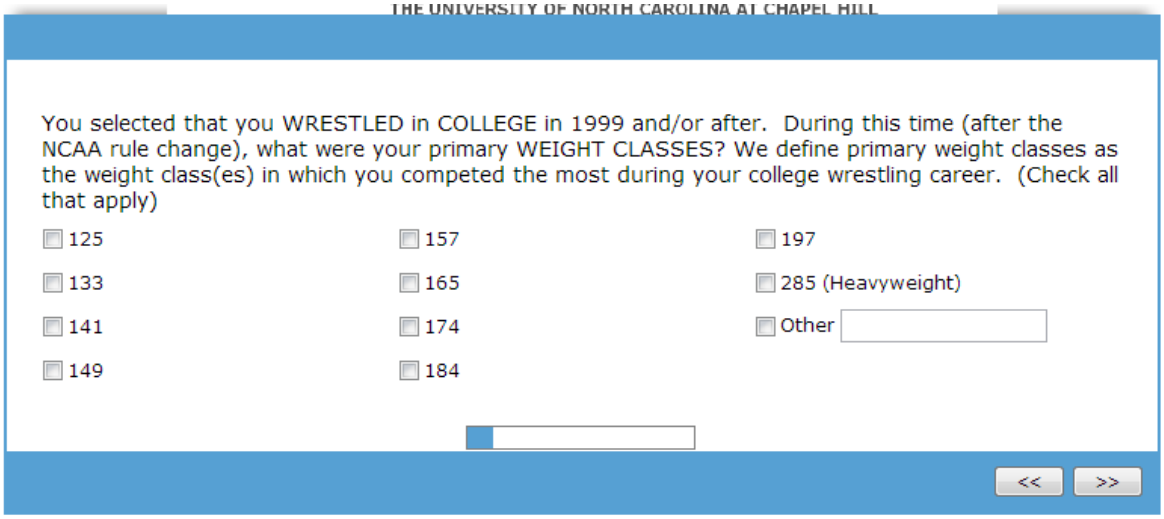
IF PRIMARY SPORT=WRESTLING



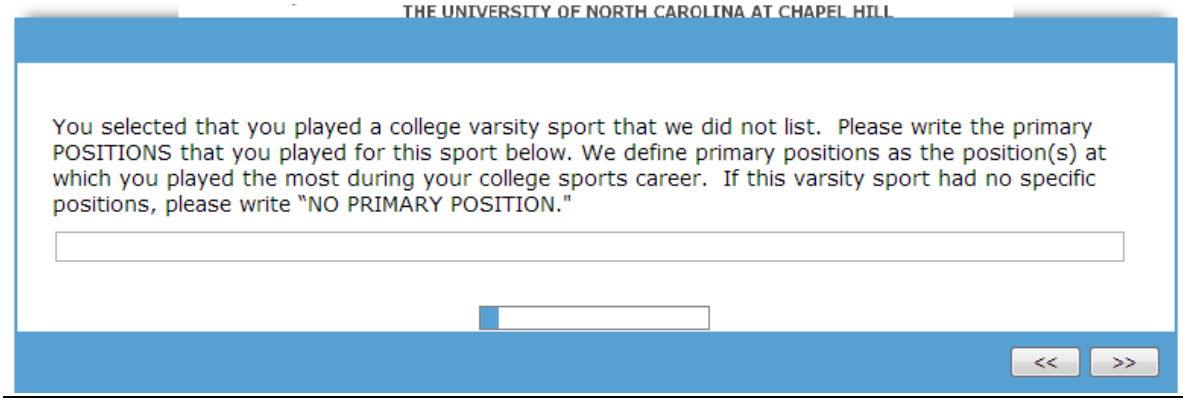
IF"BEFORE 1999" IS CHECKED



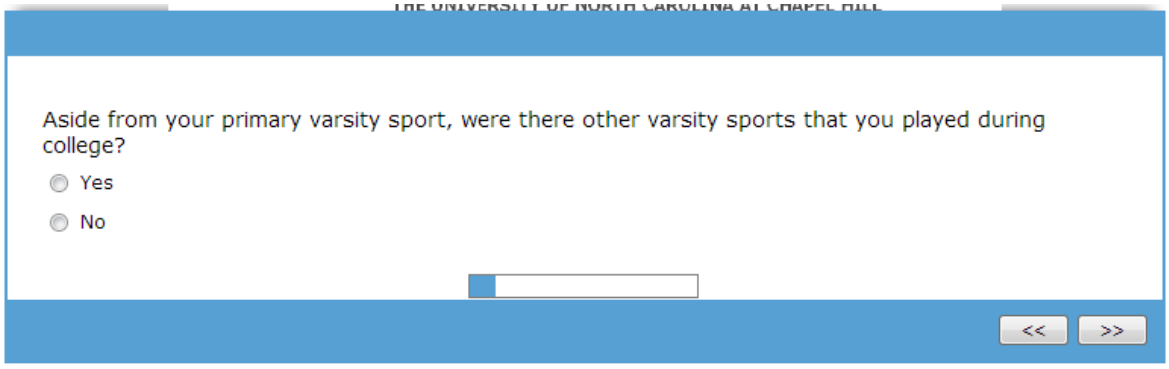
IF"1999 OR AFTER" IS CHECKED



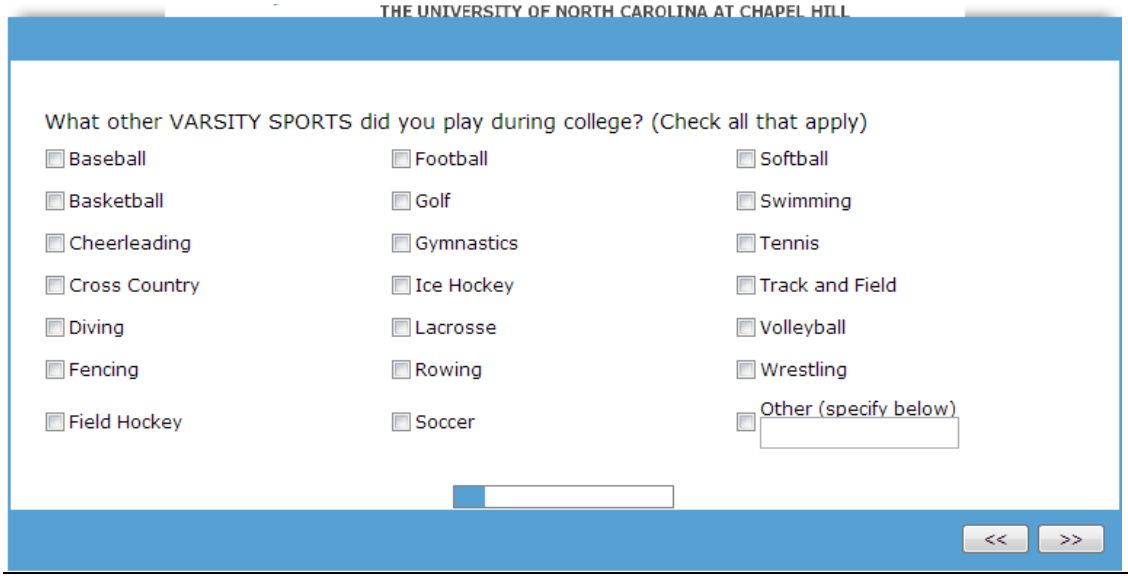
IF PRIMARY SPORT=OTHER



OTHER VARSITY SPORTS PLAYED



IF OTHER VARSITY SPORTS PLAYED=YES

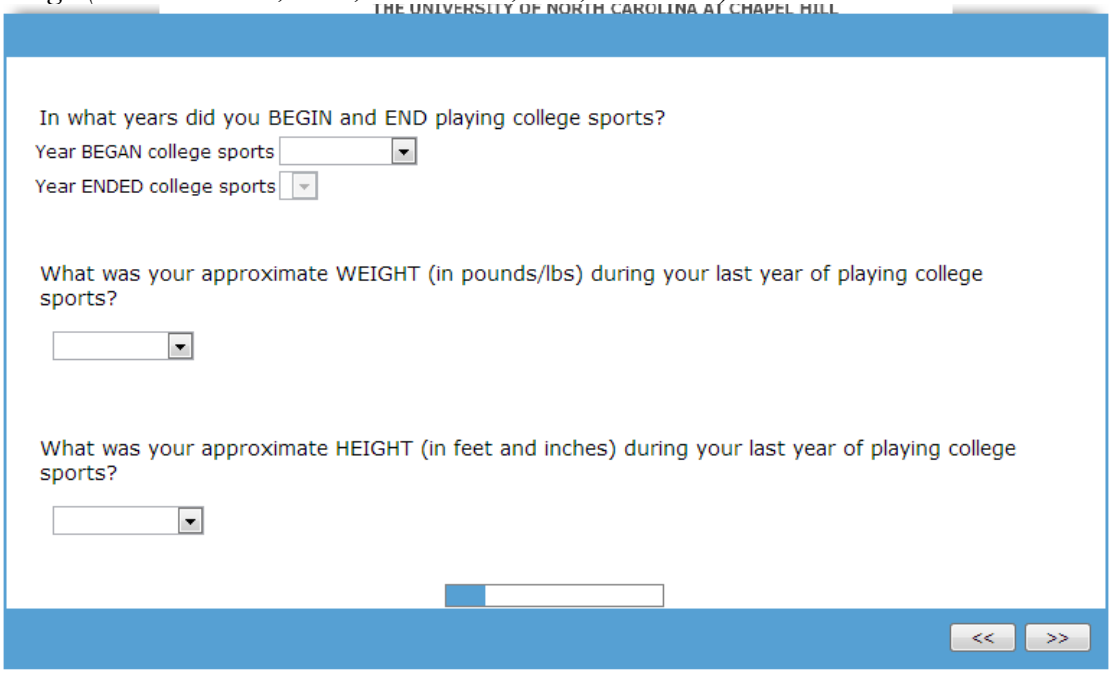


YEAR BEGAN PLAYING COLLEGE SPORTS
Range (Before 1980, 1980,1981,1982…2010,2011,2012)

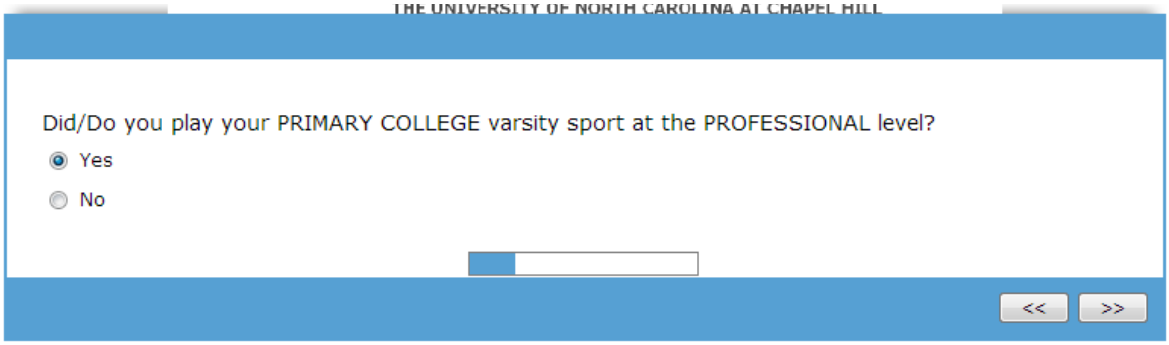
YEAR ENDED PLAYING COLLEGE SPORTS
Range (Before 1985, 1985,1986,1987…2010,2011,2012)

WEIGHT DURING COLLEGE
Range (less than 80, 80,81,82…348,349,350, over 350)

HEIGHT DURING COLLEGE
Range (less than 4'0", 4'0",4'1"…7'5",7'6", over 7'6")



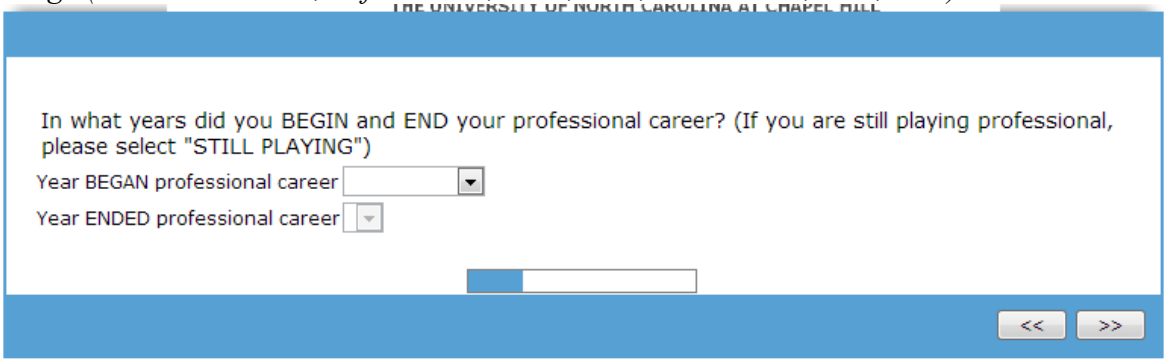
PLAYED PRIMARY SPORT PROFESSIONALLY



IF PLAYED PRIMARY SPORT PROFESSIONALLY = YES

YEAR BEGAN PROFESSIONAL CAREER
Range (Before 1987, 1987,1988,1989…2011,2012,2013)

YEAR ENDED PROFESSIONAL CAREER
Range (STILL PLAYING, Before 1987, 1987,1988,1989…2011,2012,2013)

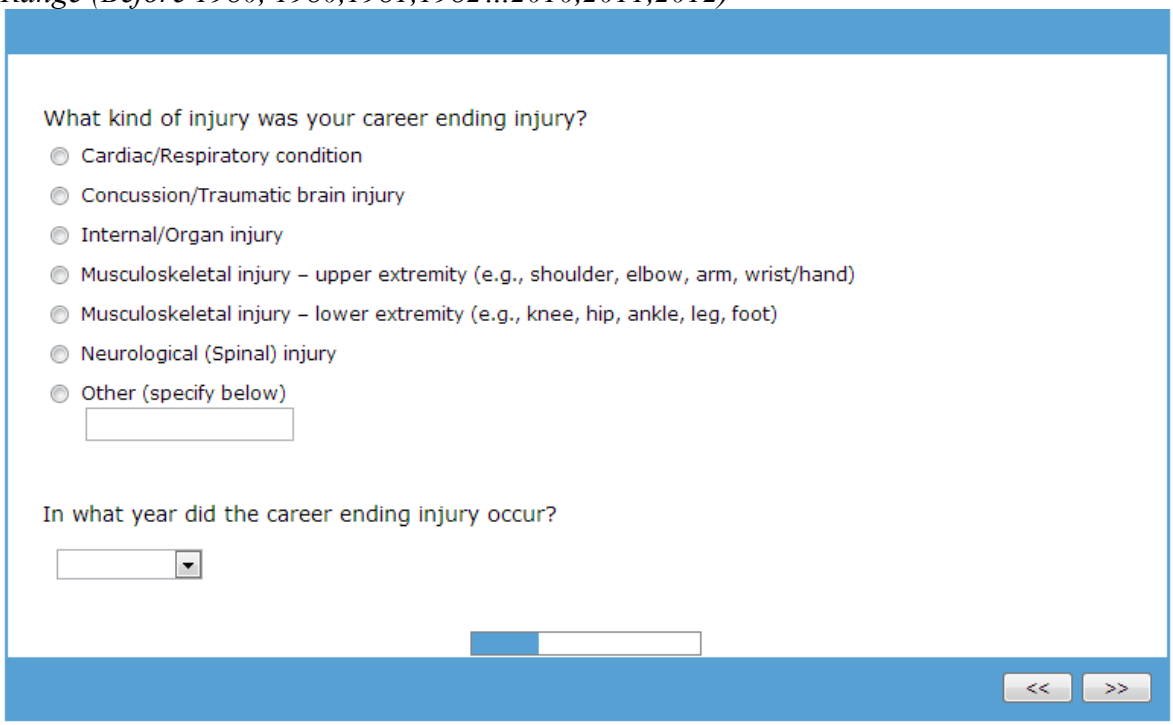


SUSTAINED CAREER-ENDING INJURY

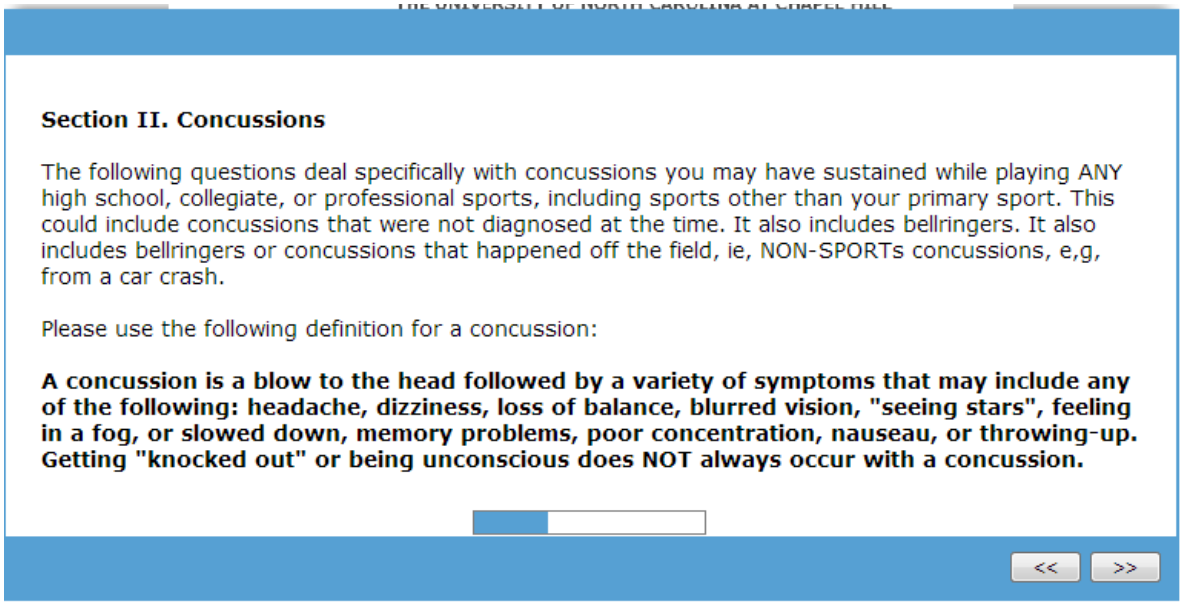
IF SUSTAINED CAREER-ENDING INJURY=YES

TYPE OF CAREER ENDING INJURY

YEAR CAREER ENDINGINJURY OCCURRED
Range (Before 1980, 1980,1981,1982…2010,2011,2012)



SECTION II



Section II. Concussions

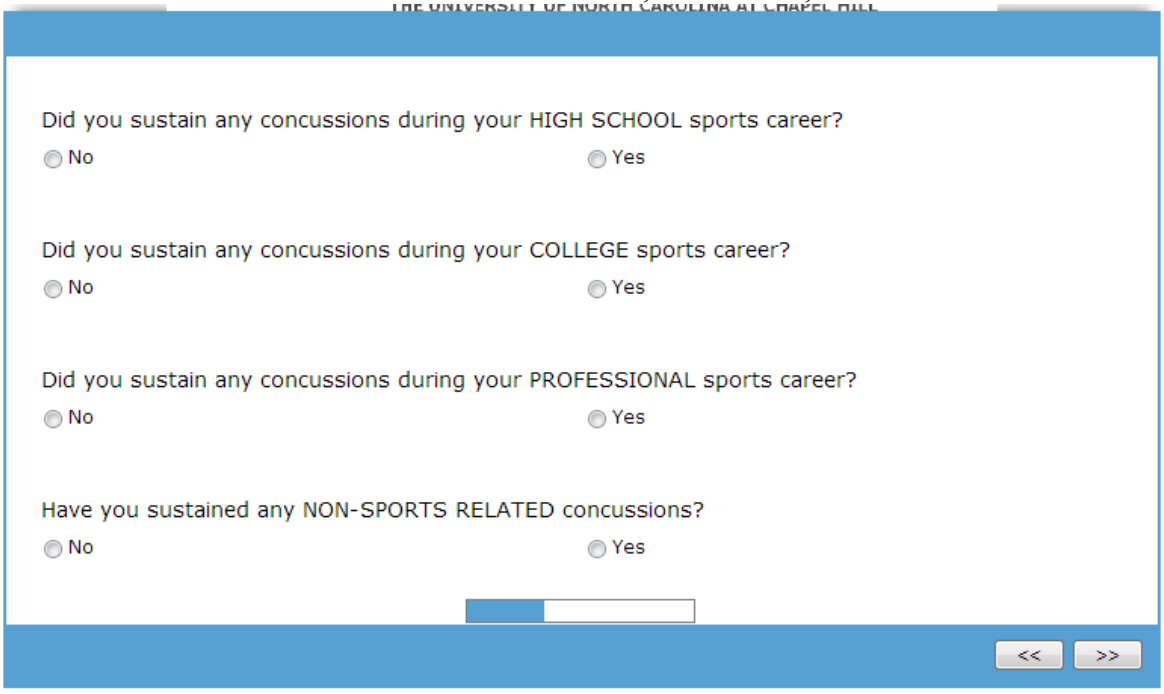
The following questions deal specifically with concussions you may have sustained while playing ANY high school, collegiate, or professional sports, including sports other than your primary sport. This could include concussions that were not diagnosed at the time. It also includes bellringers. It also includes bellringers or concussions that happened off the field, ie, NON-SPORTs concussions, e,g, from a car crash.

Please use the following definition for a concussion:

A concussion is a blow to the head followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, "seeing stars", feeling in a fog, or slowed down, memory problems, poor concentration, nauseau, or throwing-up. Getting "knocked out" or being unconscious does NOT always occur with a concussion.

<< >>

CONCUSSION HISTORY FOR HIGH SCHOOL, COLLEGE, PROFESSIONAL SPORTS



Did you sustain any concussions during your HIGH SCHOOL sports career?

No Yes

Did you sustain any concussions during your COLLEGE sports career?

No Yes

Did you sustain any concussions during your PROFESSIONAL sports career?

No Yes

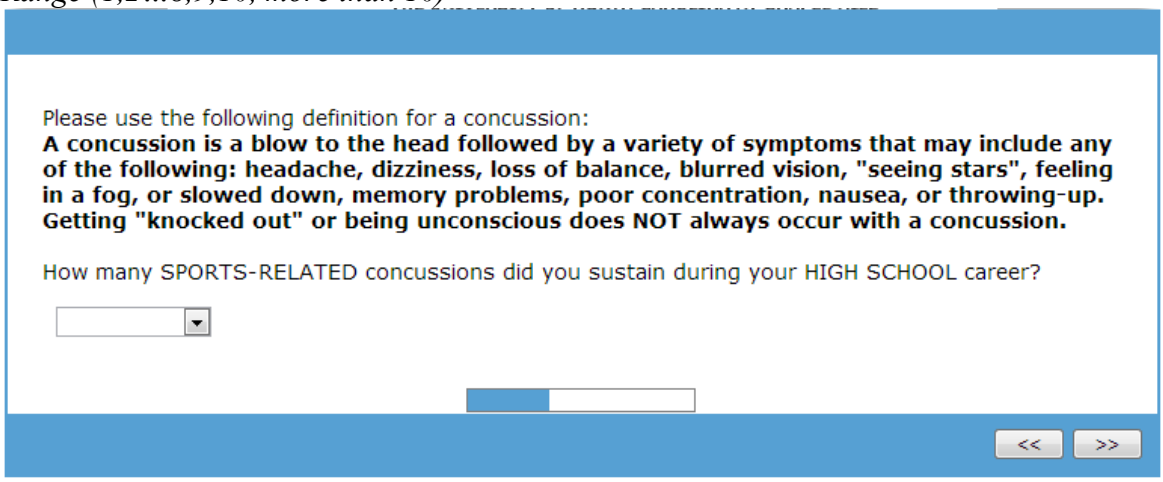
Have you sustained any NON-SPORTS RELATED concussions?

No Yes

<< >>

IF SUSTAINED CONCUSSIONS IN HIGH SCHOOL

CONCUSSIONS SUSTAINED
Range (1,2…8,9,10, more than 10)

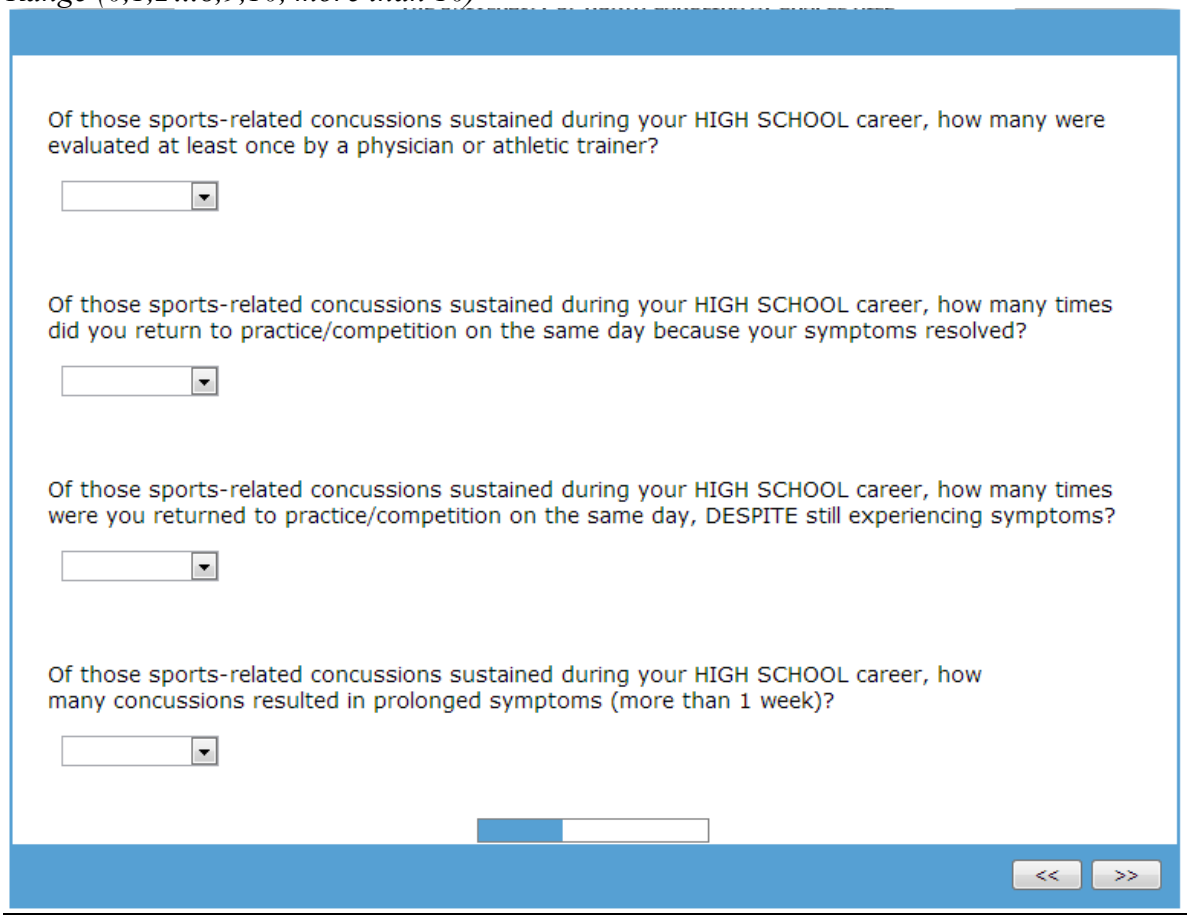


TIMES EVALUATED
Range (0,1,2…8,9,10, more than 10) – MAX OF THESE QUESTIONS DEPENDS ON "# CONCUSSIONS SUSTAINED"RESPONSE

TIMES RETURNED SAME DAY NO SYMPTOMS
Range (0,1,2…8,9,10, more than 10)

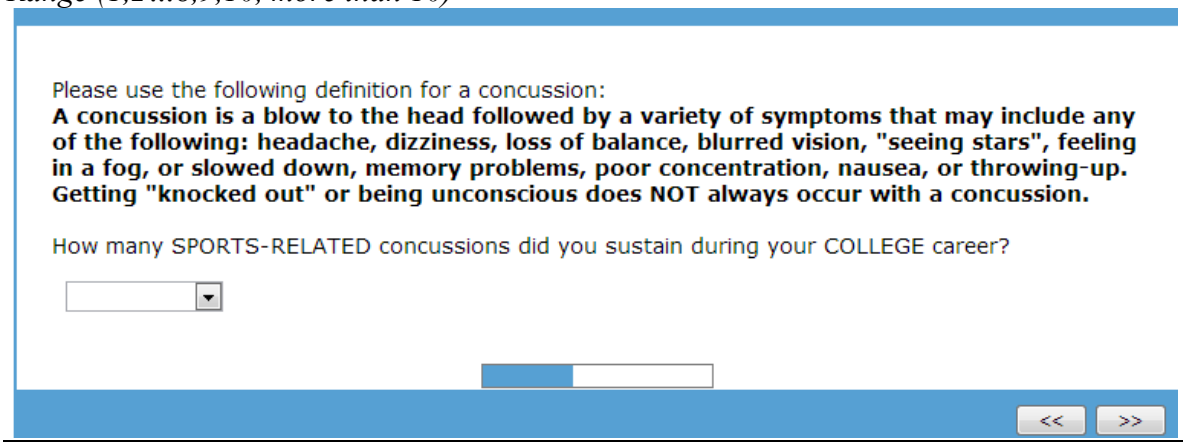
TIMES RETURNED SAME DAY STILL SYMPTOMATIC
Range (0,1,2…8,9,10, more than 10)

TIMES WITH PROLONGED SYMPTOMS
Range (0,1,2…8,9,10, more than 10)



IF SUSTAINED CONCUSSIONS IN COLLEGE

CONCUSSIONS SUSTAINED
Range (1,2…8,9,10, more than 10)

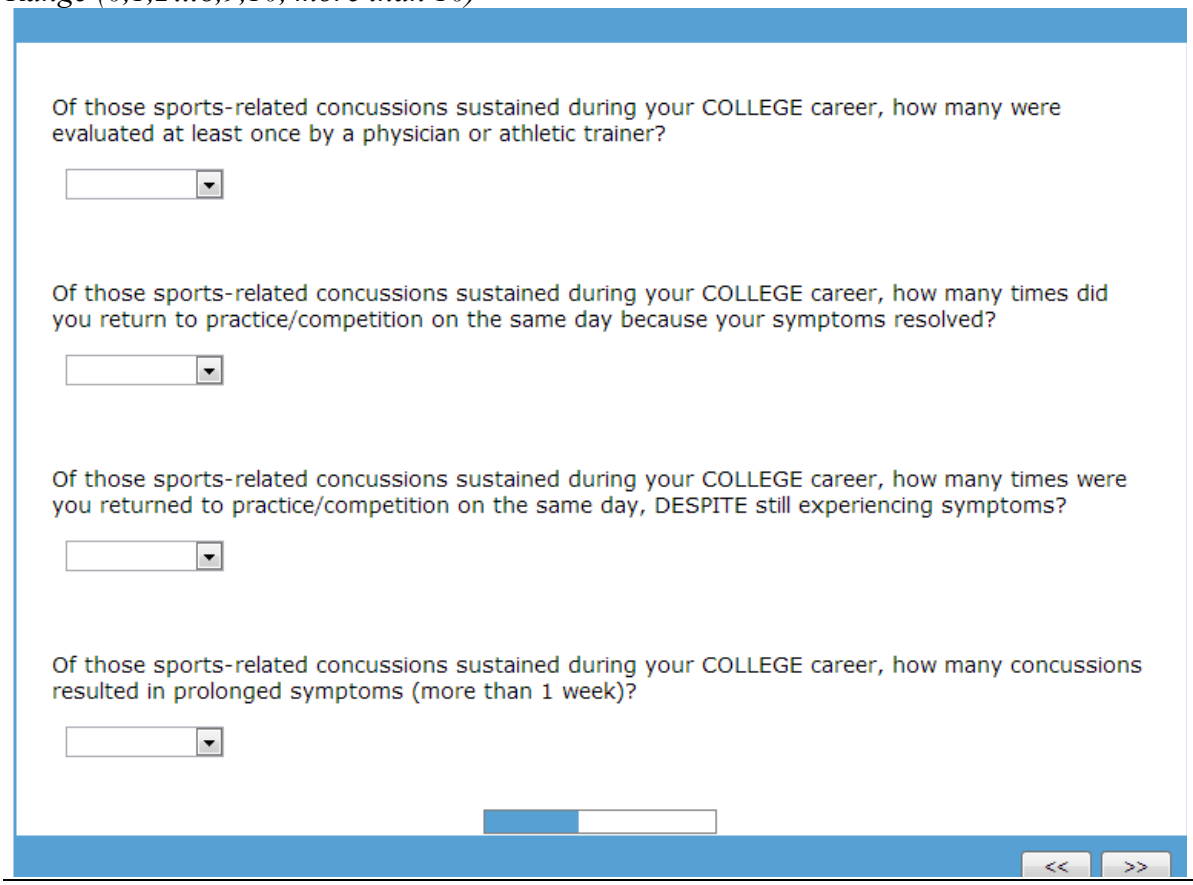


TIMES EVALUATED
Range (0,1,2…8,9,10, more than 10) – MAX OF THESE QUESTIONS DEPENDS ON "# CONCUSSIONS SUSTAINED"RESPONSE

TIMES RETURNED SAME DAY NO SYMPTOMS
Range (0,1,2…8,9,10, more than 10)

TIMES RETURNED SAME DAY STILL SYMPTOMATIC
Range (0,1,2…8,9,10, more than 10)

TIMES WITH PROLONGED SYMPTOMS
Range (0,1,2…8,9,10, more than 10)



IF SUSTAINED CONCUSSIONS IN COLLEGE
NUMBER ROWS DEPENDS ON "# CONCUSSIONS SUSTAINED"RESPONSE; THIRD PARAGRAPH APPEARS ONLY WITH "MORE THAN 10" RESPONSE

SPORT PLAYED

MONTH
Range (Jan,Feb,Mar…Oct,Nov,Dec,Don't know)

DAY
Range (1,2,3…29,30,31,Don't know)

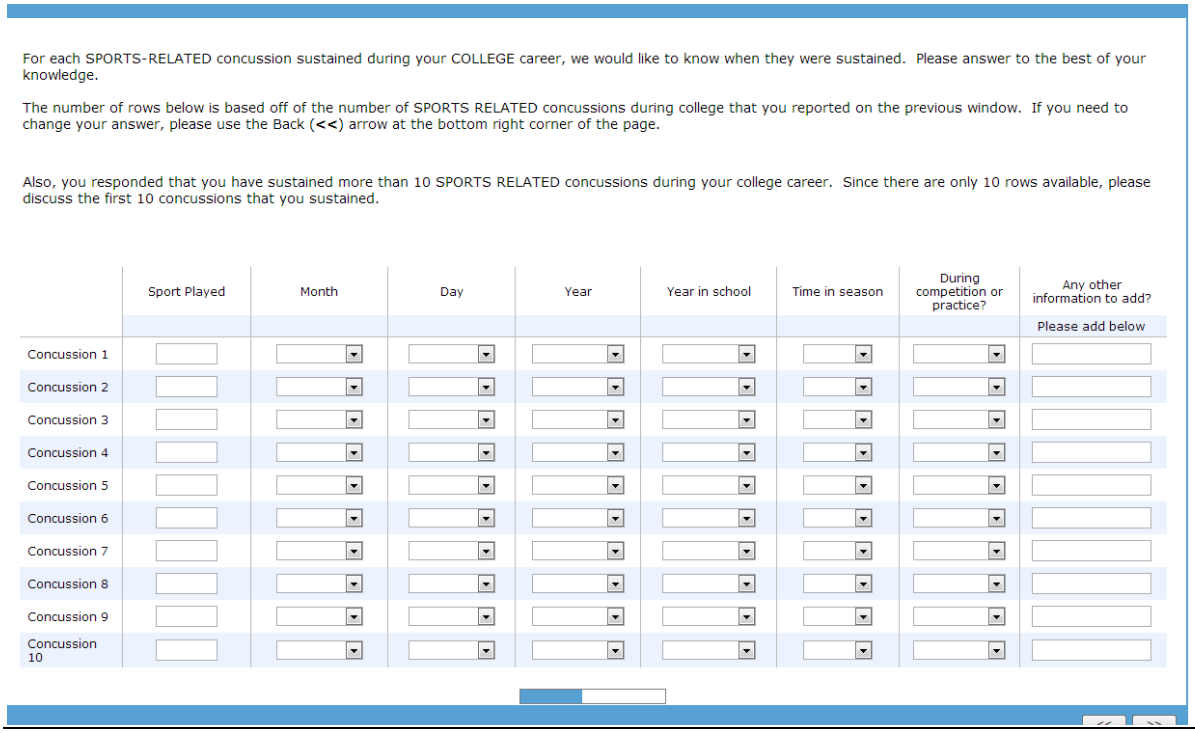
YEAR
Range (Before 1985, 1986,1987…2010,2011,2012)

YEAR IN SCHOOL
Range (Freshman, Sophomore, Junior, Senior, 5th year senior, Grad school)

TIME IN SEASON
Range (1st half, 2nd half)

DURING COMPETITION OR PRACTICE
Range (Competition, Practice)

ANY OTHER INFO?



For each SPORTS-RELATED concussion sustained during your COLLEGE career, we would like to know when they were sustained. Please answer to the best of your knowledge.

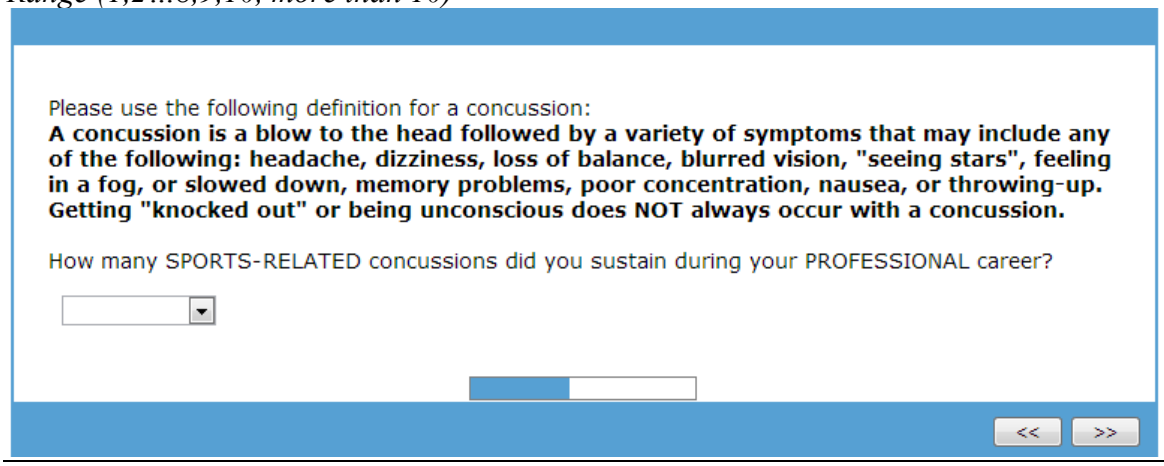
The number of rows below is based off of the number of SPORTS RELATED concussions during college that you reported on the previous window. If you need to change your answer, please use the Back (<<) arrow at the bottom right corner of the page.

Also, you responded that you have sustained more than 10 SPORTS RELATED concussions during your college career. Since there are only 10 rows available, please discuss the first 10 concussions that you sustained.

	Sport Played	Month	Day	Year	Year in school	Time in season	During competition or practice?	Any other information to add?
								Please add below
Concussion 1								
Concussion 2								
Concussion 3								
Concussion 4								
Concussion 5								
Concussion 6								
Concussion 7								
Concussion 8								
Concussion 9								
Concussion 10								

IF SUSTAINED CONCUSSIONS PROFESSIONAL

CONCUSSIONS SUSTAINED
Range (1,2…8,9,10, more than 10)

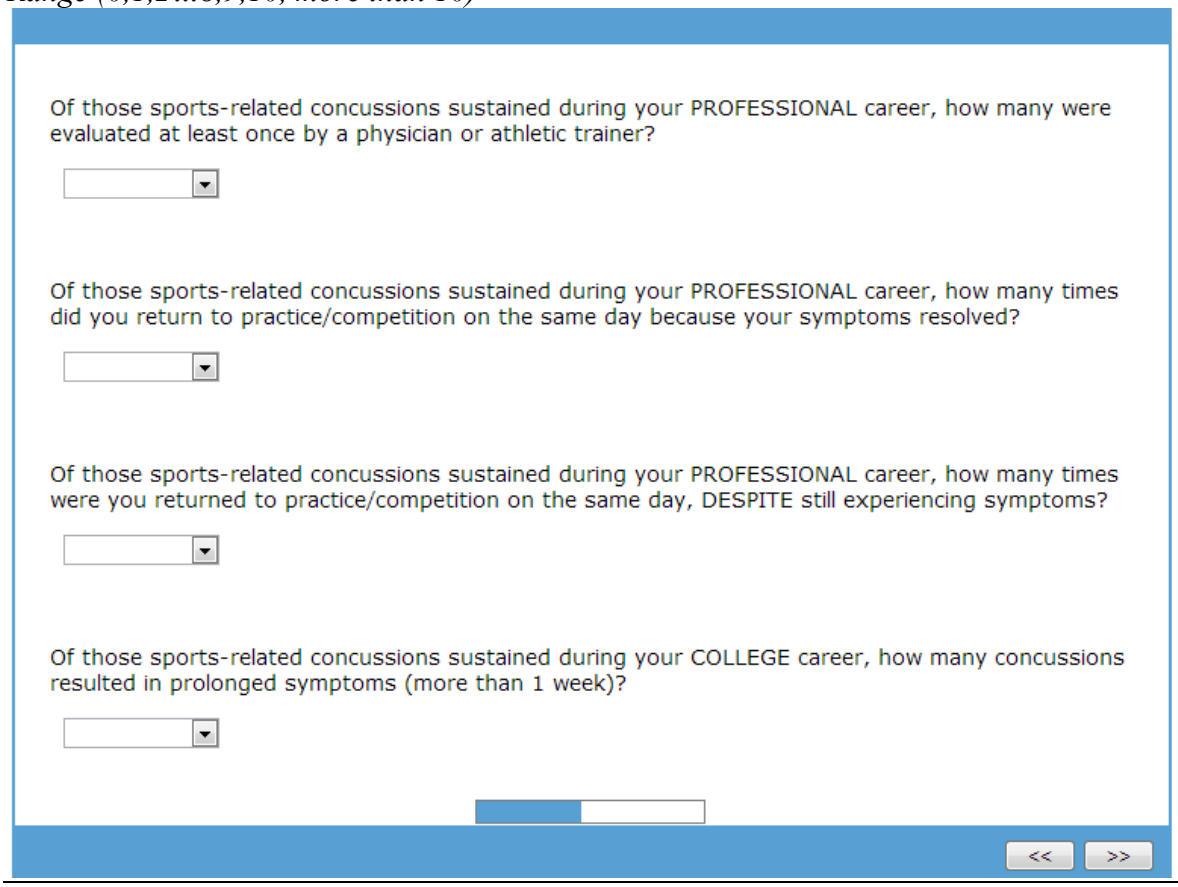


TIMES EVALUATED
Range (0,1,2…8,9,10, more than 10) – MAX OF THESE QUESTIONS DEPENDS ON "# CONCUSSIONS SUSTAINED"RESPONSE

TIMES RETURNED SAME DAY NO SYMPTOMS
Range (0,1,2…8,9,10, more than 10)

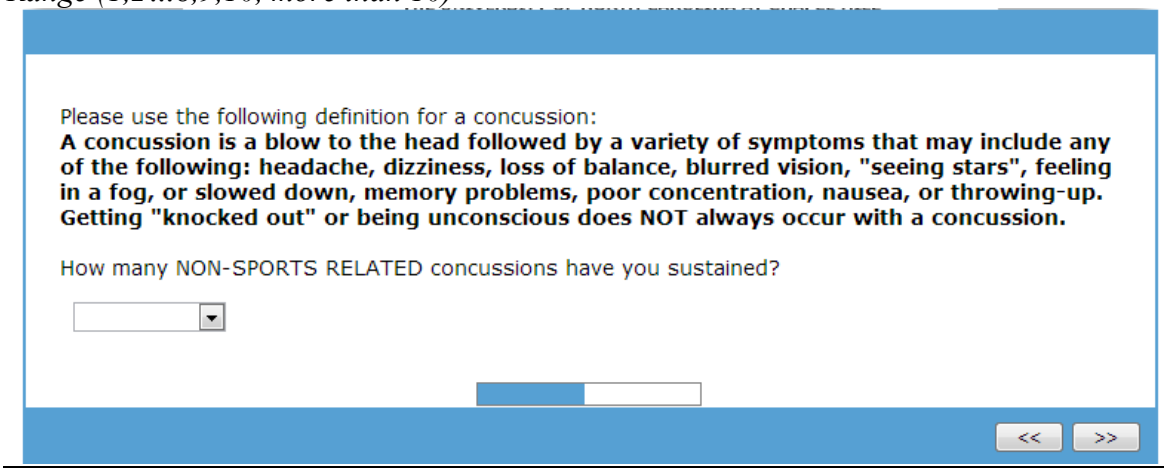
TIMES RETURNED SAME DAY STILL SYMPTOMATIC
Range (0,1,2…8,9,10, more than 10)

TIMES WITH PROLONGED SYMPTOMS
Range (0,1,2…8,9,10, more than 10)



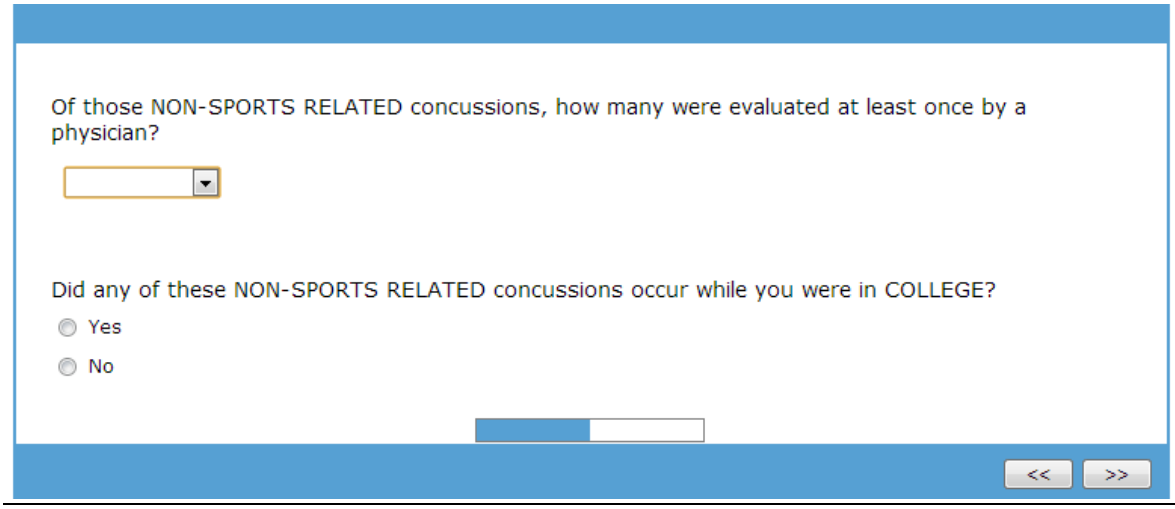
IF SUSTAINED NON SPORTS CONCUSSIONS

CONCUSSIONS SUSTAINED
Range (1,2…8,9,10, more than 10)



NUMBER EVALUATED BY PHYSICIAN – MAX OF THESE QUESTIONS DEPENDS ON "# CONCUSSIONS SUSTAINED"RESPONSE
Range (0,1,2…8,9,10, more than 10)

NON SPORT CONCUSSIONS WHILE IN COLLEGE



IF SUSTAINED NON-SPORT CONCUSSIONS IN COLLEGE
NUMBER ROWS DEPENDS ON "# CONCUSSIONS SUSTAINED"RESPONSE; THIRD PARAGRAPH APPEARS ONLY WITH "MORE THAN 10" RESPONSE

MONTH
Range (Jan,Feb,Mar…Oct,Nov,Dec,Don't know)

DAY
Range (1,2,3…29,30,31,Don't know)

YEAR
Range (Before 1985, 1986,1987…2010,2011,2012)

YEAR IN SCHOOL
Range (Freshman, Sophomore, Junior, Senior, 5th year senior, Grad school)

ANY OTHER INFO?

For each NON-SPORTS RELATED concussion sustained while you were in college, we would like to know when they were sustained. Please answer to the best of your knowledge.

The number of rows below is based off of the number of NON-SPORTS RELATED concussions you reported on the previous window. If you need to change your answer, please use the Back (**<<**) arrow at the bottom right corner of the page.

Also, you responded that you have sustained more than 10 NON-SPORTS RELATED concussions. If all these occurred while in college, please discuss the first 10 concussions that you sustained.

	Month	Day	Year	Year in school	Any other information to add? Please add below
Concussion 1					
Concussion 2					
Concussion 3					
Concussion 4					
Concussion 5					
Concussion 6					
Concussion 7					
Concussion 8					
Concussion 9					
Concussion 10					

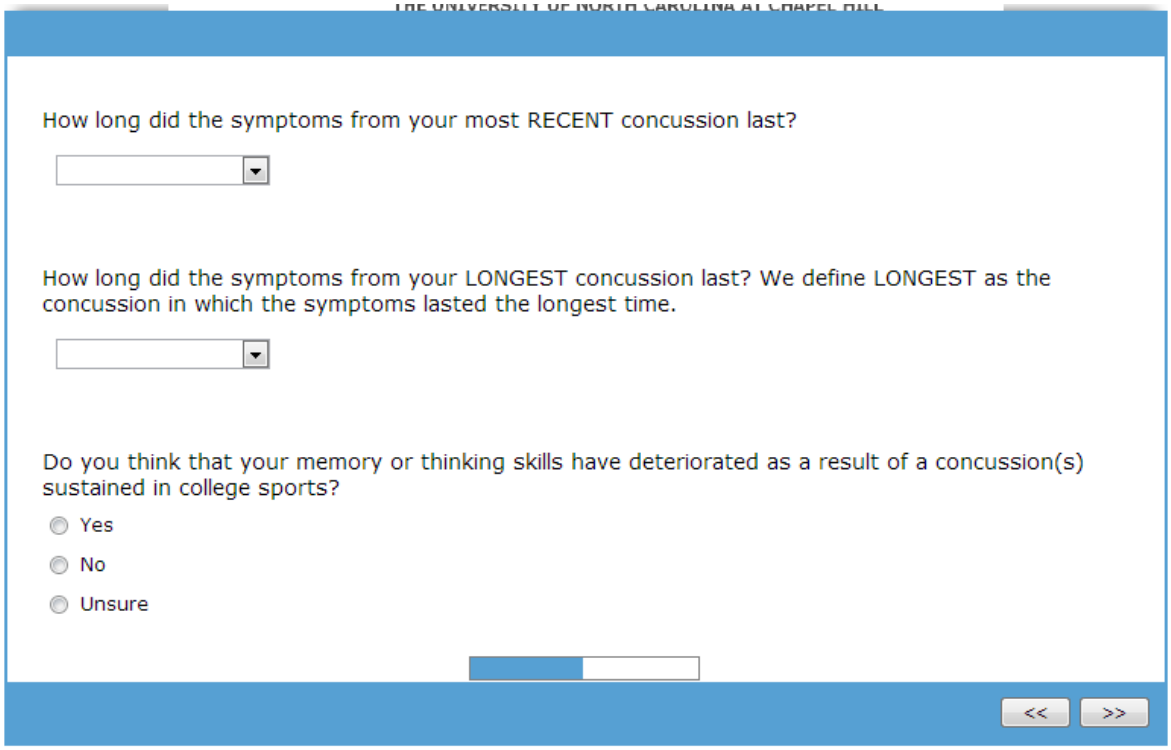
<< >>

IF SUSTAINED CONCUSSIONS IN HIGH SCHOOL, COLLEGE, PROFESSIONAL, OR NONSPORT

LENGTH OF TIME SYMPTOMS OF MOST RECENT CONCUSSION LASTED
Range (<1 day, 1 to 3 days, 3 days to 1 week, 1 to 2 weeks, 2 weeks to 1 month, 1 to 3 months, 3 to 6 months, 6 months to 1 year, 1 to 2 years, 2 to 5 years, 5 to 10 years, more than 10 years)

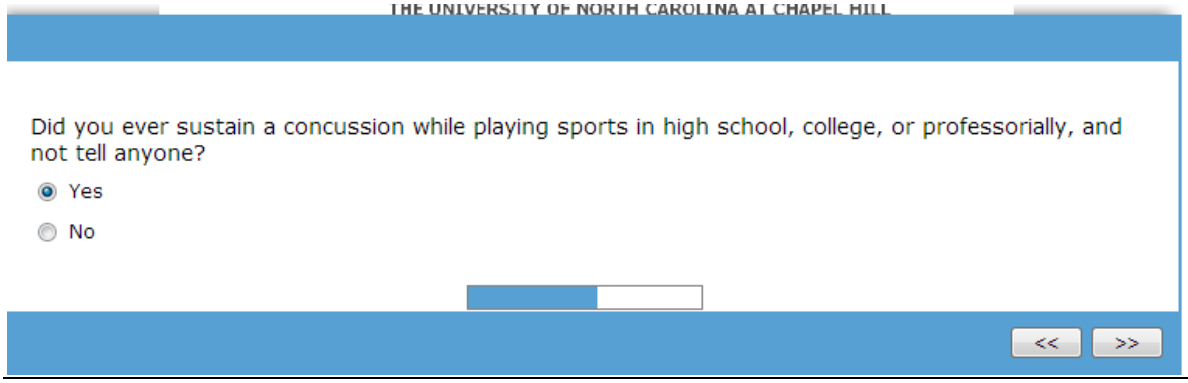
LENGTH OF TIME SYMPTOMS OF LONGEST CONCUSSION LASTED
Range (<1 day, 1 to 3 days, 3 days to 1 week, 1 to 2 weeks, 2 weeks to 1 month, 1 to 3 months, 3 to 6 months, 6 months to 1 year, 1 to 2 years, 2 to 5 years, 5 to 10 years, more than 10 years)

MEMORY DETERIORATED DUE TO CONCUSSIONS



IF SUSTAINED CONCUSSIONS IN HIGH SCHOOL, COLLEGE, OR PROFESSIONAL,

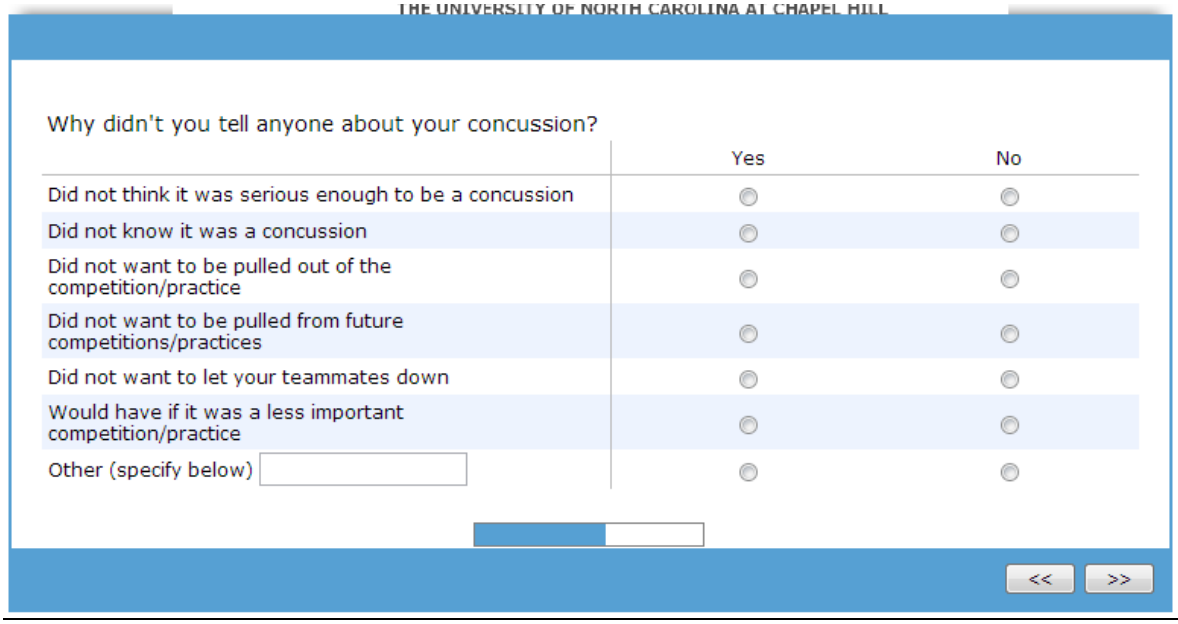
NON-DISCLOSURE OF CONCUSSIONS



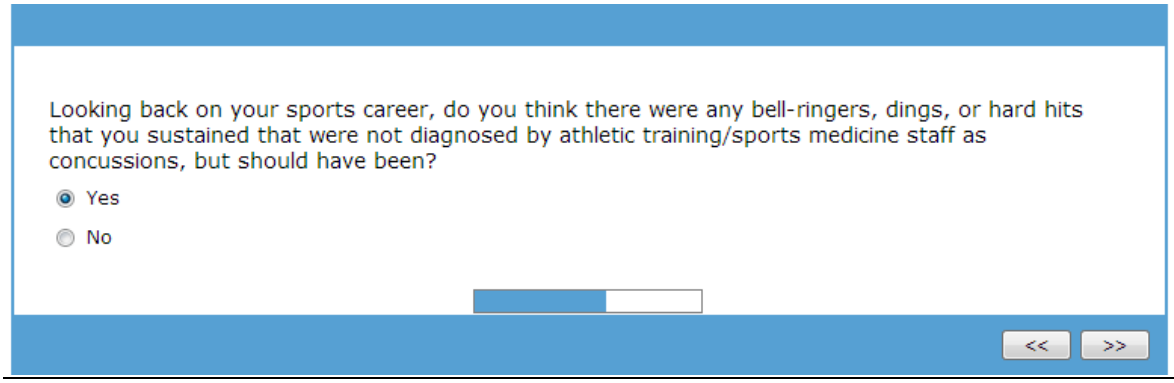
IF NON-DISCLOSURE OF CONCUSSIONS=YES

OCCURRED WHILE PLAYING COLLEGE SPORTS *(ONLY IF HAD CONCUSSION DURING COLLEGE SPORTS CAREER)*

REASONS FOR NON-DISCLOSURE

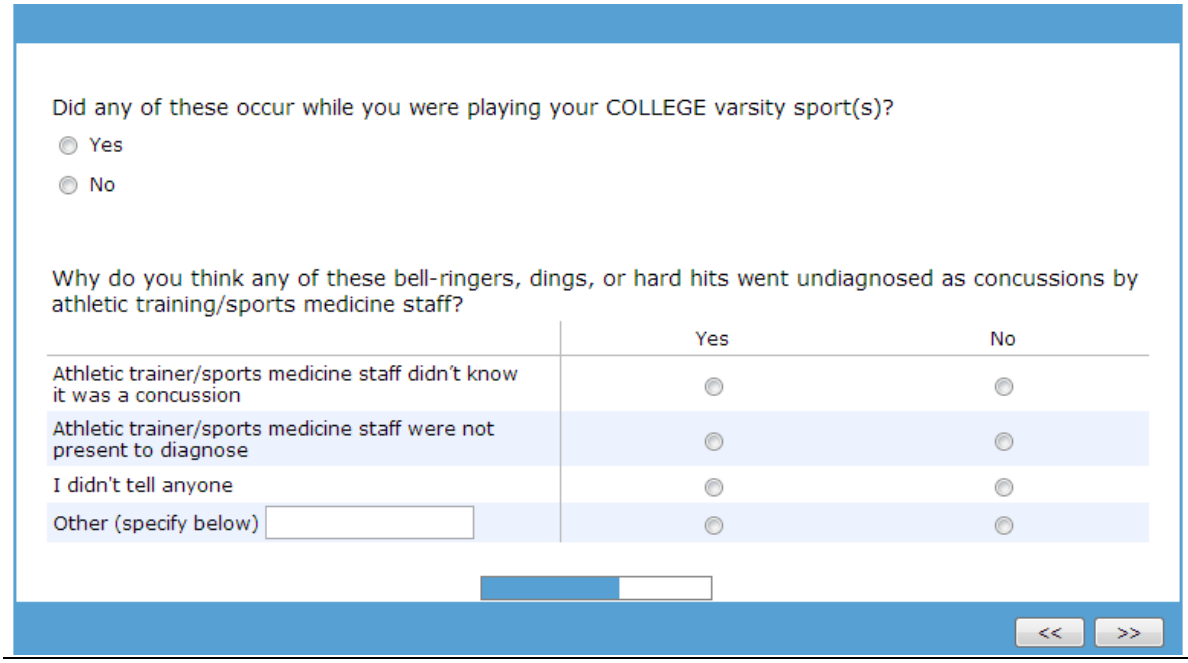


ANY HARD HITS THAT SHOULD HAVE BEEN DIAGNOSED CONCUSSIONS?



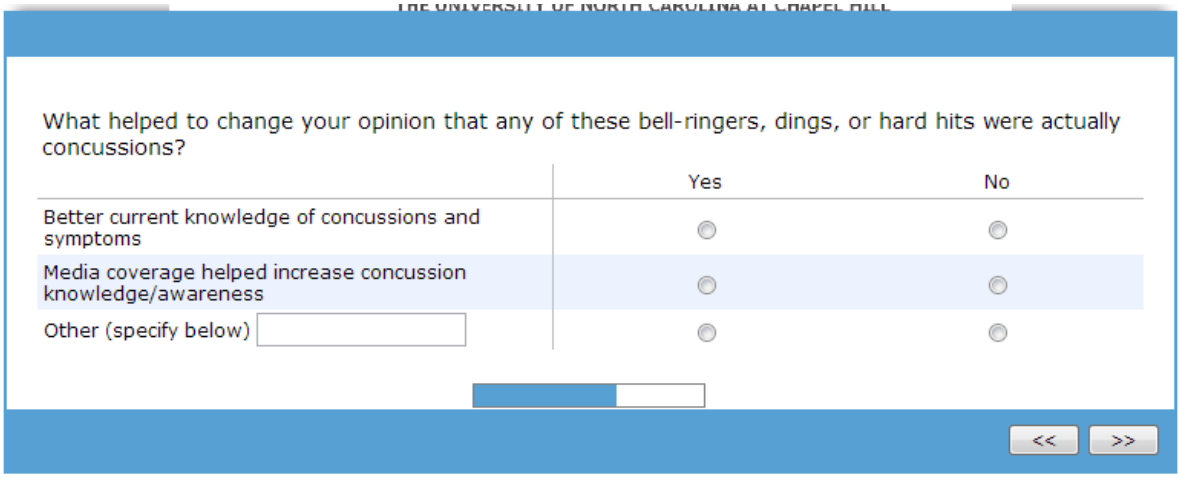
IF ANY HARD HITS THAT SHOULD HAVE BEEN DIAGNOSED CONCUSSIONS?=YES

REASONS THEY WENT UNDIAGNOSED?



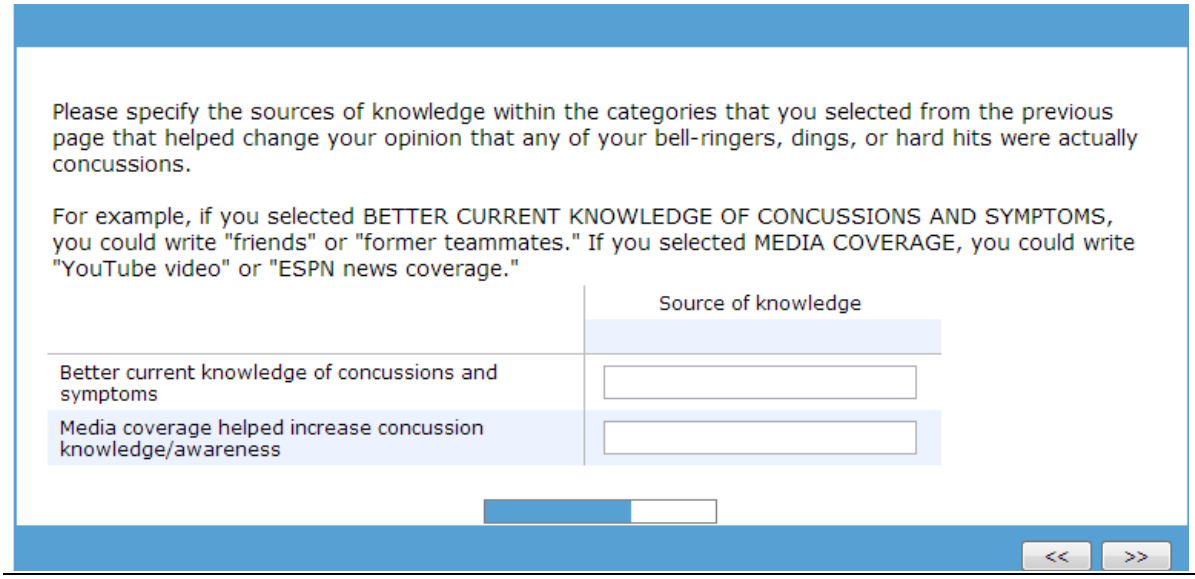
IF ANY HARD HITS THAT SHOULD HAVE BEEN DIAGNOSED CONCUSSIONS?=YES

WHAT HELPED TO CHANGE MIND THAT HARD HITS WERE REALLY CONCUSSIONS?

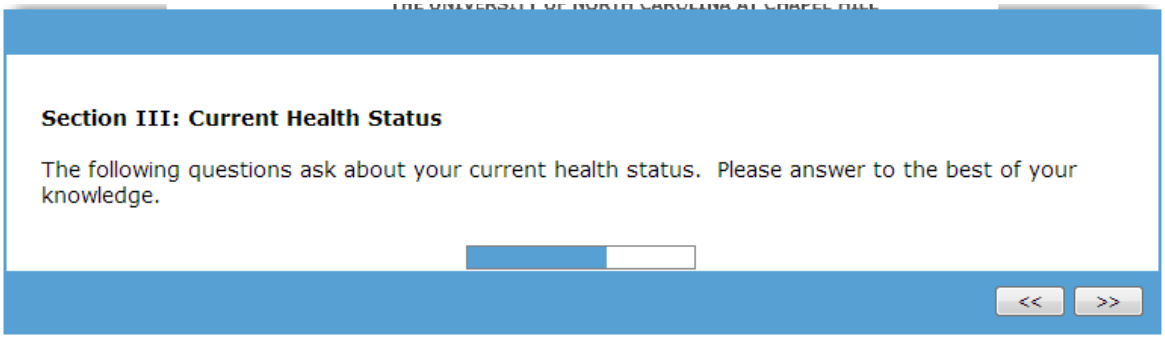


SPECIFIC SOURCES OF KNOWLEDGE

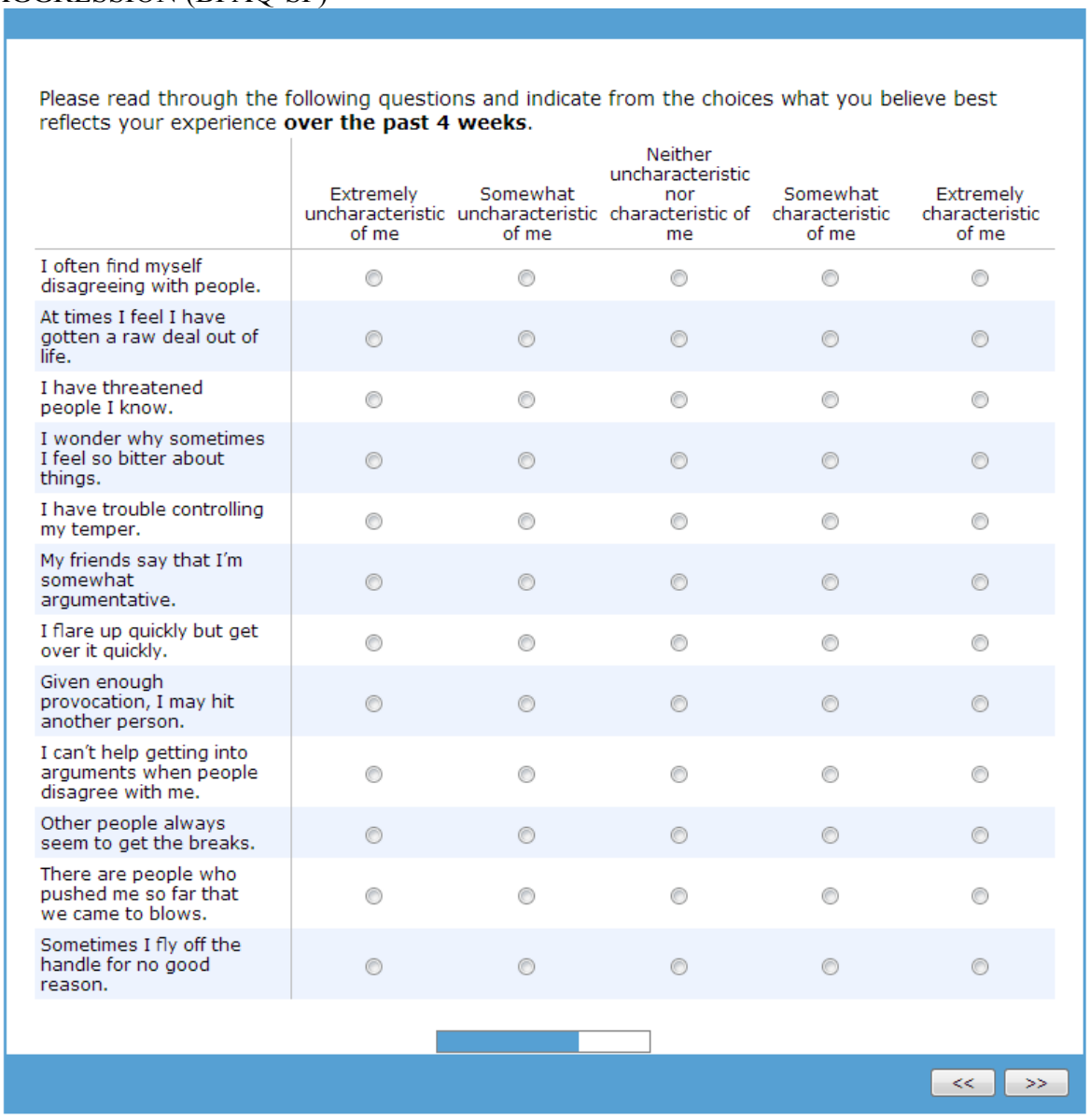
ROWS APPEAR IF YES IS SELECTED FOR SAME ROWS ON PREVIOUS WINDOW



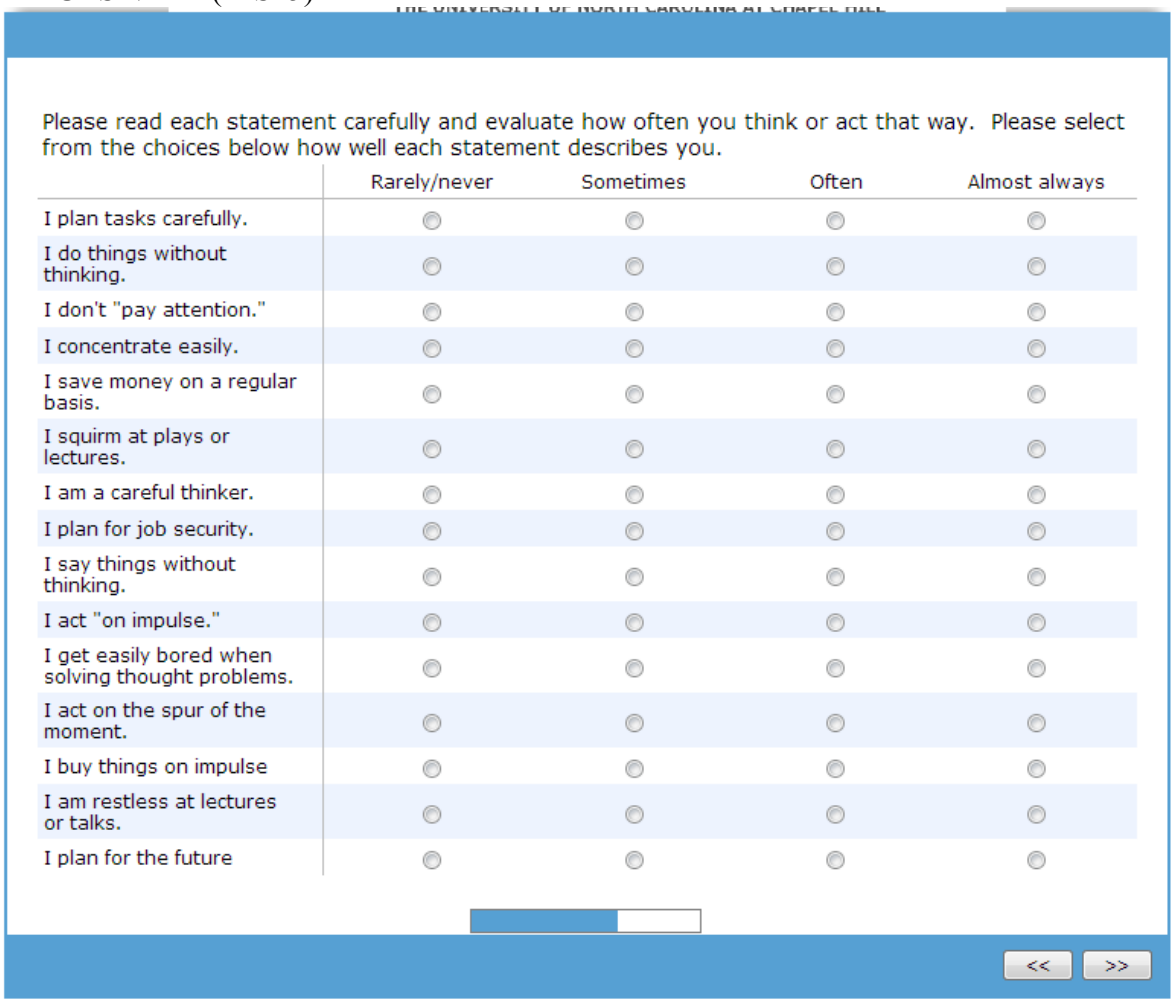
SECTION III



AGGRESSION (BPAQ-SF)



IMPULSIVITY (BIS15)



Please read each statement carefully and evaluate how often you think or act that way. Please select from the choices below how well each statement describes you.

	Rarely/never	Sometimes	Often	Almost always
I plan tasks carefully.	○	○	○	○
I do things without thinking.	○	○	○	○
I don't "pay attention."	○	○	○	○
I concentrate easily.	○	○	○	○
I save money on a regular basis.	○	○	○	○
I squirm at plays or lectures.	○	○	○	○
I am a careful thinker.	○	○	○	○
I plan for job security.	○	○	○	○
I say things without thinking.	○	○	○	○
I act "on impulse."	○	○	○	○
I get easily bored when solving thought problems.	○	○	○	○
I act on the spur of the moment.	○	○	○	○
I buy things on impulse	○	○	○	○
I am restless at lectures or talks.	○	○	○	○
I plan for the future	○	○	○	○

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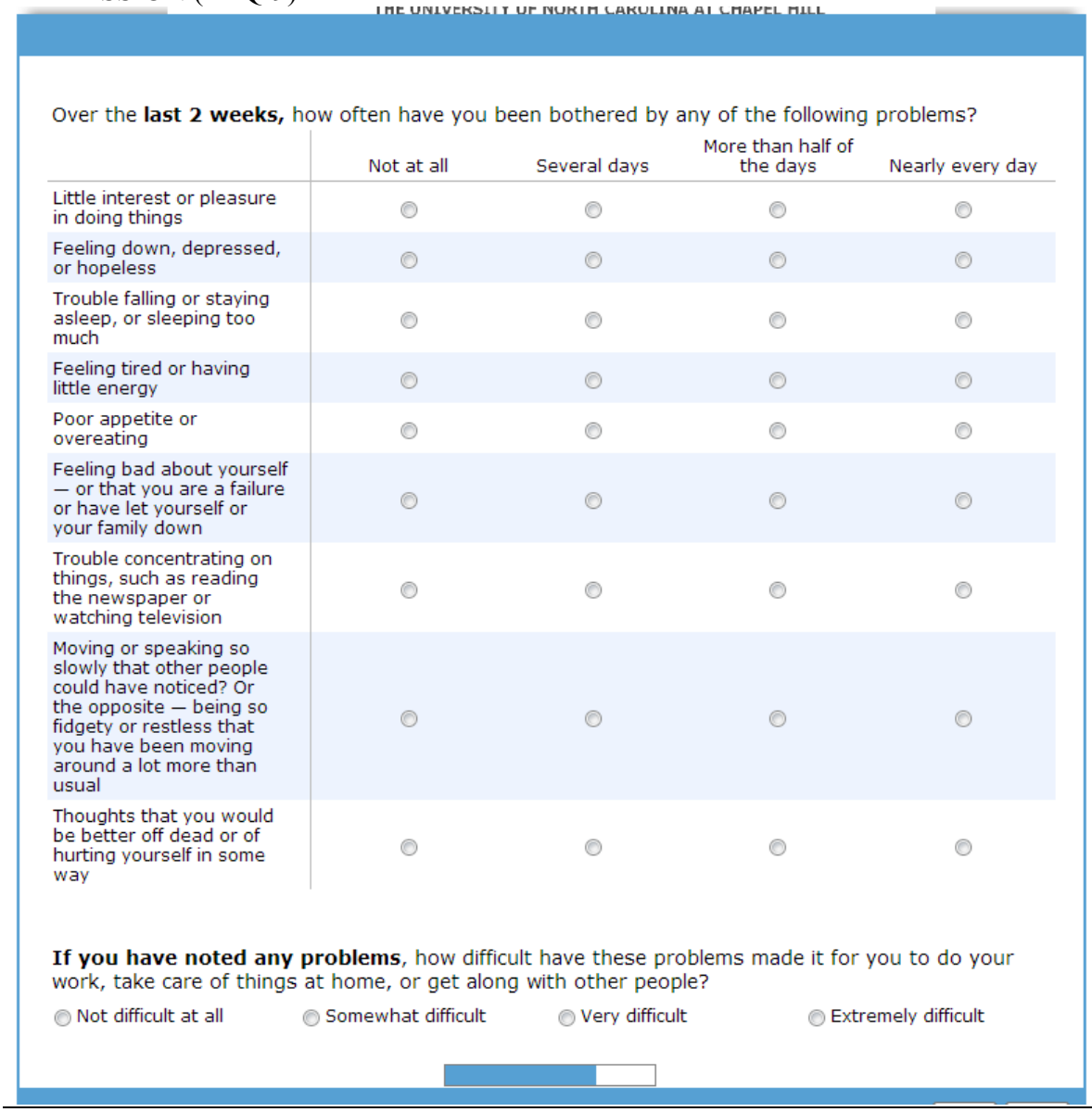
DEPRESSION (PHQ-9)



THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

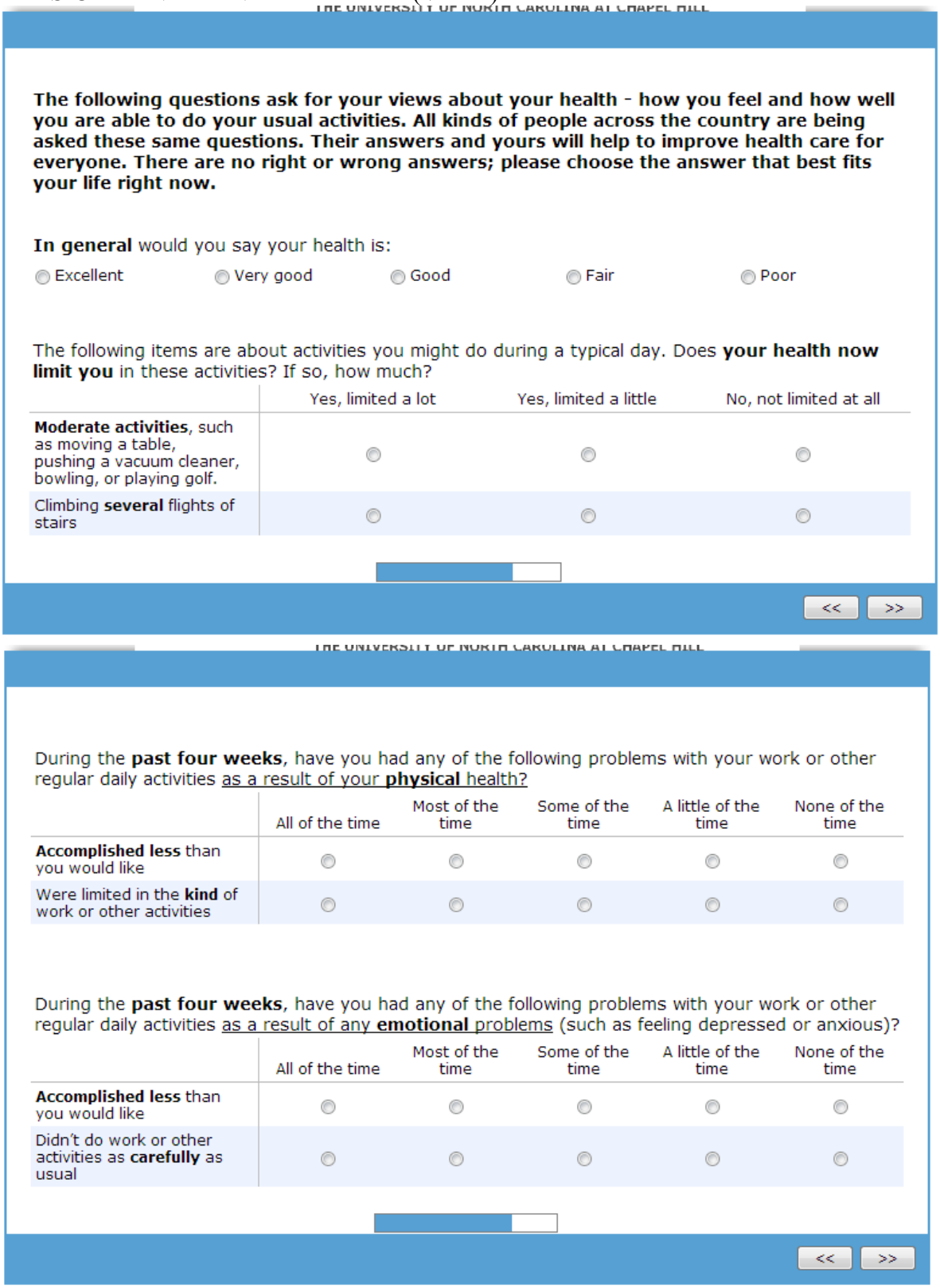
Over the **last 2 weeks,** how often have you been bothered by any of the following problems?

	Not at all	Several days	More than half of the days	Nearly every day
Little interest or pleasure in doing things	○	○	○	○
Feeling down, depressed, or hopeless	○	○	○	○
Trouble falling or staying asleep, or sleeping too much	○	○	○	○
Feeling tired or having little energy	○	○	○	○
Poor appetite or overeating	○	○	○	○
Feeling bad about yourself — or that you are a failure or have let yourself or your family down	○	○	○	○
Trouble concentrating on things, such as reading the newspaper or watching television	○	○	○	○
Moving or speaking so slowly that other people could have noticed? Or the opposite — being so fidgety or restless that you have been moving around a lot more than usual	○	○	○	○
Thoughts that you would be better off dead or of hurting yourself in some way	○	○	○	○

If you have noted any problems, how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people?

○ Not difficult at all ○ Somewhat difficult ○ Very difficult ○ Extremely difficult

PHYSICAL AND MENTAL HEALTH (VR-12)



The following questions ask for your views about your health - how you feel and how well you are able to do your usual activities. All kinds of people across the country are being asked these same questions. Their answers and yours will help to improve health care for everyone. There are no right or wrong answers; please choose the answer that best fits your life right now.

In general would you say your health is:

Excellent | Very good | Good | Fair | Poor

The following items are about activities you might do during a typical day. Does **your health now limit you** in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf.			
Climbing **several** flights of stairs			

<< >>

During the **past four weeks**, have you had any of the following problems with your work or other regular daily activities as a result of your **physical** health?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Accomplished less than you would like					
Were limited in the **kind** of work or other activities					

During the **past four weeks**, have you had any of the following problems with your work or other regular daily activities as a result of any **emotional** problems (such as feeling depressed or anxious)?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Accomplished less than you would like					
Didn't do work or other activities as **carefully** as usual					

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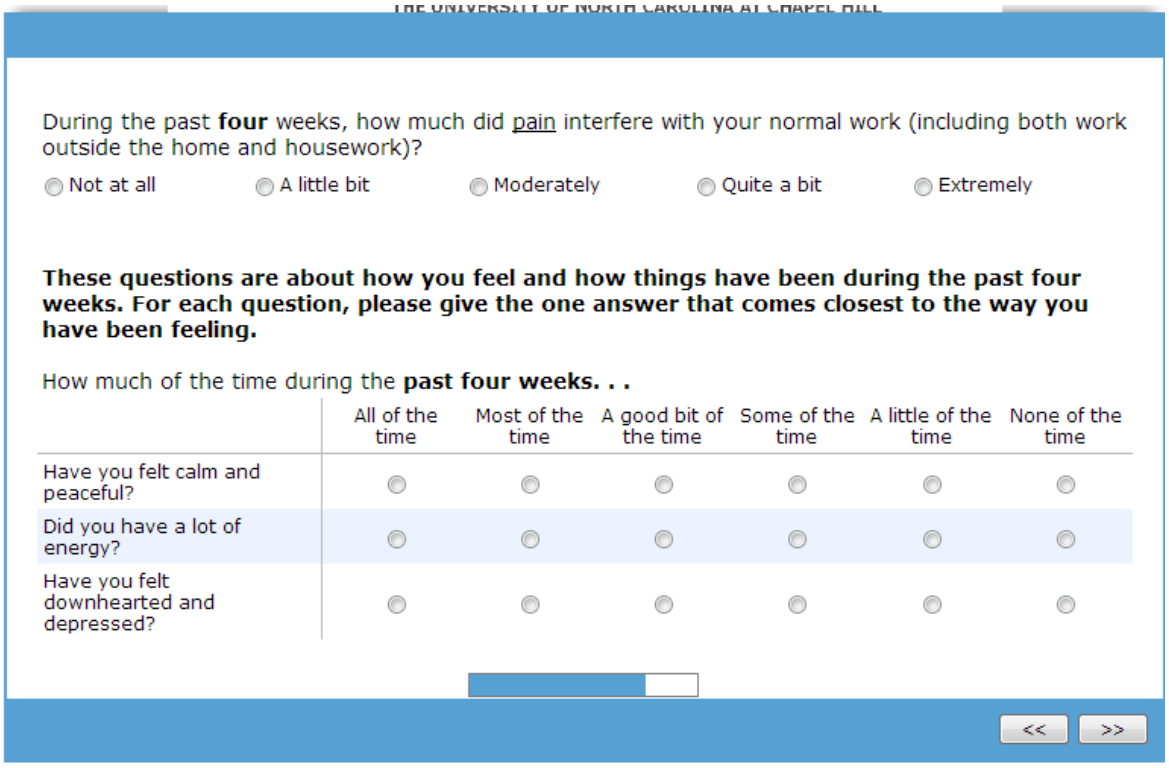
During the past four weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?
Not at all
A little bit
Moderately
Quite a bit
Extremely
These questions are about how you feel and how things have been during the past four weeks. For each question, please give the one answer that comes closest to the way you have been feeling.
How much of the time during the past four weeks. . .
All of the time
Most of the time
A good bit of the time
Some of the time
A little of the time
None of the time
Have you felt calm and peaceful?
Did you have a lot of energy?
Have you felt downhearted and depressed?
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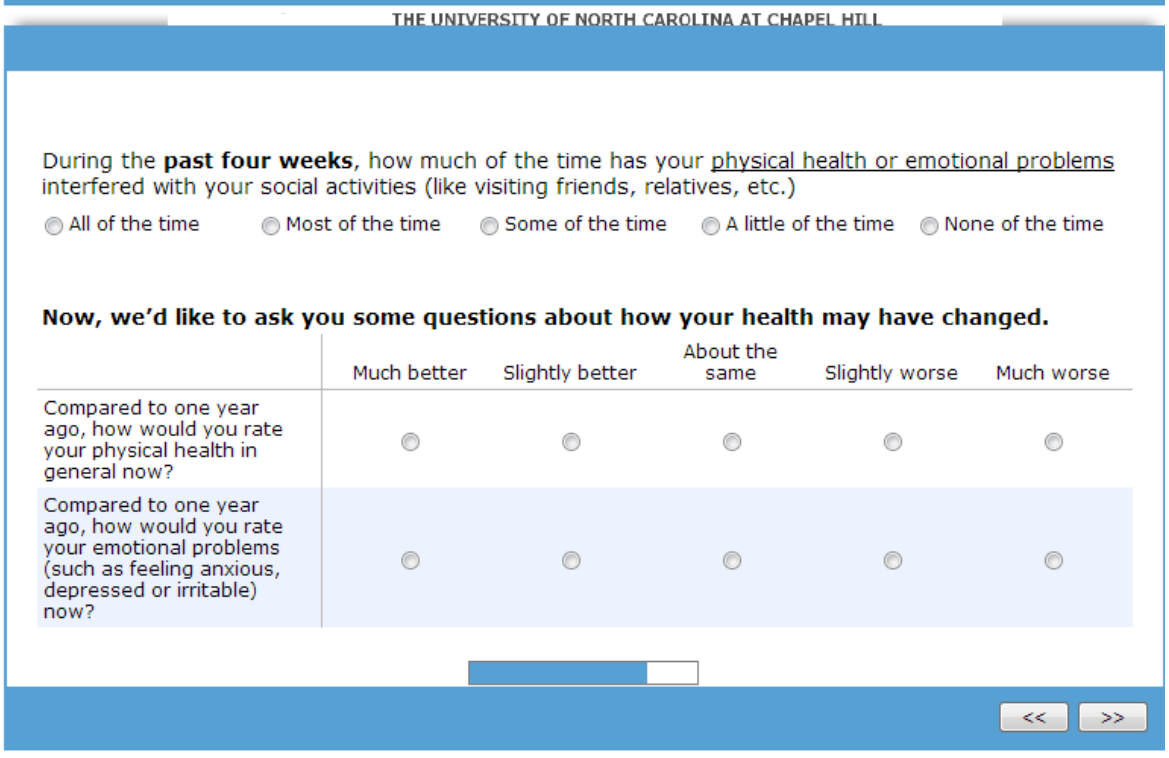
THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
During the past four weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)
All of the time
Most of the time
Some of the time
A little of the time
None of the time
Now, we'd like to ask you some questions about how your health may have changed.
Much better
Slightly better
About the same
Slightly worse
Much worse
Compared to one year ago, how would you rate your physical health in general now?
Compared to one year ago, how would you rate your emotional problems (such as feeling anxious, depressed or irritable) now?
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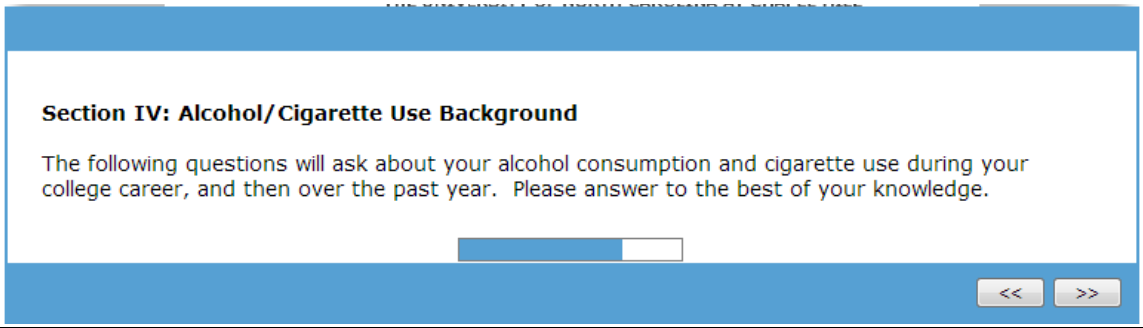
SECTION IV

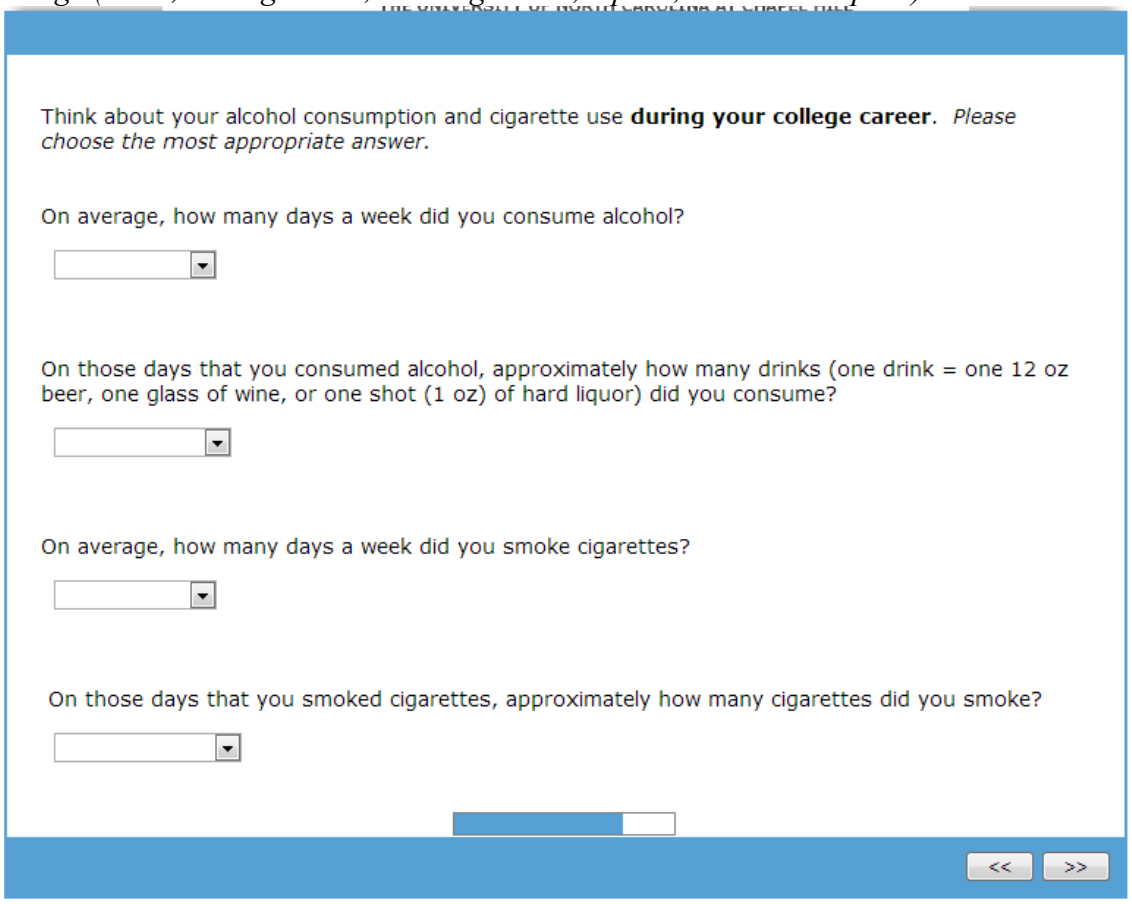


ALCOHOL USE DURING COLLEGE - #DAYS/WEEK
Range (None, 1-2 days/week, 3-4 days/week, 5-7 days/week)

ALCOHOL USE DURING COLLEGE - #DRINKS/DAY
Range (None, 1-2 drinks, 3-5 drinks, 6-7 drinks, 8 or more drinks)

CIGARETTE USE DURING COLLEGE- #DAYS/WEEK
Range (None, 1-2 days/week, 3-4 days/week, 5-7 days/week)

CIGARETTE USE DURING COLLEGE- #CIGARETTES/DAY
Range (None, 1-5 cigarettes, 6-10 cigarettes, 1 pack, more than 1 pack)

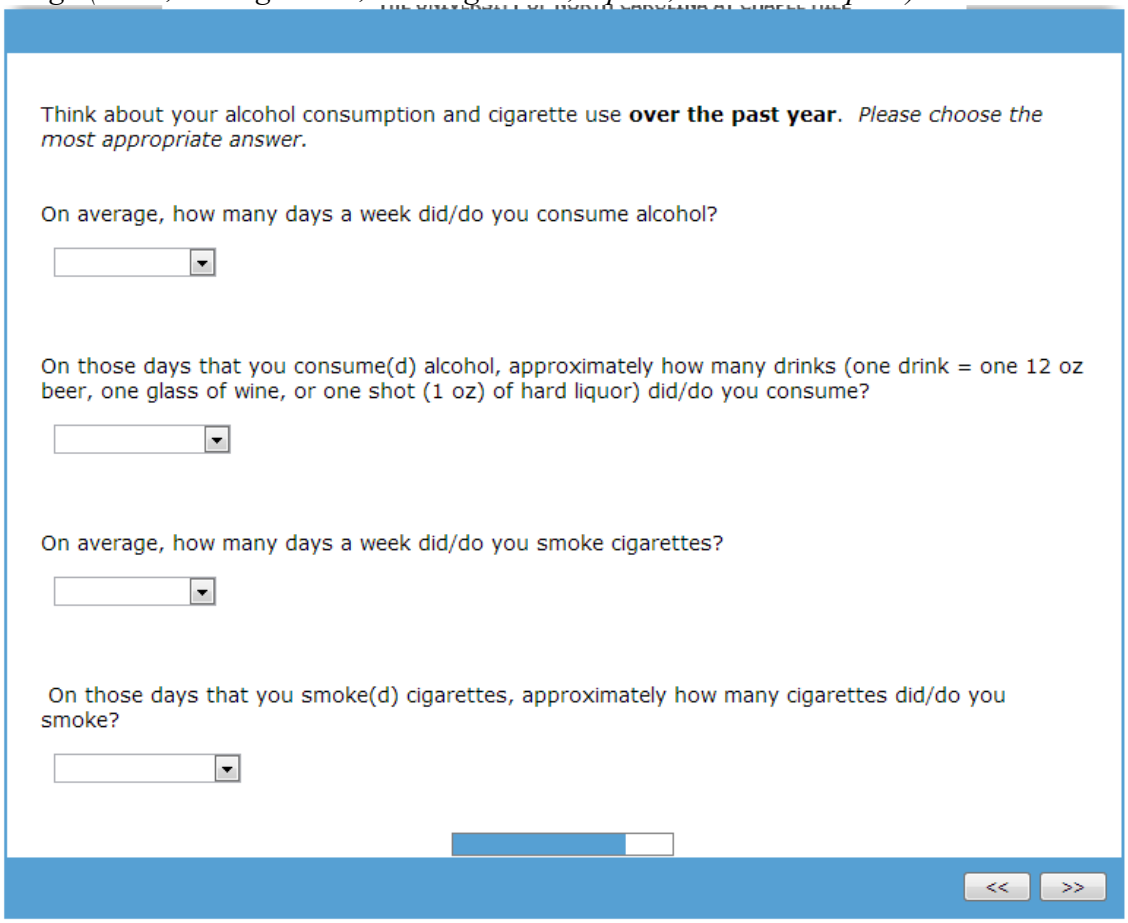


ALCOHOL USE OVER PAST YEAR - #DAYS/WEEK
Range (None, 1-2 days/week, 3-4 days/week, 5-7 days/week)

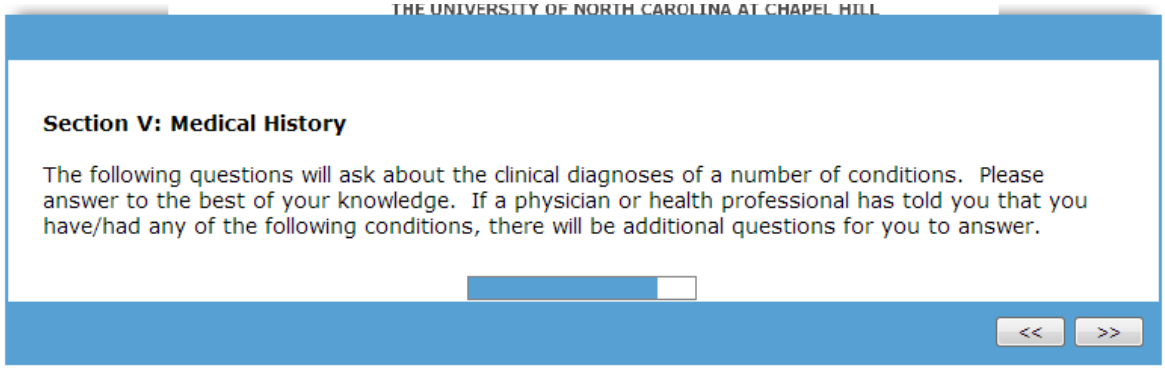
ALCOHOL USE OVER PAST YEAR - #DRINKS/DAY
Range (None, 1-2 drinks, 3-5 drinks, 6-7 drinks, 8 or more drinks)

CIGARETTE USE OVER PAST YEAR - #DAYS/WEEK
Range (None, 1-2 days/week, 3-4 days/week, 5-7 days/week)

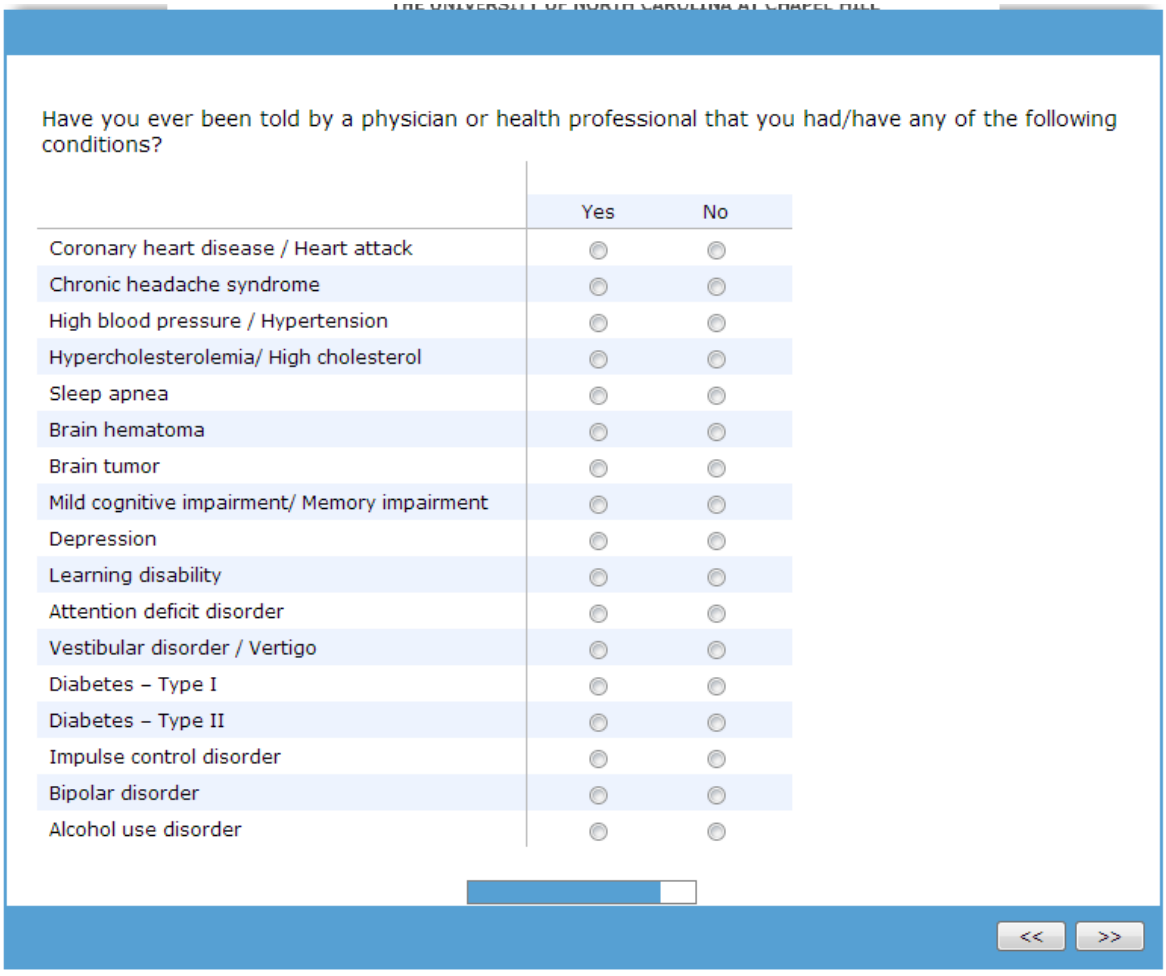
CIGARETTE USE OVER PAST YEAR - #CIGARETTES/DAY
Range (None, 1-5 cigarettes, 6-10 cigarettes, 1 pack, more than 1 pack)



SECTION V



MEDICAL HISTORY



ROWS APPEAR IF YES IS SELECTED FOR SAME ROWS ON PREVIOUS WINDOW

You have selected that you have been told by a physician or health professional that you had/have the conditions below. Please answer each of the three questions related to each condition.

	Do you currently have the problem OR has it occured at all within the last 3 months?		Do you receive medicine or treatment for the condition?		Does it limit your activities (e.g., housework, exercise, or social activities)?		
	Yes	No	Yes	No	Often	Some	Never
Coronary heart disease / Heart attack	○	○	○	○	○	○	○
Chronic headache syndrome	○	○	○	○	○	○	○
High blood pressure / Hypertension	○	○	○	○	○	○	○
Hypercholesterolemia/ High cholesterol	○	○	○	○	○	○	○
Sleep apnea	○	○	○	○	○	○	○
Brain hematoma	○	○	○	○	○	○	○
Brain tumor	○	○	○	○	○	○	○
Mild cognitive impairment/ Memory impairment	○	○	○	○	○	○	○
Depression	○	○	○	○	○	○	○
Learning disability	○	○	○	○	○	○	○
Attention deficit disorder	○	○	○	○	○	○	○
Vestibular disorder / Vertigo	○	○	○	○	○	○	○
Diabetes – Type I	○	○	○	○	○	○	○
Diabetes – Type II	○	○	○	○	○	○	○
Impulse control disorder	○	○	○	○	○	○	○
Bipolar disorder	○	○	○	○	○	○	○
Alcohol use disorder	○	○	○	○	○	○	○

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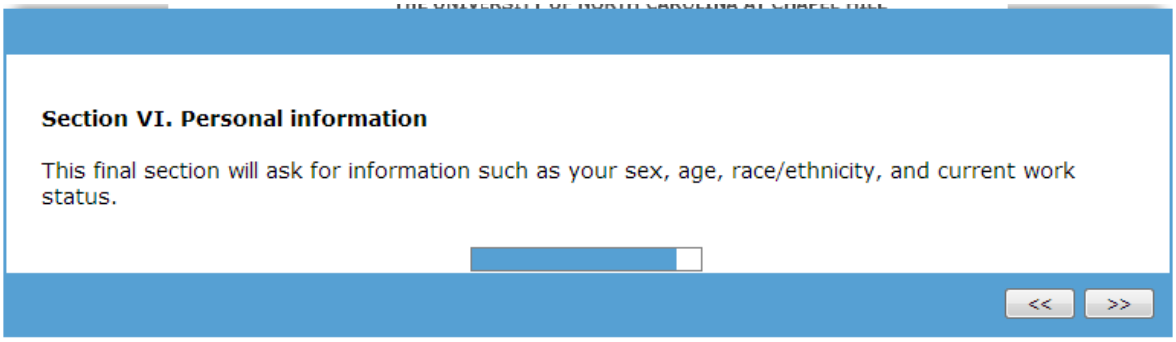
SECTION VI

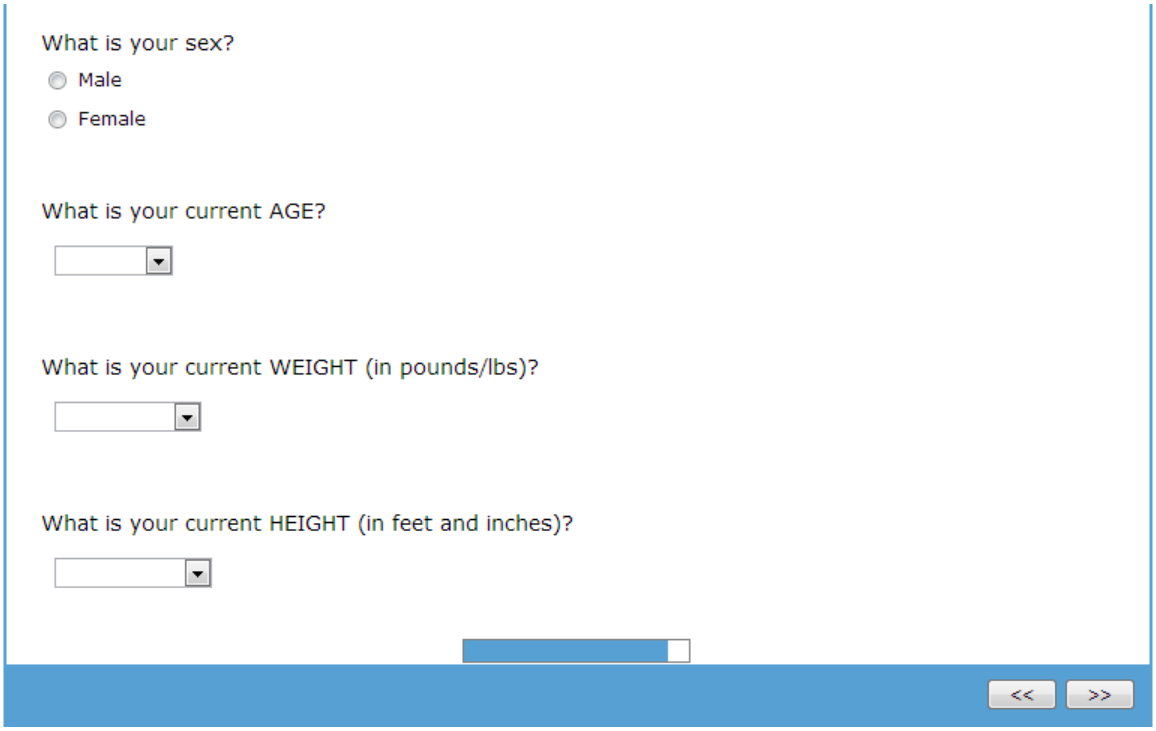


SEX
Range (Male, Female)

CURRENT AGE
Range (under 18, 18,19,20…97,98,99, over 99)

CURRENT WEIGHT
Range (less than 80, 80,81,82…348,349,350, over 350)

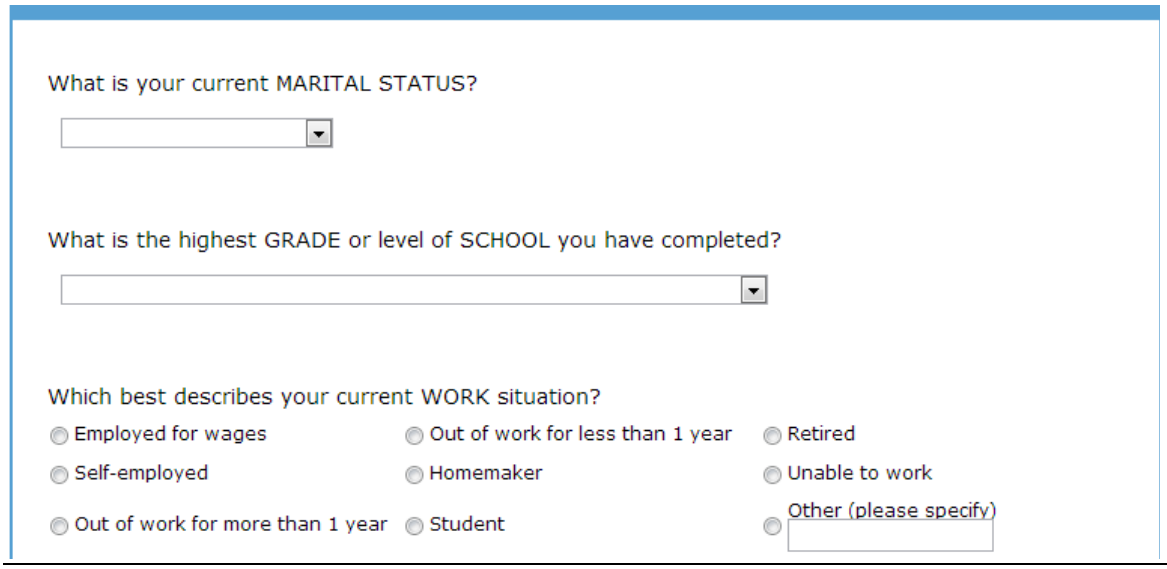
CURRENT HEIGHT
Range (less than 4'0", 4'0",4'1"…7'5",7'6", over 7'6")



CURRENT MARITAL STATUS
Range (Married, Separated/Divorced, Living with significant other, Widowed, Single)

CURRENT EDUCATION LEVEL
Range [High school graduate – high school diploma or equivalent (for example: GED)
Some college, but no degree
Associate degree (for example: AA, AS)
Bachelor's degree (for example: BA, AB, BS)
Postgraduate school or degree (for example: MA, MS, PhD, MD, JD, MBA)]

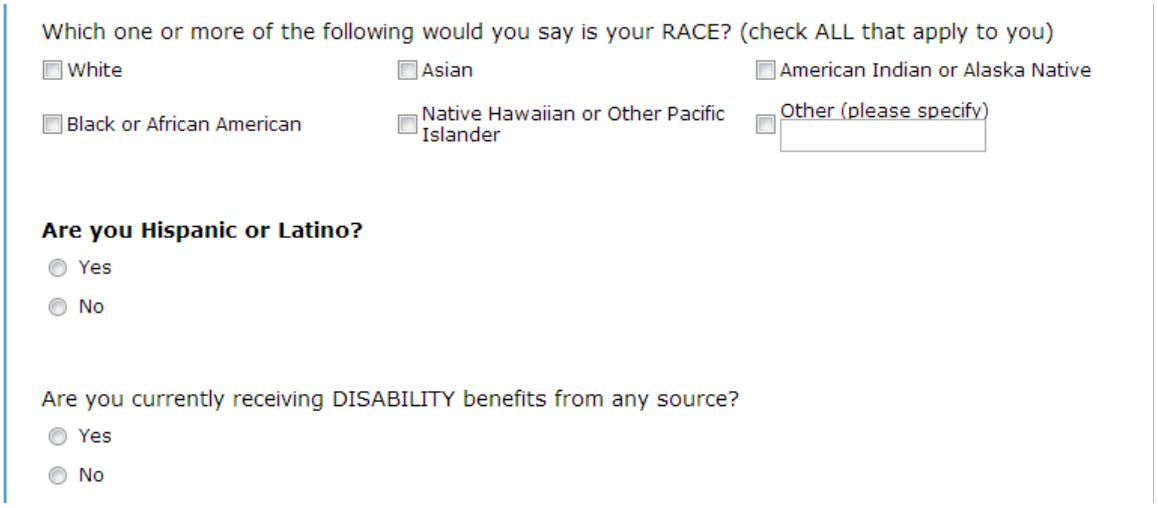
CURRENT WORK STATUS



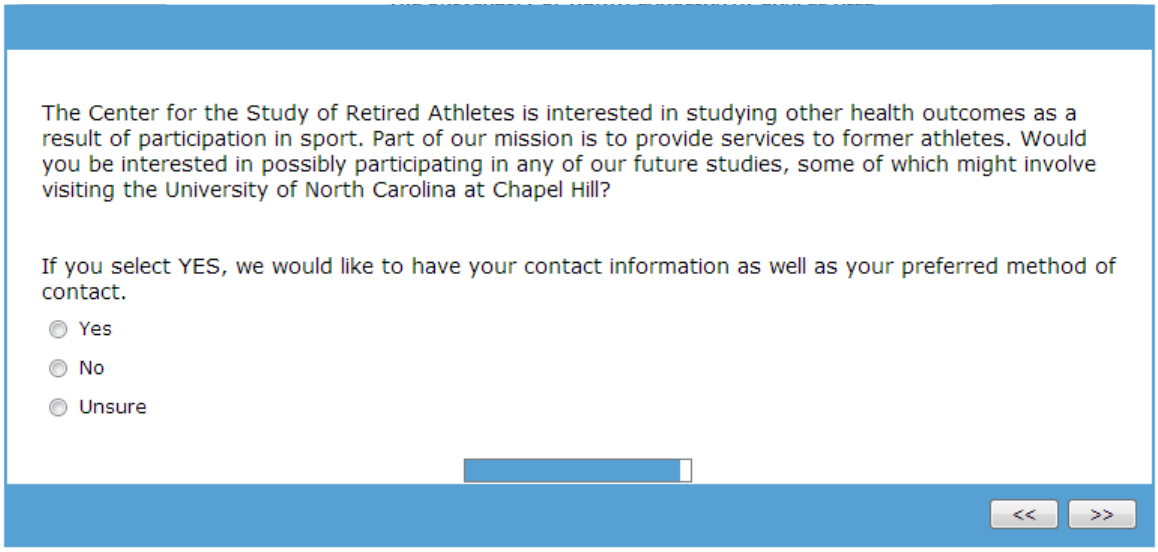
RACE

ETHNICITY

DISABILITY STATUS

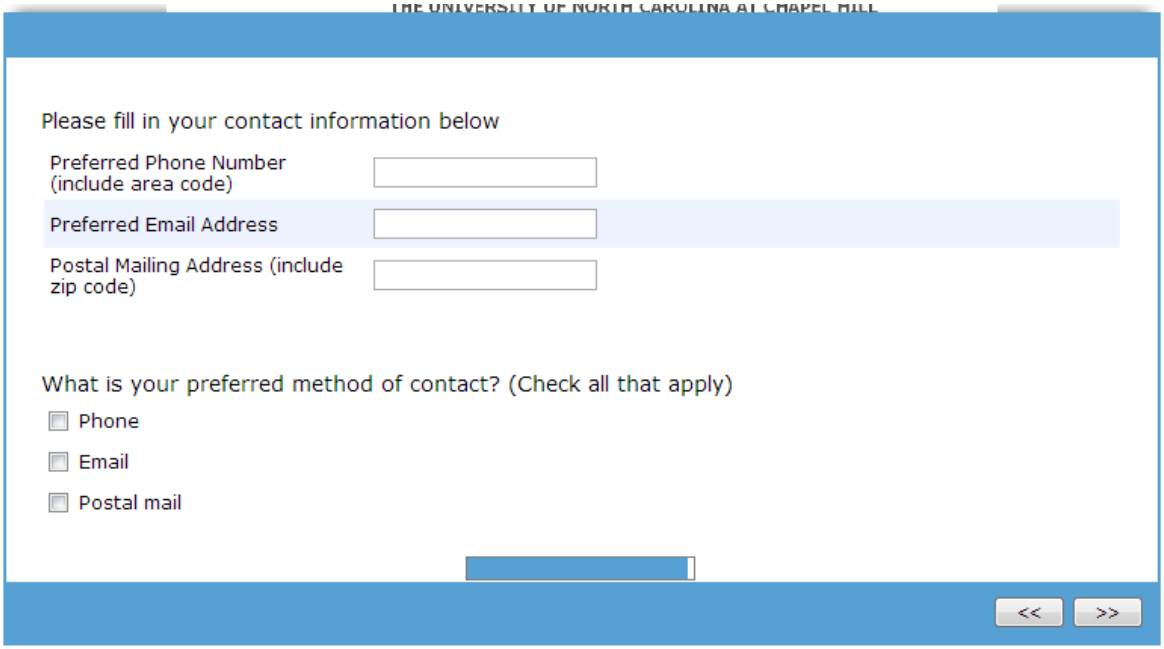


RECRUIT FOR OTHER STUDIES

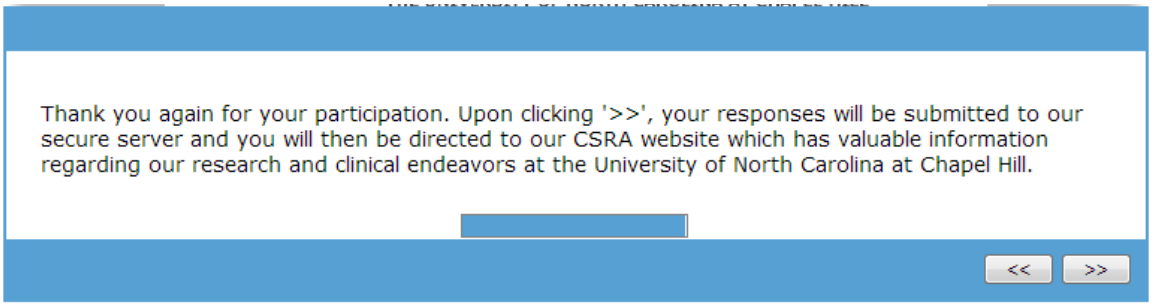


IF WILLING TO SHARE CONTACT INFO

CONTACT INFORMATION



LAST WINDOW



REDIRECT TO CSRA WEBSITE

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