THE EFFECT OF SUBCONCUSSIVE BLOWS ON FINE MOTOR CONTROL

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Kinesiology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2011

Urbana, Illinois

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ABSTRACT

Concussion has been shown to cause immediate impairment in motor control. However, the effect of subconcussive blows is much more controversial. The clinically accepted recovery time from concussion is 7-10 days. However, recent studies involving EEG and complex motor tasks have revealed deficits up to 12 years post injury. Several studies have shown cognitive deficits associated with subconcussive blows while other studies have shown there are no ill effects. Few studies have examined the effect of subconcussive blows on motor function. PURPOSE: To further elucidate the effect of subconcussive blows on fine motor control. METHODS: Twenty athletes (age 20.7 ± 2.76) and twenty non-athletes (age 21.5 ± 2.26) with no history of concussion or contact sports, were recruited from NCAA Division-I sports teams, university club teams, and student population. All subjects completed a Purdue pegboard task, finger tapping task and an isometric force control task. Group differences in test performance were assessed using a t-test and a 3-way ANOVA with repeated measures. RESULTS: Data analysis revealed differences in between athletes and non-athletes in the finger tapping test. Non-athletes 2nd highest, 3rd highest, and average tapping scores were higher than those of athletes ($p=.023$, $p=.008$, and $p=.019$ respectively). Three way ANOVA with repeated measures revealed that non-athletes outperformed athletes at 2 levels of visual gain, 128 and 512 pixels/N ($p=.045$ and $p=.009$ respectively). No other significant between group's differences were found. CONCLUSION: There are differences in fine motor control between athletes and non-athletes. Non-athletes displayed better finger quickness and slightly better isometric force control, outperforming athletes on the tapping test and isometric force control test respectively. There was no difference in finger dexterity as performances on the Purdue peg board test were equal. Athletes are at higher risk for head injury than non-athletes and several of these athletes may have sustained a concussion and not reported it. Finger speed and isometric force control may be more affected than manual dexterity or perhaps those tasks were simply more difficult. Further study involving data collected from athletes with and without history of concussion is necessary to further elucidate the effects of subconcussive blows on fine motor control.

Keywords   concussion, subconcussive blows, fine motor control, dexterity, athletes, non-athletes

ACKNOWLEDGMENTS

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CHAPTER 1: INTRODUCTION

BACKGROUND

Concussion is defined as a complex pathophysiological process affecting the brain, caused by traumatic biomechanical forces. These forces usually result in neurological impairments which are usually short lived and resolve spontaneously (McCrory, 2009). Concussion often results in a graded set of clinical symptoms including loss of consciousness, amnesia, headache, and nausea, among others. Most symptoms resolve within 7 days (McCrea, 2009). Concussions are common in many sports but occur most often in football with concussion rates (percentage of football players sustain concussions) at approximately 5% for high school and college populations and 7% for professional players (Powell, 1999; Guskiewicz, 2000; Pellman, 2004). Concussion rates for football would be higher but many concussions go unreported as athletes often don't believe their injury is serious enough to warrant attention (McCrea, 2004) Most other sports have concussion rates of less than 2% with some reaching as low as .14% (Powell, 1999).

Physiologically, head injuries result in an increase in neurotransmitter release and ion flux which leads to an energy crisis. The Na+-K+ pump must work overtime to restore balance so glucose metabolism is initiated but blood flow is reduced due to swelling. There is also an increase in calcium release which can inhibit mitochondrial function and further the energy crisis, as well as start pathways that lead to cell death (Giza, 2001).

Postural control deficits have been shown to be associated with concussion and postural control assessment has been recommended for use in current sideline assessments and as a marker for return-to-play considerations (Guskiewicz, 1996; Guskiewicz, 2001; Guskiewicz, 2001). Studies have utilized multiple balance tests including the BESS and the SOT to show that concussed athletes have decreased postural stability when compared to baseline or matched

controls (McCrea, 2003; Guskiewicz, 2001). Concussion has also been shown to cause deficits in gait and affect overall coordination. A study done by Parker et al. (2006) revealed that athletes developed a more conservative gait post injury, when compared to uninjured controls, and that those deficits can last up to 28 days post injury. In a further study, Parker et al. (2007) showed that concussed individuals display more mediolateral sway when completing dynamic motor tasks 28 days post injury when all neurocognitive deficits and symptoms have resolved. Parker et al. (2008) also found that athletes consistently perform worse than non-athletes on dynamic motor tasks, whether concussed or not. These results are alarming considering they exceed the accepted 7 day recovery period recommended by the National Athletic Trainers Association (NATA) (Guskiewicz, 2004).

There has also been research to link concussion to long term motor control issues. De Beaumont et al. (2007) did a study in which they used an electroencephalogram (EEG) to assess differences between previously concussed athletes and uninjured controls. They found that previously concussed athletes had impaired motor function and that an increased cortical silent period (CSP) and deficits were positively correlated with increased concussion number and severity (De Beaumont, 2007). Sosnoff et al. (2011) also did a study on the long term effect of concussion on balance. They used the sensory organization test (SOT) to compare motor function between previously concussed athletes and those with no history of concussion. Previously concussed athletes were anywhere from 6 months to 12 years post injury. Sosnoff et al. (2011) found that athletes had altered postural control strategies as they were less able to control their balance in the mediolateral direction. Other studies have shown that concussion may result in long term fine motor deficits, as Slobounov et al. (2002) showed that athletes who

were 10-20 months post-concussion performed worse on a fine motor control task and had altered motor function as shown by EEG.

Despite these findings, it is still unclear how fine motor control is affected by concussion. It is also unclear the effect subconcussive blows may play in the alteration of brain function. Thus the purpose of this study is to further elucidate the effect of subconcussive blows on fine motor control.

HYPOTHESIS

Research has shown concussion has a long term effect on postural stability (Sosnoff, 2011) and fine motor control (Slobounov, 2002). Differences in postural stability have also been revealed between athletes and non-athletes (Parker, 2008). The effect of subconcussive blows is controversial as some studies have shown they result in no deficits (Miller, 2007) while others have shown the opposite (Witol, 2002). However, more research is needed. Therefore, the purpose of this study was to further elucidate the effect of subconcussive blows on fine motor control. We hypothesize that athletes and non-athletes will display differences in fine motor control tasks. We also hypothesize that there will be differences in isometric force control with athletes showing better ability to control isometric force with visual feedback.

CHAPTER 2: LITERATURE REVIEW

<u>CONCUSSION DEFINITION</u>

A concussion is a complex pathophysiological process affecting the brain, caused by traumatic biomechanical forces. These forces may be caused by a direct blow to the head, face, neck or elsewhere, or by an impulsive force transmitted to the head. As a result of these forces, neurological impairments occur which are usually short lived and resolve spontaneously (McCrory, 2009).

Concussion may also result in neuropathological changes but these are due a functional problem rather than a structural injury. This is supported by the lack of abnormal results seen on standard structural neuroimaging devices such as MRI and CT (McCrory, 2009).

Concussion also results in a graded set of clinical symptoms. Some of the common symptoms are loss of consciousness, amnesia, headache, nausea or vomiting, dizziness, balance problems, sensitivity to light or noise, feeling "in a fog", concentration problems, fatigue, and irritability, among others. These symptoms usually follow a sequential course but in certain cases may persist. In most cases, post concussion symptoms resolve within about a week but a very small percentage, about 3%, have symptoms lasting up to and beyond 1 month (McCrea, 2009). It is important to note that not all of these symptoms need be present to diagnose a concussion and if too much emphasis is placed upon any one symptom misdiagnosis of concussion severity can occur (McCrory, 2009).

<u>EPIDEMIOLOGY</u>

The epidemiology of concussions varies among sports and levels of competition. Contact sports such as football have some of the highest concussion rates and tend to be the

focus of more studies (Powell, 1999; Guskiewicz, 2000; Pellman, 2004). Despite this emphasis, concussions occur in many sports including wrestling, baseball, field hockey, women's volleyball, softball, men's and women's basketball, and men's and women's soccer (Powell, 1999). Level of competition also plays a role as concussion rate has been shown to be highest at the high school and professional levels and lower at the collegiate level (Guskiewicz, 2000; Pellman, 2004).

Football accounts for the majority of concussions among all sports at the high school level and has been shown to account for up to 63% of all cases with concussion rates (percentage of total players suffering a concussion) reported to be as low as 3.9% or as high 5.6% (Powell, 1999; Guskiewicz, 2000). Concussion rates among college football players have been reported to be 5.4% at division III, 4.5% at division II, and 4.4% at division I (Guskiewicz, 2000). The concussion rate at the professional level is slightly higher at roughly 7% (Pellman, 2004). This increase has been attributed to the higher velocity hits in the NFL due to the increased size, speed, and skill of the players. Concussion rates for other sports are slightly lower at 1.58% for wrestling, 1.14% for women's soccer, 1.04% for women's basketball, .92% for men's soccer, .75% for men's basketball, .46% for women's field hockey and softball, .23% for baseball, and .14% for volleyball (Powell, 1999).

The exact number of sports-related concussions that occur annually is unknown but the Center for Disease Control and Prevention previously estimated approximately 300,000 concussions per year but more current estimations have it closer to 1.6 to 3.8 million concussions per year (Thurman, 1998; Langlois, 2006). The main reason that epidemiologists have trouble accurately estimating concussion rates is that many medical practitioners still use the old definitions that only use LOC as a marker of concussion which ultimately results in many

unreported concussions.   In a study done my McCrea et al. (2004), 15.3% of high school

football players reported suffering a concussion on a post-season survey. Of those athletes only

47.3% reported their injury. Over half of the concussions suffered during the football season

went unreported. The most common reason for not reporting a concussion was the athlete did

not think it was serious enough to warrant medical attention. Other reasons included not wanting

to leave the game, not knowing it was a concussion and not wanting to let their teammates down

(McCrea, 2004).

PATHOPHYSIOLOGY

The underlying pathophysiology of concussion has become an important topic in

concussion research by noting that the injury is one of functional change and not structural.

Immediately following head injury, the intra and extracellular environments of injured neural

tissue change drastically. There is a stark increase in neurotransmitter release and ion flux. The

binding of excitatory transmitters leads to increased neuronal depolarization and further ion flux

with potassium flowing out of cells and calcium flowing in. This causes the Na+-K+ pump to

work overtime in order to restore resting membrane potential of the cells (Giza, 2001). The

increased work load of the ion pump increases the need for ATP and glucose metabolism is kick

started. Unfortunately, increased glucose metabolism leads to a state hypermetabolism when

overall cerebral blood flow is decreased. The discrepancy between the glucose supply and

demand causes a cellular energy crisis, which ultimately may be a contributing factor to post

concussion vulnerability. Following the initial state of hypermetabolism the brain transitions to a

stage of depressed metabolism. Increase in calcium level post concussion can inhibit

mitochondrial function and further the energy crisis not to mention activate pathways leading

directly to cell death (Giza, 2001). The physiological changes that occur within the brain are directly correlated to, and are likely the cause of, the symptoms that injured athletes experience (Henry, 2010). This information coupled with the fact that imaging devices, such as MRI and CT, haven been proven to be ineffective at diagnosing concussions increases the need for a greater knowledge of the physiological processes at work (Kant, 1997).

ACUTE POSTURAL EFFECTS

Postural control deficits have been shown to be associated with concussion and postural control assessment has been recommended for use in current sideline assessments and as a marker for return-to-play considerations (Guskiewicz, 1996; Guskiewicz, 2001; Guskiewicz, 2001). The use of postural evaluation in athletes with suspected concussions is not new as Romberg's tests have been included in neurologic evaluations for some time. Researchers and medical clinicians have recognized the importance of postural evaluation as part of a comprehensive approach when evaluating injured athletes (Guskiewicz, 2001). Several different stability assessment tools are currently available for use by researchers and clinicians. The simplest of which is the Balance Error Scoring System (BESS). The BESS was developed as a way to test postural stability without the need of expensive equipment. It utilizes three different stance positions and tests on firm and soft surfaces for a total of 6 different trials (Riemann, 1999). The BESS has been shown to have high test-retest reliability with values reaching .92 in some research (Broglio, 2009). A study done by McCrea et al. (2003) utilized the BESS to compare concussed athletes with matched controls. The study revealed that athletes who had suffered a concussion showed greater postural deficits than matched control subjects. Another common assessment tool is the Sensory Organization Test (SOT) administered using NeuroCom

Smart Balance Master. It utilizes a force plate system to measure vertical ground reaction forces produced as the body's center of gravity moves around a fixed base of support. The SOT is designed to disrupt the sensory selection process by altering available sensory information while measuring a subject's ability to minimize postural sway (Guskiewicz, 2001). The SOT consists of 18 trials, in which the subject is asked to stand as motionless as possible. Three trials are completed for each of 6 different conditions, each of which utilizes a different combination of stimuli (Guskiewicz, 2001). The SOT has proven an effective measure of postural deficits as a study performed by Guskiewicz et al. (2001) found that athletes who suffered a concussion had decreased postural stability post injury when compared to baseline assessments and uninjured controls.

ACUTE GAIT EFFECTS

Alterations in gait and overall coordination have been shown to be correlated with concussion in recent literature, and although gait assessment is not currently part of the return-to-play guidelines, evidence is building to suggest that it should.

Parker et al. (2006) performed a study in which they tested gait stability of concussed subjects. Single and dual task walking trials were used to assess gait stability and recovery over the span of 28 days in 15 college athletes with grade 2 concussions. The single task condition was simply walking in a straight line with no obstructions. The dual task condition was the same with the addition of a simple cognitive task, spelling 5 letter words in reverse, subtracting by 7's, or reciting the months of the year in reverse. Subjects were tested at 2, 5, 14, and 28 days post-injury and were matched to uninjured controls tested at the same time intervals. Gait patterns were recorded using a motion tracking camera system. Parker et al. (2006) found that concussed

subjects adopted a more conservative gait pattern than their uninjured counterparts. Concussed subjects had increased difficulty with the dual task condition as they showed decreased gait velocity throughout and decreased stride length at days 2 and 5 when compared to the single task condition. In contrast the uninjured controls accommodated to the dual task by day 5 and showed no differences in performance between the 2 tasks. The dual task condition also resulted in increased mediolateral sway and sway velocity at days 2 and 5, then seemed to normalize by day 14 but was increased again at day 28. Parker et al. (2006) suggested that the deterioration from day 14 to day 28 may have been caused by increased exertion as all of the subjects had returned to full activity by day 14. This suggests that current return-to-play guidelines may not allow enough time for full recovery (Parker, 2006).

In a further study, Parker et al. (2007) tested dynamic motor and cognitive recovery to discover any correlation between the two processes. The same methods as the previous study were used to test gait stability while the ImPACT testing battery was used to assess cognitive recovery. Both gait stability and neurophsychological testing was administered 2, 5, 14, and 28 days post-injury. Subjects included 29 college athletes who had suffered grade 2 concussions and matched controls. All neuropsychological variables had recovered by day 14 with visual motor processing speed and reaction time recovering by day 5, while visual memory and symptom scores normalized by day 14.   Gait stability testing revealed that mediolateral sway was increased through day 28 for the dual task condition in concussed individuals only. The dual task condition also resulted in adoption of a more conservative gait in the concussion group on all days. Parker et al. (2007) found correlations between reaction time and dual-task medial–lateral sway, and reaction time and sway velocity but only for the first day of testing. This

suggests that these recovery processes proceed at different rates and more time may need to be allowed for full recovery before athletes are allowed to return to play (Parker, 2007).

Parker et al. (2008) did another study where they used the same gait analysis protocol to assess the difference between athlete and non-athlete recovery from concussion. In this study, 28 subjects, half of which were athletes and half of which were non-athletes, suffering from grade 2 concussions were tested along with matched controls. They also assessed differences between contact sport types, breaking the athletes into low-velocity, athletes more likely to take many sub-concussive blows, versus high-velocity, athletes more likely to take high speed concussive blows. Parker et al. (2008) found that athletes consistently performed more poorly than non-athletes, whether concussed or not. The athletes exhibited significantly greater sway excursion and faster sway velocity as well as decreased walking speed and center of mass to center of pressure separation when compared to non-athletes. These differences were more prominent during the dual-task compared to the single-task condition and were apparent through day 28. The low velocity impact athletes were also found to display greater sway than high velocity impact athletes. This study shows that participation in contact sports causes a decrement in motor ability with sub-concussive blows increasing that decrement (Parker, 2008).

LONG TERM EFFECTS OF CONCUSSION ON MOTOR CONTROL

There are currently few studies that elucidate the long term effects of concussion on motor control. De Beaumont et al. (2007) performed a study in which they used Transcranial Magnetic Stimulation (TMS) to investigate the effect of concussion on motor cortex function. There were a total of 45 participants in this study, broken up into 3 groups with 15 subjects each. The first group was the multiple concussion group, having a history of 2 or more concussions

each. The second group was the single concussion group and the 3rd was the control group.

Each subject was more than 9 months removed from their last injury. They used TMS to

stimulate the motor cortex resulting in an involuntary muscle contraction of the dorsal

interosseous muscle. One of the main outcomes studied was the Cortical Silent Period (CSP).

The CSP is the downtime between a TMS stimulated muscle contraction and the following

voluntary muscle contraction. De Beaumont et al. (2007) found that CSP was significantly

greater in athletes with multiple concussions when compared to normal controls. They also

found that CSP was greater in those athletes who had suffered more severe concussions. Five

athletes from the multiple concussion group were reinjured after the first testing session and all

were retested 6 to 15 months post-injury. All 5 of them had a significantly increased CSP post-

injury. These results show that concussions result in long term motor system dysfunctions which

are exacerbated by multiple concussions and increased concussion severity (De Beaumont,

2007).

Slobounov et al. (2002) did a study in which they tested the fine motor control of

12 subjects, 6 with history of concussion and 6 controls, while simultaneously recording EEG

activity. They tested fine motor control using an isometric force production task in which

subjects applied force to a load cell to match a force production line peaking at either 25% or

50% maximum voluntary contraction (MVC). The line was represented on a computer screen as

was visual feedback in the form of a trace. All subjects with a history of concussion were 10-20

months removed from their most recent injury. Subjects within the concussion group performed

significantly worse on the 50% MVC task than the control group. The concussion group was

unable to provide a consistent force to match the line. The concussion group was also found to

have abnormal EEG activity prior to voluntary contraction. This altered brain activity likely

played a role in the concussion groups' inability to properly activate the proper motor program. These findings suggest that concussion causes a reduction in brain activity and impaired fine motor control (Slobounov, 2002).

De Beaumont et al. (2011) did another study in which they used a force platform, random alternating movement (RAM) task, and transcranial magnetic stimulation (TMS) to test for motor system abnormalities in formerly concussed athletes. A total of 36 subjects, 21 athletes with history of concussion and 15 matched controls, participated in this study. All subjects were collegiate football players and all athletes in the concussed group were at least 9 months post-injury. They used a force plate to assess center or pressure (COP) displacement as each subject was standing on it as steadily as possible. They also calculated approximate entropy (ApEn) which takes into account each data point in order to assess the ability of the subject to make postural adjustments. The RAM involved sitting in a chair with elbows bent to 90° and held close to the body. The subject was then instructed to rotate (pronate/supinate) 2 handheld spheres as quickly as possible. Velocity, bimanual coordination (ability to move both hands equally) as well as overall performance, i.e. combination of velocity and movement accuracy, was assessed. There were 3 conditions for this task: both hands, dominant hand, and non-dominant hand. The TMS protocol was similar to that used in previous studies by De Beaumont (2007). De Beaumont et al. (2011) found that previously concussed athletes had significantly lower ApEn values, or increased COP oscillation regularity, in the anteroposterior direction and higher, but not significant, values in the mediolateral direction. They also found that previously concussed athletes performed the RAM task with greater velocity in all conditions. However there was no difference between the groups when looking at overall performance values. The TMS results were in agreement with previous research as previously concussed athletes had

longer CSP and longer CSP was correlated with number of concussions. They hypothesized that the increased COP oscillation regularity in the AP direction is likely due to the fact that previously concussed athletes will purposefully activate lower leg musculature to increase stability in order to adapt post-injury. They also hypothesized that the athletes were likely moving faster during the RAM due to performance motivation. They favored speed over movement accuracy. This study shows concussion causes long term alterations in motor function as COP oscillation regularity was altered and CSP was elongated in preciously concussed athletes (De Beaumont, 2011).

Sosnoff et al. (2011) did a study in which they utilized the sensory organization test (SOT) to assess the postural control dynamics of 224 athletes, 162 of which had a history of concussion. All previously injured subjects were at least 6 months removed from their last concussion, but time ranged from 6.4 months to 12.5 years post injury. The SOT utilizes 6 conditions in which the subjects support surface or visual surroundings, or both, move in conjunction with their COP. The SOT also includes eyes open and closed conditions. The SOT generates 4 different scores based on performance: composite balance, somatosensory ratio, visual ratio, and vestibular ratio. Sosnoff et al. (2011) also calculated the ApEn to better assess subjects ability to adapt postural control strategies. They found that athletes with a history of concussion had a higher visual ratio score than uninjured athletes but all SOT scores for both groups were above normal values. They also found that athletes with a history of concussion display different postural control strategies than athletes without a history of concussion. Previously concussed athletes displayed increased ApEn values (i.e. increased postural sway irregularity) in the AP direction as the task increased in difficulty. However, the non-concussed athletes displayed just the opposite; they had decreased ApEn values (i.e. decreased postural-

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sway irregularity) in the AP direction as the task increased in difficulty. They found the exact opposite result in the ML direction. The previously concussed athletes had decreased ApEn values as the task increased in difficulty while the unconcussed athletes had increased ApEn values as task difficulty increased. These results are in agreement with the previous study as concussed athletes show greater control in the AP direction but an inability to adjust in the ML direction. Although all subjects performed above normal values on the SOT there was a difference in balance strategy between previously concussed and unconcussed subjects. This shows that concussion has a long term effect on motor ability that may be more pronounced with age (Sosnoff, 2011).

EFFECT OF SUBCONCUSSIVE BLOWS

Subconcussive blows are a controversial topic as investigators are divided on their true effect. Some investigators have shown that subconcussive blows have little impact on cognitive ability (Miller, 2007; Guskiewicz, 2002), while others have found decrements associated with them (Witol, 2002; Webbe, 2003).

The cumulative effect of subconcussive blows was shown by Witol and Webbe in a study they did in 2002. In their study, they used a neurocognitive test battery to assess neuropsychological deficits in 60 soccer players. The neurocognitive test battery included The Shipley Institute of Living Scale, Trail Making Test Parts A and B, Paced Auditory Serial Addition Test (PASAT), Facial Recognition Test (FRT), Rey–Osterreith Complex Figure Test (CFT), and Rey Auditory Verbal Learning Test (RAVLT). The 60 soccer players and 12 controls were broken into different groups based on current heading frequency for the first data analysis. Neither career length nor current level of participation was taken into account when

forming these groups. The 4 groups were: Control (no heading), low (0-4 times per game), moderate (5-8 times per game), and high (9 or more times per game). The only significant result was that it took players in the high heading frequency group significantly longer to complete trail making test A. The Shipley estimated IQ scores were near significant with the high heading frequency group scoring lower than the rest. They were then broken into 4 groups based on lifetime heading practices. This measure was calculated by multiplying estimated headers per game by career length. The 4 groups for this division were formed by keeping the 12 controls in the 1st group and creating break points in the distribution for the 3 remaining groups. This group arrangement revealed more significant effects as those in the high lifetime heading group were significantly slower in the trail making test A and scored significantly lower on the Shipley estimated IQ test. Players with the highest amount of lifetime heading, or subconcussive blows, scored the lowest on tests measuring attention, concentration, cognitive flexibility and general intellectual functioning (Witol, 2002). This study shows that subconcussive blows cause a decrement in cognitive ability over short and long periods of time.

Subconcussive blows may have additive effect physiologically as well as functionally. As mentioned earlier, when a person suffers a head injury a neurometabolic cascade is triggered that results in further injury to the tissue. After a head injury, there is an increase in neurotransmitter release and ion flux which leads to an energy crisis as the Na+-K+ pump must work overtime to restore balance but blood flow is reduced due to swelling. There is also an increase in calcium release which can further the energy crisis as well as start pathways that lead to cell death (Giza, 2001). Subconcussive blows can have a similar effect if enough are sustained. Similar neurometabolic processes occur to a lesser extent after a subconcussive blow

and if multiplied, especially over a multiple year career, similar damage to that developed from

concussive head injuries can develop.

CHAPTER 3: METHODOLOGY

<u>SUBJECTS</u>

A total of 40 subjects were recruited for this study. The subjects were divided into 2 groups classified as athletes and non-athletes. Subjects in the athletes group were recruited from NCAA sanctioned sports as well university club sports at the University of Illinois. Subjects in the non-athlete group were recruited from the general student population. Exclusion criteria for all subjects included having ever played football, wrestling, rugby, hockey, soccer, or lacrosse in an organized league. All subjects self reported having never been diagnosed with a concussion and none were suffering from any concussion like symptoms, or injuries to the hand, arm, or shoulder. Approval from the Institutional Review Board was obtained prior to testing.

<u>PROTOCOL</u>

Each subject was tested in a 1 on 1 basis in a quiet, distraction free environment and all followed the same protocol. Subjects were seated comfortably at a desk during testing. At the beginning of the test session, each subject would fill out a health history questionnaire and fill out a consent form. The fine motor tasks were then performed in this order: peg board, tapping test, isometric force control test.

Health history questionnaire

A custom screening instrument written by the investigators was completed by each subject. Subjects were asked about past participation in contact sports as well as current activity level. Subjects were also asked about previous concussion history as well as current concussion like symptoms and other current injury status.

Purdue peg board

This test was used to assess manual speed and dexterity. The Purdue peg board is a wooden board with 2 lines of holes aligned down the middle of the board. Along the top of the board are 4 pockets containing 5 pegs each. Subjects were instructed to start with their right hand palm down in a marked area on the board. On command from the investigator, subjects were instructed to place the metal pegs one at a time into the holes going down the left side of the board. Subjects were given 30 seconds to complete the task and the total number of pegs correctly placed was recorded. This task was repeated 3 times and subjects were encouraged to beat their previous score each time.

Finger Tapping test

This test was used to asses finger speed. For this test, A laptop computer keyboard and an open word processing document were used. Each subject was instructed to start with their hand face down flat on the computer keyboard with their right index finger on the spacebar. On command from the investigator, subjects were instructed to tap the spacebar as fast as possible with the index finger. Subjects were given 30 seconds to tap the space bar as many times as possible. Each subject completed 3 trials and were encouraged to beat their previous scores.

Isometric Force Control Test

This test was used to assess isometric force control in the index finger. A custom apparatus was built for this test. A load cell was setup to measure and record force production during finger abduction. The load cell was connected to a Coulbourne Instruments analog to digital converter box, which was connected to a laptop computer. Data was collected using LabView software. Prior to testing, the concept of the test and load cell were explained to each subject. The subject was then instructed on how to appropriately place their right hand into the

finger slots. The investigator explained to each subject that the task would involve applying force to the load cell via index finger abduction. Each subject was also instructed to apply force using the distal interphalangeal joint of the index finger. Finger abduction was used in order to isolate the dorsal interossei muscle. This muscle was chosen because it is seldomly used, effecetively avoiding differences in fine motor skill. Subjects were asked to perform 2 tasks:

Maximum voluntary contraction (MVC):

On command, Subjects were instructed to apply maximum force to the load cell by performing right index finger abduction. Subjects were instruced to hold this maximal isometric contraction for 6 seconds. Visual feedback in the form of a force trace was displayed on the computer screen at gain 4 pixels/N. Each subject completed 3 trials and each MVC was recorded.

Isometric force control:

Subjects were taken through 36 trials where they were asked to apply constant pressure to the load cell for 20 seconds. Each subject was provided visual feedback in the form of a force trace and a target line on the computer screen. Subjects were instructed to adjust force output to match the target line as best they could. The target line was set at either 5% or 30% of the subject's highest MVC. Visual gain and % MVC were randomized for each trial. The gain was varied between 4, 16, 64, 128, 256 and 512 pixels/N. Each level of gain was repeated 3 times for each %MVC resulting in 36 randomly assigned trials. During the course of the study, 11 subjects (7 non-athletes and 4 athletes) were forced to switch MVC's partway through the test. This was due to an inability to sustain their original force output. In the case that this happened, a note was made by the investigator.

Each score for the Purdue peg board test and the tapping test were recorded. Descriptive statistics as well as independent samples T Test were used to analyze differences between peg board and tapping test scores. All 3 MVC results were recorded in newtons (N). Isometric force control data was pooled and coefficients of variation were calculated for each condition (MVC x gain). A 3-way (Group x MVC x Gain) repeated measures ANOVA was used to assess differences in isometric force control. Descriptive statistics were used to analyze other data collected from the health history questionnaire. All data analysis was completed using Microsoft Excel and SPSS statistical package version 17 (SPSS, Inc; Chicago, IL). Analyses were considered significant when $p<0.05$.

CHAPTER 4: RESULTS

A total of 40 subjects were recruited and data from all 40 was collected and analyzed. Subjects in the athlete group averaged 20.7 ± 2.76 years old, 74.13 ± 4.23 inches tall, and weighed 184.9 ± 28.28 lbs. The athlete group consisted of 8 basketball players, 6 track & field athletes, 3 volleyball players, 2 rowers, and 1 tennis player. The non-athlete group averaged 21.5 ± 2.26 years old, 70.35 ± 4.09 inches tall, and weighed 173.9 ± 28.01 lbs. All 40 subjects were male.

Athletes had an average highest peg board score of 17.1 ± 1.71 pegs and an average peg board score of 15.62 ± 1.62 pegs. Non-athletes averaged 17.65 ± 1.87 pegs for their highest peg board score and averaged 16.2 ± 1.7 pegs across all trials. T-test analysis revealed no significant differences between any peg board scores, including all trials and average score. Athletes averaged 194.3 ± 21.36 taps, 188.2 ± 19 taps, and 181.7 ± 17.32 taps for their highest, 2nd highest, and 3rd highest scores respectively and averaged 188.07 ± 18.99 taps per trial. Non-athletes averaged 208.90 ± 31.65 taps, 204.00 ± 30.61 taps, and 199.60 ± 30.3 taps for their highest, 2nd highest, and 3rd highest scores respectively and averaged 204.17 ± 30.74 taps across all trials. T-test analysis reveals differences in tapping test scores. Non-athletes scored significantly higher than athletes on the 2nd highest, 3rd highest and overall average tapping test scores ($p=.023$, $p=.008$, and $p=.019$ respectively).

Three way ANOVA (Group x MVC x Gain) with repeated measures was run to compare mean force output, standard deviation of force output, and coefficient of variation of force output. When comparing mean force output across both groups, MVC's, and all visual gains, a group x MVC effect revealed athletes output significantly more force at both 5% and 30% MVC ($p=.019$). When comparing standard deviations of force output across both groups, MVC's, and

visual gains, significant effects were found for MVC (p<.05), Gain (p=.011), and MVC x Gain (p=.049). Subjects displayed more variable isometric control when testing at 30% MVC versus 5% MVC (p=.0005). All subjects displayed the most consistent isometric control at 256 pixels/N (p=.01), and the least consistent isometric control at 4, 16, and 64 pixels/N. Performance at 512 pixels/N (p=.029) and 128 pixels/N (p=.045) fell in between with subjects performing better at 512 pixels/N. All subjects displayed better isometric control across all visual gains at 5% MVC versus 30 % MVC (p=.049). When comparing coefficients of variation across groups, MVC's, all visual gains, no significant effects were revealed. However, when comparing athletes to non-athletes at each level of visual gain, significant differences were revealed at 128 and 512 pixels/N (p=.045 and p=.009 respectively) with non-athletes outperforming athletes. No other significant interactions were found. All means, standard deviations, and variances for both groups, both MVC's, and all visual gains are listed in appendix B.

CHAPTER 5: DISCUSSION

These results supported our hypothesis that athletes and non-athletes would perform differently on fine motor control tests but did not support our hypothesis that athletes would outperform non-athletes at the isometric force control task. In the peg board test, a clinical measure of motor control, there was no differences in amount of pegs placed in the pegboard as non-athletes and athletes performed equally well. This could be because the purdue peg board is not a challenging enough task to differentiate between our 2 groups of subjects. Or, sport participation may not have an effect on fine motor control as measured by the test.

There were differences between groups in the tapping test as non-athletes out performed athletes. Non-athletes had consistently higher scores as their second and third highest, as well as their average tapping scores were significantly better than the athletes. However, maximum tapping scores were not significantly different but there was a strong trend ($p=.052$). As a group, the athletes scored better with every trial scoring the lowest on the first trial and the highest on the third. Non-athletes performed just the opposite scoring the highest on their first trial and the lowest on their third. The differences in scores may be then caused by a difference in strategy. Anecdotally, athletes appeared to get a feel for the test before putting forth maximal effort while non-athletes appeared to exert high effort from the start.

We find it feasible that some of the athletes may have sustained a head injury and not reported it. Simply by playing sport, athletes are at a higher risk for head injury than non-athletes. If a head injury was sustained the athlete may have incurred enough damage to result in this deficit. This test may also be more sensitive to differences in fine motor control as the peg board test failed to reveal any differences.

Athletes had higher force output than non-athletes on the isometric force control test at both 5% and 30% MVC. This is not remarkable considering the differences in training level and physical condition that likely exist between the 2 groups. However, the muscle targeted by this task, the dorsal interossei muscle, was selected because it is seldom used and training differences should be minimized. All subjects showed more variable isometric force control when completing the task at 30% versus 5% MVC. This is expected as higher force output is necessary for the 30% MVC task. All subjects generally performed better as visual gain increased. This is also expected as subjects received more visual assistance as the gain increased. Non-athletes outperformed athletes for 2 conditions of the isometric force control task at 512 pixels/N and 128 pixels/N ($p=.009$ and $p=.045$ respectively). As mentioned earlier, athletes had higher force production than non-athletes. Increased force production would inherently make the task more difficult, especially across 36 trials. Also, more non-athletes than athletes (7 vs. 4) were forced to switch MVC's as they could not maintain that force throughout all 36 trials. More athletes completed the task at higher force output, inherently increasing variation due to higher demands.

The results of this study may be due to one of several factors: First, non-athletes have better fine motor control than athletes. Second, athletes and non-athletes may inherently have different motor control skills. Third, athletes competing in non-contact sports are at higher risk for head injury /subconcussive blows, and some damage may have been sustained leading to differences in fine motor control.

Athletes are heavily focused on gross motor control as most of what they do involves movement of multiple body segments and the use of large muscle groups. Perhaps they have trained their motor cortex in such a way that gross motor control is more highly regulated than

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fine motor control. That is not to say that fine motor control is neglected as many of the athletes used here, i.e. basketball players, must have good fine motor control to be successful in their sport. However, Non-athletes do not train as much or in the same fashion as athletes, if at all and thus their gross motor control may be less acute. It is hard to say that one group may accomplish more fine motor control tasks than the other and to do so would be pure speculation. However, non-athletes are likely to have more free time then athletes to accomplish tasks that emphasize fine motor control (i.e. musical instruments). This may result in accentuated fine motor control versus gross motor control as they are stimulating their motor cortex differently then athletes.

All of the athletes in this study participate in non-contact sports and have no history of documented concussion. However, given the inherent risks of participating in sports and the amount of unreported concussions, it is not unlikely that any of these athletes could have sustained a head injury at some point. Over half of the athletes in this study participate in either basketball (8 subjects) or volleyball (3 subjects), both of which have low risk of head injury, <1%. Despite this fact, head injuries still occur as players can potentially collide with each other or the floor, or get struck by the ball (Powell, 1999). Several of these athletes may have experienced such an incident and it may have gone unreported. Concussion may result in diminished fine motor control as Slobounov et al. (2002) showed in their study in which they utilized a similar fine motor control task. Their task focused on a ramp phase utilizing a concentric contraction as opposed to the isometric task used here. They also utilized 2 different force levels in their task choosing 25 and 50% MVC as opposed to 5 and 30% used here. They found that concussed athletes displayed in inability to match the target line in their ramp phase to 50% MVC as well as altered brain activity shown using EEG (Slobounov, 2002). It seems

unlikely that concussion /subconcussive blows played a role here but as self reported history of

concussion was the only measure used it is impossible to know.

CHAPTER 6: CONCLUSIONS

In conclusion, we have demonstrated that there are differences in fine motor control between athletes and non-athletes. Non-athletes displayed better finger quickness as they outperformed athletes in the tapping test. Non-athletes also displayed slightly better isometric force control as they outperformed athletes on 2 conditions of the isometric force control test. However, there were no differences in finger dexterity as both groups performed equally well on the purdue peg board test. Head injuries have been shown to cause deficits in fine motor control (Slobounov, 2002) although there is not a lot of research to support it. Athletes participating in non-contact sports are still at higher risk for head injury than non-athletes and several of these athletes may have sustained a concussion and not reported it. Finger speed and isometric force control may be more affected than manual dexterity or perhaps those tasks were simply more difficult. The conclusions made in this study are limited as it is a means to an end rather than an end itself. The next step is to compare this data with data collected from athletes with and without history of concussion who participate in contact sports. This next step would further elucidate the effects of concussion/subconcussive blows on fine motor control.

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APPENDIX A: HEALTH HISTORY QUESTIONNAIRE

HEALTH HISTORY QUESTIONNAIRE

Age _____   Height (in) _____   Weight (lbs) _____

What sport do you currently play, if any? _____

Have you ever played any of the following sports?

Football   Yes   No

Hockey   Yes   No

Wrestling   Yes   No

Soccer   Yes   No

Lacrosse   Yes   No

Rugby   Yes   No

Are you currently being treated for or experiencing concussion related symptoms?

Yes   No

Are you currently being treated   for an injury to the hand, arm, or shoulder?

Yes   No

Have you ever been diagnosed with a concussion by a medical professional (Doctor, Athletic

Trainer, EMT)

Yes   No

APPENDIX B: DATA TABLES

Peg Board Test Scores						
Group	Trial 1	Trial 2	Trial 3	Highest	2nd Highest	3rd Highest	Average
Athletes	14.4	15.7	16.75	17.1	15.65	14.1	15.62
Non-athletes	15.1	16.25	17.25	17.65	16.4	14.55	16.2

Table 1 – Peg board scores across all trials, including average highest, 2nd highest,3rd highest and overall average score (* p<.05)

Tapping Test Scores						
Group	Trial 1	Trial 2	Trial 3	Highest	2nd Highest	3rd Highest	Average
Athletes	186	188.5	189.7	194.3	188.2*	181.7*	188.07*
Non-athletes	206.1	203.75	202.65	208.9	204*	199.6*	204.17*

Table 2 – Tapping test scores across all trials, including average highest, 2nd highest,3rd highest and overall average score (* p<.05)

Mean Force Output (N) at 5% MVC						
Group	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N	Average
Athletes	2.47	2.17	2.01	2.01	1.90	1.93	2.08*
Non-athletes	1.55	1.26	1.16	1.20	1.09	1.17	1.24*

Table 3 – Mean force output across all gains at 5% MVC (* p<.05)

Mean Force Output (N) at 30% MVC						
Group	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N	Average
Athletes	8.52	9.78	10.52	10.12	10.64	10.65	10.04*
Non-athletes	4.52	5.32	5.97	6.34	5.72	6.24	5.69*

Table 4 – Mean force output across all gains at 30% MVC (* p<.05)

Mean Standard Deviation at 5% MVC						
Group	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N	Average
Athletes	1.09	0.67	0.47	0.47	0.52	0.58	0.63*
Non-athletes	0.76	0.54	0.43	0.39	0.37	0.35	0.47*

Table 5 – Mean standard deviation across all gains at 5% MVC (* p<.05)

Mean Standard Deviation at 30% MVC						
Group	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N	Average
Athletes	1.63	1.67	1.91	1.77	1.39	1.59	1.66*
Non-athletes	1.24	1.28	1.10	1.17	1.20	1.02	1.17*

Table 6 – Mean standard deviation across all gains at 30% MVC (* p<.05)

Mean Standard Deviation for All Subjects					
MVC	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N
5%	0.92	0.61	0.45	0.43	0.44	0.46
30%	1.43	1.48	1.50	1.47	1.30	1.31
Both	1.18	1.04	0.98	0.95*	0.87*	0.89*

Table 7 – Mean standard deviation for all subjects across all gains and both MVC's
(* p<.05)

Mean Coefficient of Variation at 5% MVC						
Group	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N	Average
Athletes	0.49	0.39	0.34	0.37	0.39	0.41	0.40
Non-athletes	0.60	0.49	0.39	0.37	0.37	0.33	0.42

Table 8 – Mean coefficient of variation across all gains at 5% MVC (* p<.05)

Mean Coefficient of Variation at 30% MVC						
Group	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N	Average
Athletes	0.32	0.24	0.26	0.26	0.19	0.20	0.24
Non-athletes	0.31	0.27	0.20	0.19	0.23	0.16	0.23

Table 9 – Mean coefficient of variation across all gains at 5% MVC (* p<.05)

Mean Coefficient of Variation across both MVC's					
Group	4 pixels/N	16 pixels/N	64 pixels/N	128 pixels/N	256 pixels/N	512 pixels/N
Athletes	0.40	0.31	0.30	0.31*	0.29	0.31*
Non-Athletes	0.46	0.38	0.29	0.28*	0.30	0.25*

Table 10 – Mean coefficient of variation of all subjects across all gains (* p<.05)