

ABSTRACT

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This study investigated the effects of muscle fatigue on the proprioceptive accuracy of knee injured and surgical individuals. SS were 18 control, 17 knee injured without surgery and 14 knee injured with surgery. Average time post-trauma for the non-surgical knee injured SS was 11.3 months and 11.5 months for surgical knee SS. All SS were randomly tested on two separate occasions with either rest or fatigue treatment. At least 24 but not more than 48 hours was required between testings. One testing consisted of knee angle teaching followed by pre-rest angle measurements, the rest treatment and then post-rest angle measurements. The other testing consisted of knee angle teaching, pre-fatigue angle measurements, the fatigue treatment performed on the Cybex II isokinetic dynamometer, and post-fatigue angle measurements. Two angles were tested for knee replication, 30 and 60 degrees. The SS were blindfolded during knee angle teaching and also during pre- and post-angle replications to determine proprioceptive accuracy. Two 3 X 2 X 2 analysis of variance (ANOVA) were computed for 30 and 60 degree mean angle measurements to compare pre- and post-mean angle differences between control, injured and surgical groups for the fatigue and rest treatment. Results of statistical analysis showed no significant difference ($P > 0.05$) between pre- or post-treatment (rest or fatigue) 30 and 60 degree mean angle measurements. Results therefore indicate that at the 30 and 60 degree joint angle measurements fatigue will not compromise conscious proprioception for injury or surgery SS.

THE EFFECT OF MUSCLE FATIGUE
ON PROPRIOCEPTIVE ACCURACY
FOLLOWING KNEE INJURY

A Thesis Presented
to
The Graduate Faculty
University of Wisconsin - La Crosse

In Partial Fulfillment
of the Requirements for the
Master of Science Degree

by
Brent E. Griffin
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UNIVERSITY OF WISCONSIN - LA CROSSE
College of Health, Physical Education and Recreation
La Crosse, Wisconsin 54601

Candidate: Brent E. Griffin

We recommend acceptance of this thesis in partial fulfillment
of this candidate's requirements for the degree:

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The candidate has completed his oral report.

<u>Kimberly L. Wood</u> Thesis Committee Chairperson	<u>June 23, 1986</u> Date
<u>Mark A. Korwinski</u> Thesis Committee Member	<u>8/22/86</u> Date
<u>Jordan Aker</u> Thesis Committee Member	<u>8/26/86</u> Date
<u>George J. Dennis Jr.</u> Thesis Committee Member	<u>8/26/86</u> Date

This thesis is approved for the College of Health, Physical
Education and Recreation.

<u>John C. Mitchem</u> Dean College of Health, Physical Education and Recreation	<u>August 27, 1986</u> Date
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<u>Jay C. Amundson</u> Dean of Graduate Studies	<u>Sept. 15, 1986</u> Date
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DEDICATION

To my wife,

Shirley

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CHAPTER I

INTRODUCTION

The ability to perceive one's body in space, sometimes referred to as position or movement sense, is termed conscious proprioception. This awareness of self involves perception of body joint position when stationary or during movement without the use of visual clues. There are three basic sensory cues coming from the joints: (1) the angle of the joint when stationary and moving; (2) an awareness of the direction of movement; and (3) the speed of joint angle change. This information is relayed via joint and other mechanoreceptors to the central nervous system (Burgess, Wei, Clark, & Simon, 1982).

Recent work in the area of proprioception shows a growing belief that body awareness is contributed by the muscles themselves. The receptors responsible for this body sense of position and movement are most likely the muscle spindle receptors (Glencross & Thornton, 1981; Goodwin, McCloskey, & Matthews, 1972a,b; Kelso, 1978).

One situation in which joint mechanoreceptors are removed is surgical joint arthroplasty. Clinical evidence by Grigg, Finerman, and Riley (1973) has shown an accurate preservation of joint position sense for active and passive movement in total hip arthroplasty patients. Cross and

McCloskey (1973) looked at joint arthroplasty in the fingers and toes of patients, reporting that proprioceptive awareness remains in the absence of joint receptors (mechanoreceptors). Because of these findings and others, there are indications that extracapsular components are involved in joint position sense, however, present research has not shown precisely which mechanoreceptors, in muscle or other tissues, are involved (Goodwin et al., 1972a,b). Though some research is not as clear with regard to elimination of joint mechanoreceptors as are the joint arthroplasty studies, there is support for the possibility that proprioceptive awareness may have a significant contribution from joint mechanoreceptor mechanisms.

Proprioceptive awareness following joint injury is reported in the literature to decrease (Freeman, Dean, & Hanham, 1965; Glencross & Thornton, 1981). Since many mechanoreceptors are located in the capsule and ligaments of joints, any injury or disruption to a ligament or capsule may lead to a rupturing of the nerve fibers that terminate in mechanoreceptors. Therefore, ligamentous and capsular injury may lead to partial joint deafferentiation (Freeman et al., 1965). According to Glencross and Thornton (1981), if in fact the total number of receptors are reduced through injury, fewer mechanoreceptors are available for activation when terminal joint positions are reached. This will result in more degrees of error in joint proprioception. This hypothesis is supported

by their work on ankle injury which demonstrated that joint angle replication error is greatest in more severely injured subjects. A linear trend was seen between the degree of error and range of motion of the joint angle, with the largest angle replication error occurring at the largest range of motion of the ankle joint.

The majority of the research to date is on proprioceptive awareness by means of passive or active range of motion of the joint. Little research has investigated the area of muscle fatigue and its relationship to joint awareness, therefore, a study that looks at joint injury and fatigue of the involved muscles seems timely.

Statement of the Problem

The problem in this study was to examine the effects of lower extremity muscle fatigue on the proprioceptive accuracy (30 and 60 degrees) of some knee injured and some post-surgical individuals. In order to answer this problem, the following subproblems were defined:

1. What are the effects of fatiguing exercise and rest on proprioceptive accuracy of knee injured subjects?
2. What are the effects of fatiguing exercise and rest on proprioceptive accuracy of surgical knee subjects?
3. What are the effects of fatiguing exercise and rest on proprioceptive accuracy of normal (control) knee subjects?

4. Is there any difference in proprioceptive accuracy before or after fatiguing exercise and rest between surgical, injured and control subjects?

Hypotheses

The null hypotheses tested at the 0.05 level of significance were:

1. For each group considered separately (surgical, injured, control), the proprioceptive accuracy before fatiguing exercise will not be significantly different from their proprioceptive accuracy after fatiguing exercise.
2. For each group considered separately (surgical, injured, control), the proprioceptive accuracy before rest will not be significantly different from their proprioceptive accuracy after rest.
3. There will be no significant difference in the proprioceptive accuracy between the surgical, injured, and normal (control) subjects either before or after fatigue and rest treatments.

Assumptions

The following assumptions were adopted for this study:

1. The subjects answered the history questionnaire honestly and accurately.
2. Honest attempts to duplicate the joint angles were made by the subjects.

3. Subjects had truly reached a state of muscular fatigue while working on the Cybex II isokinetic dynamometer during the fatiguing exercise.

Delimitations

The delimitations set for this study were:

1. The subjects were volunteers from the County of La Crosse, Wisconsin.
2. The knee injured and surgical subjects were at least 5 months, but not greater than 22 months, post-injury or surgery.
3. During the testing, the subjects were not allowed to look at their lower extremity. Thus, no visual assistance was included during the teaching phase, the immediate angle replication (pre-rest and pre-fatigue angles) or the angle replication following the treatment variable (fatigue or rest).
4. All knee angles measured during the study were done in the sitting position.
5. Verbal prompting was utilized during the teaching of joint angles. No verbal prompting was given during immediate angle replication (pre-rest and pre-fatigue) nor during the angle replication following treatment (fatigue or rest).

Limitations

The following limitations of the study were identified:

1. Individual diagnoses resulting from type and severity

- of knee injuries and surgeries varied among subjects.
2. Number of subjects in each group (control,18; injury,17; surgical,14) may have limited the power of statistical analysis.
 3. There was no control over individual differences in psychological attitude, prior experience with the testing instruments, and subject's natural motor coordination.
 4. The subjects' activity and conditioning levels may have varied.

Definition of Terms

Cybox II isokinetic dynamometer- An isokinetic device that can test and measure strength, power, and endurance of muscles and their associated joints. The machine has an accommodating resistance mechanism thus allowing the speed of movement to be constant throughout a joint's range of motion.

Fatigue- The peak torque of the quadriceps dropping below 50% of the maximum peak torque for at least three consecutive repetitions as demonstrated on the Cybox II dual channel recorder during the fatigue treatment.

Joint arthroplasty- The surgical removal of a body joint, with the substitution of an internal prosthetic device.

Kinesthetic awareness- Ability to detect displacement of a joint, to direct a limb to a given point, and to consciously control and grade muscular movements and forces without vision (McCloskey, 1978).

Knee injury- An injury that has been sustained by trauma to the knee resulting in damage to the joint capsule, knee ligaments, and/or joint muscles.

Knee surgery- A surgical operation to the knee in order to correct any structural damage or deformity that may be present.

Peak torque- The maximum force an individual can exert at a distance around an axis of rotation on the Cybex II dynamometer. It is recorded on the chart recorder as the highest peak of the torque curve that can be obtained.

Proprioceptive awareness- Consciousness of body position when stationary or during movement without the use of vision.

Static position sense- Awareness of body position at rest without the use of vision.

CHAPTER II
REVIEW OF LITERATURE

Introduction

Proprioceptive awareness or conscious proprioception may be divided into dynamic and static components. The first, kinesthetic awareness is essentially the ability to detect displacement of a joint, to direct a limb to a given point, and to consciously control and grade muscular movements and forces without vision (Horch, Clark, & Burgess, 1975; McCloskey, 1978). The second is static position sense, an awareness of body position at rest without the use of vision (Cohen, 1958).

A knowledge of anatomy and physiology is necessary to understand the mechanism of conscious proprioception. The following aspects will therefore be reviewed: joint neurology, articular mechanoreceptors, cutaneous receptors, muscle receptors, and muscle fatigue.

Joint Neurology

The joints of the body contain mechanoreceptors which are neural structures responsive to physical stimuli such as tension, pressure, stretch, and compression. Movement of the joint may cause one or more of these physical conditions to exist, resulting in deformity of the receptors. If deformity

of mechanoreceptors is significantly strong enough to elicit a threshold receptor potential, firing of the parent axon will occur (Adams, 1977). The action potential thus created is transmitted from the mechanoreceptor through the peripheral nerve fiber and on to the central nervous system for further transmission and information relay.

Wyke (1967) indicates that the joints of the body have a dual pattern of peripheral nerve innervation. The first way is by specific articular nerves reaching the joint capsule as independent branches of adjacent peripheral nerves. The second way is by non-specific articular branches of related muscle nerves. An example used by Wyke (1967) is the knee joint which is supplied by three specific articular nerves; a posterior, medial, and lateral articular nerve. These nerves are derived from the posterior tibial, femoral (or obturator), and lateral popliteal nerves, respectively. Intra-muscular branches of nerves to the sartorius and quadriceps musculature also supply the knee joint. This concept of Wyke's dual pattern of peripheral innervation to the joints suggests the possibility that articular branches off the peripheral nerves and articular branches off the related muscle nerves may have different functions for proprioceptive awareness.

At present, understanding of the central nervous system in processing peripheral kinesthetic sense from joint mechanoreceptors remains speculative in nature. Mountcastle and Powell (1959) manipulated the joints of the monkey and

recorded electrical activity at the postcentral gyrus in the brain similar to that of slowly and rapidly adapting mechanoreceptors firing from the joints that were manipulated. They concluded that joint receptors have their peripheral topography represented at the cortex. Mountcastle, Poggio, and Werner (1963) also studied the monkey's leg joint and were able to record electrical responses at the thalamic neurons corresponding to responses of slowly adapting joint mechanoreceptors. As a result of the central nervous system (CNS) receiving input from peripheral mechanoreceptors, the ability to perceive conscious joint position and movement may be possible.

Articular Mechanoreceptors

Types of Joint Receptors

There are five basic types of joint mechanoreceptors located in and around the joints. Each serve as a type of transducer to allow physical stimuli to be transmitted via the receptor's primary afferent fiber. According to Rowinski (1985), this information transmitted to the CNS may serve three major functions: (1) to influence activity of motor units that act to regulate the aperture, position, and angulation of the joint, (2) to influence upper motor neurons that govern the patterns and coordination of muscle activity at the joint, and (3) to influence the activity of neural pathways that mediate some of the perceptions associated with awareness of joint conditions.

Golgi-Mazzoni corpuscles. These endings are multi-terminating endings within a thin encapsulation and are located in the inner surface of the joint capsule. The mechanoreceptor's parent nerve fiber is small and myelinated (5-8 um). The corpuscles are slowly adapting and have a low mechanical threshold for activation. They are sensitive to compression of the joint capsule and insensitive to stretching of the capsule (Rowinski, 1985).

Ruffini endings. Spray-type terminal endings found in the fibrous layer of the joint capsule and are essentially sensitive to stretching of the joint capsule. Ruffini endings are slowly adapting with a low mechanical threshold. The parent axon is medium to large (8-17 um) and myelinated (Rowinski, 1985).

Pacinian corpuscles. These receptors are multi-laminated, cone-shaped structures. They are located in the deeper layers of the fibrous capsules of the joints, at the junction of the synovial membrane and fibrosum (layer) of the joint capsule and intra-articular and extra-articular fat pads. These receptors are more highly concentrated on the medial and lateral areas of the joint capsule (Newton, 1982). The parent nerve fiber is medium size and myelinated (8-12 um). They have a low mechanical threshold of activation have a rapid adaptation of firing frequency. Pacinian corpuscles are inactive in immobile joints and become active only at the onset and termination of joint movement (Wyke, 1967).

Golgi ligament endings. These receptors are morphologically similar to golgi tendon organs and are found in joint ligaments. Their parent nerve is large and myelinated (13-17 μ m). The mechanoreceptors are slowly adapting and have a low to high mechanical threshold. Wyke (1967) states that these receptors are inactive in immobile joints and are active only in the extreme ranges of active or passive movement.

Free nerve endings. They are nociceptive and non-nociceptive receptors which are slowly adapting with low to high thresholds. These endings become active when the receptors are subjected to mechanical, heat or chemical stimulation, and are found in joint ligaments, capsules, synovium and fat pads (Adriaensen, Gybels, Handwerker, & VanHees, 1983). Schaible and Schmidt (1983) state that some of the free nerve endings can be activated by noxious and non-noxious stimuli, thus allowing them their nociceptive and non-nociceptive properties and making them sensitive mechanoreceptors.

Role of Joint Receptors in Kinesthetic Sense

Research in the 1950s and into the early 1960s stressed the role of joint receptors as making the primary contributions in the perception of kinesthetic sense (Boyd & Roberts, 1953; Freeman et al., 1965; Freeman & Wyke, 1966; Gelfan & Carter, 1967; Wyke, 1967). In 1953, Boyd and Roberts published results from a study they did on the knee joint of the cat.

The posterior articular nerve to the cat's knee joint was dissected away from the posterior tibial nerve and small recording electrodes were inserted to record joint sense organ response to knee angle changes. They observed that the posterior articular nerve of the knee joint was capable of sustained discharge at frequencies which were dependent on the position of the joint. Furthermore, they reported that the impulse frequency recorded for the knee joint at any position appeared to be specific for that position and was independent of the rate of movement necessary to reach the specific joint angle. As a result of this work, they postulated that if proprioceptive awareness was only derived from muscle spindles and Golgi tendon organs the process would have to be quite complicated. Boyd and Roberts (1953) stated that:

...the length of a particular muscle at any moment cannot be deduced by any simple process from the frequencies of the discharges from its muscle-spindles and tendon-organs as these frequencies are affected by the tension in the muscle as well as by its length. Additional factors which might have to be taken into account include the motor discharge to the muscle, the positions of other joints, the position of the body relative to gravity, the places at which the body is supported, and the magnitude and position of any externally applied load (p. 53).

A clinical study by Freeman and associates (1965) on the functional instability of the foot again supported this growing belief in deafferentiation of the articular mechanoreceptors resulting in reduced proprioceptive awareness.

The ankle joint was studied under injury and control conditions, where subjects were treated by physical therapy alone, physical therapy with coordination exercises, and immobilization for three weeks. Results indicated that patients treated by coordination exercises had a lower incidence of functional instability of the ankle and a reduced incidence of proprioceptive deficit. In light of this observation, however, it appeared contradictory that a mechanical injury resulting in what the researchers called "partial joint deafferentiation" from ligament and capsular trauma without a high chance of neural regeneration could be made better through coordination exercises. Thus, it would seem that detection of movement does not depend entirely on joint mechanoreceptors and therefore other kinesthetic mechanisms such as muscle or tendon afferent organs may contribute to kinesthetic sense.

Researchers, such as Clark and Burgess (1969, 1975), have shown that articular mechanoreceptors are unable to provide steady-state position information over most of the working range of a joint. In fact, articular nerve activity at the extremes of the range (flexion/extension) was observed to be much more pronounced than at mid-range positions. In the 1975 study, Clark and Burgess looked specifically at the lateral (LAN), medial (MAN), and posterior (PAN) articular nerves supplying the cat knee joint. The angles studied were at intermediate positions of the working range (mid-range

positions) and were observed only while the joint was stationary. Test results showed that there was negligible tonic activity at the intermediate angles for the LAN. Of the 672 MAN fibers examined, it was shown that only 6 (0.9%) gave slowly adapting responses at intermediate angles. Forty-five (6.3%) of the 713 PAN fibers showed slowly adapting responses at the intermediate angles. It was also observed that there was great variation in the number of PAN fibers per animal tested (1 to 21). The discharges of the PAN did not vary considerably during the flexion-extension angles of the joint. However, it was interesting to note that these fibers responded to small intravenous doses of succinylcholine. This suggested to the authors that there may be muscle spindle involvement. They further were able to localize mid-range receptors to the popliteal muscle by dissection. This research, thus, has lent support to the fact that other mechanoreceptors (i.e. muscle and tendon receptors) may be responsible for kinesthetic and static position proprioception during a considerable extent of the working range of the knee in the cat.

Injury to Joint Receptors

Knee injuries are common in sports, and usually have a higher incidence among athletes that participate in contact sports (Fulkerson, 1981; Sonne-Holm, Fledellus, & Ahn, 1980). As a result of the tremendous functional demands made by weight bearing stresses such as walking, running, and jump-

ing, the knee suffers derangement of its function and stability more frequently than any other joint (Gartland, 1974).

The ligaments, and to a lesser degree, the joint capsule are the main structures responsible for knee stability. Medial stability of the knee is maintained by the medial collateral ligament. Lateral stability is provided by the lateral collateral ligament. Within the joint itself are the cruciate ligaments. The anterior cruciate ligament prevents forward displacement of the tibia on the femur. The posterior cruciate ligament prevents backward displacement of the tibia on the femur (Gartland, 1974). According to Freeman et al. (1965), there are many articular mechanoreceptor nerve fibers found in the ligaments and joint capsule. Traction injuries to these areas may result in rupture of collagen fibers as well as the mechanoreceptor's nerve fibers which have a lower tensile strength than collagen. The authors also state that ligamentous and capsular trauma may therefore lead to partial joint deafferentiation and that this defect may be permanent.

Glencross and Thornton (1981) tested subjects that had received treatments for ankle injuries at least eight months prior to the beginning of the study. They classified ankle injury subjects into three groups: severe, moderate, and mild injury. Their basic testing procedures involved passively moving the ankle of the subject to one of four ankle positions (105, 120, 130, 140 degrees). The subject was then required to replicate the movement. The researchers' obser-

vations showed a linear relationship between the degree of error and the range of motion, the greatest error occurring at the largest angles of movement, and significantly greater error for the injured than for the uninjured control conditions (except at 105 degrees). Another finding was that the error was greatest for the severely injured group and least for the mildly injured group at the 140 and 130 degree test positions. Glencross and Thornton (1981) stated that:

If the total number of receptors is reduced through injury, then fewer cells are available for activation when terminal joint positions are reached, resulting in increased degree of error in joint position sense (p. 26).

A study done by Barrack, Skinner, Brunet, and Cook (1983) indicated that joint laxity alone, without any injury, is enough to interfere with knee joint position sense. They inferred that more research needs to be done to determine if the mechanoreceptors do in fact mediate protective and postural reflexes.

The concept of mechanoreceptors and potential influence on reflexes was studied by Kennedy, Alexander, and Hayes (1982) through the evaluation of the quadriceps reflex after injecting fluid into the intraarticular joint capsule. Results showed that the infused knee (60cc saline) caused an inhibition (30-50%) of the reflex-evoked quadriceps contraction. Therefore, capsular distention resulted in stimulating the mechanoreceptors to cause quadriceps inhibition. According to Kennedy et al. (1982), the relationship of the mechano-

receptors to ligamentous structures has not been as well established. They reported that the capsular and ligamentous structures, when stretched, may act to initiate a reflex which would protect the joint by muscular splinting in situations of abnormal stress. Failure of the mechanoreceptor feedback via stretched or damaged ligaments may result in loss of reflex muscular splinting with the possibility that below normal responses may increase the chances of acute or chronic injuries.

Removal of Joint Receptors (Joint Arthroplasty)

In 1973, Cross and McCloskey conducted clinical research on prosthetic joint replacement. The purpose was to determine if good kinesthetic sensation remained following surgical removal of joints, ligaments, and their associated capsules in replacement for a prosthetic joint. These studies tested patients that had metacarpophalangeal or metatarsophalangeal joint replacements. The procedure was quite simple in that the joints tested were moved through a constant angular velocity with the patient's vision excluded. Subjects were then required to state the direction of the imposed movement as soon as it was perceived.

Cross and McCloskey's observations showed that despite the lack of joint afferents the subjects were still able to perceive joint movement. One drawback to the study, however, was the cutaneous input to the subject's fingers or toes by touching them when the joint was moved or by the stretching

of the skin over the joint when being moved.

Probable causes for the kinesthetic preservation include the following: muscle afferents by pulling of the flexor/ extensor tendons of the fingers or great toe, cutaneous afferents from stretching of the skin overlying the joints, or the influence of the cutaneous afferents on the fusimotor neurons or of synapses acted upon by muscle afferents (Cross & McCloskey, 1973). These probable causes help support the theory that kinesthetic sense remains in the absence of joint receptors.

Research conducted by Grigg and colleagues (1973) was similar to the work of Cross and McCloskey (1973) but studied total hip patients. Ten of the patients were tested within two weeks following surgery and six were evaluated four to eight months post-operatively. The purpose of this study was to look at the contribution capsular and ligamentous afferents have on joint position sense and to see the extent of sensory deficit the patient might have after hip replacement. Their study showed that passive movement of the hip greater than 5 degrees was minimally, if at all, impaired and that the ability to accurately position the hip actively was not impaired. The researchers' observations supported what clinical exam has shown, that there is little if any reduction in joint position sense following surgery. This research, again, has provided support of extracapsular components to joint position sense.

Current research seems to support two major hypotheses concerning the importance of joint mechanoreceptors. One is the concept that the joints and their respective receptors do not contribute to the proprioceptive awareness and that the muscles are the more likely candidates for this function. The second is the possibility that muscle and joint receptors work together in their proprioceptive role. However, each may contribute differently during active or passive movement of the joint, as well as throughout the actual joint's range of motion. This idea of combined mechanoreceptor and muscle afferent input together was looked at by Miller (1973) when she studied the elbow joint of the cat and subjected this stabilized joint to twitch contractions of the associated joint muscles. These twitch contractions produced phasic bursts of spikes in the joint nerve. Vibration was also able to elicit these same bursts of activity of the joint nerve. The results were conveyed by Miller (1973) as an apparent direct mechanical coupling between the vibrated or contracting muscles and the tissues of the joint containing the receptors, thus suggesting the possibility that joint afferent discharge may be modulated by way of muscle movement. The total role of joint mechanoreceptors remains incomplete. Present research continues to search for answers in the understanding of the role that joint receptors play in the process of proprioception.

Cutaneous Receptors

Cutaneous mechanoreceptors are possible sources for relaying proprioceptive clues, due to the skin being stretched and/or relaxed as a joint moves through its normal range of motion. There are four cutaneous senses: touch-pressure, cold, warmth, and pain. The skin contains various types of peripheral sensory receptors to transduce the cutaneous senses and then transmit this information over peripheral nerves to the central nervous system for processing (Chusid, 1976; Ganong, 1977).

Clark et al. (1979) studied the contributions of cutaneous and joint receptors for static knee position. They conducted their study by anesthetizing the knee joint, skin around the knee, or a combination of knee joint and skin around the knee. The subjects were then required to match the position of their right leg to the pre-set position of the left leg. As a result of this testing, no difference in the ability of the subjects to correctly detect flexion or extension of the knee joint angles was observed. According to the authors, neither the skin nor the joint input appeared necessary for an awareness of static knee joint angle and knee position information. Thus, by elimination of receptors in the joint and skin as input for static knee position sense, it seems possible that receptors in the muscles may in fact have a role to play.

Another interesting sidelight to the study by Clark et al. (1979) was their comparison of different joints. By looking at the effects of anesthetizing the skin and joints of the fingers, it was noted in their unpublished research that the movement of the fingers required the cutaneous input of the skin for an adequate perception of joint angles.

Burgess et al. (1982) reviewed the literature on cutaneous receptors and summarized that there is no evidence at present that cutaneous receptors contribute to joint position sense in the knee. However, this review only applied to the joints proximal to the hands and feet.

According to the literature the influence of cutaneous afferent input on joint awareness is not well established. That is to say some joints may place greater importance on this type of sensory input, e.g. finger joints of the hand, and other joints, such as the knee, may not need this peripheral input at all or perhaps minimally for joint awareness.

Muscle Receptors

Muscle receptors have been researched as potential mechanoreceptors for kinesthetic and proprioceptive awareness. Three major groups, or types of receptors, in muscle have been found. Muscle spindles (intrafusal fibers), with primary and secondary nerve endings, function as receptors for the stretch reflex. These intrafusal fibers are in parallel with the muscle fibers (extrafusal fibers) in which they reside. Secondly, Golgi tendon organs are receptors which originate

in the tendons of their respective muscles. They lie in series with the muscle fibers and may serve to inhibit contractile responses evoked by the muscle spindle (intrafusal fiber). Thus by the muscle spindle and Golgi tendon organ interaction, a fine tuning or smoothness of muscle performance is made possible. Thirdly, free nerve endings exist which become active when muscle tissue is subjected to excessive chemical or mechanical irritation. The associated peripheral nerves conduct impulses to the posterior spinal cord for processing of information. Some of the of the fibers will relay afferent information to lower motor neurons for the stretch reflex. Other afferent fibers synapse with ascending nerves of the spinothalamic tracts to transmit information to higher brain centers for processing and final interpretation (Chusid, 1976).

According to Eklund (1972), proprioceptive awareness of the knee joint has been shown to be influenced by muscle vibration. This was a unique human subject study in which normal subjects were tested for knee joint angle replication while experiencing one of three different treatment methods. Each subject was given either the first treatment, a voluntary contraction on the part of the subject at a knee angle ranging between 30 to 60 degrees of knee flexion; the second treatment, a passive lifting of the subject's leg on the part of the experimenter; or, the third treatment, a tonic vibration reflex (TVR) which is an involuntary vibra-

tion induced contraction. Results showed that subjects of the first treatment group accurately indicated with the other leg the angle to which they had moved the treatment leg voluntarily. However, during passive lifting of the treatment leg by the experimenter, the group two treatment subjects would lift the opposite leg higher than the first when asked to match the angle. The reverse situation happened when TVR was involuntarily induced to cause extension of the knee joint, with the group three subjects undershooting the desired angle with the opposite leg.

Eklund concluded that the results support the theory that information from proprioceptors in muscles appears to affect the sense of position. These proprioceptors may have been muscle spindles, thus the results could be viewed as indicating low activity of the muscle spindles during passive movement of the knee, intermediate during voluntary movement of the knee, and high during tonic vibratory reflex of the knee. High receptor activity during TVR gave an illusion of the quadriceps muscle being longer, i.e. the knee more flexed, whereas low receptor activity, i.e. during passive movement of the knee, gave the illusion of the knee being more extended.

Other research has shown that by vibrating muscles of a specific joint there can be large distortions in joint angle proprioception (Goodwin, McCloskey, & Matthews, 1972a,b). Goodwin et al. (1972a) observed that the perceived position

of a limb may be attributed to three kinds of signals: (1) afferent from joint receptors, (2) efferent from motor centers to muscle spindles, and (3) afferent from muscle spindles. McCloskey (1978) stated:

The principal receptors subserving the senses of movement and position are intramuscular receptors, probably the primary and secondary endings of the muscle spindles. Of the evidence advanced over the past 25 years purporting to show that intramuscular receptors have no role in kinesthesia, none now stands unchallenged (p.812).

After compiling research of joint replacement (Cross & McCloskey, 1973; Grigg et al., 1973), joint articular receptor (Burgess et al., 1982; Clark et al., 1979; Gandevia & McCloskey, 1976), and muscle receptor studies (Goodwin et al., 1972a,b; Matthews & Simmons, 1974), all concluded that muscle receptors play an important role in the proprioceptive sense in man.

Little research has been conducted on muscle fatigue and the potential effect it may have on muscle receptors. If proprioceptive awareness depends on a substantial input from muscle receptors, it may be possible that muscle fatigue could have an effect on the respective muscle receptors, thus influencing the proprioceptive mechanism for body awareness. The role of muscle fatigue, however, needs to be considered before a direct implication of fatigue on the muscle receptors is possible.

Muscle Fatigue

Muscular fatigue can be viewed as a state in which there is a failure of the muscle to voluntarily contract. Current research continues on fatigue, allowing further insight into its probable causes. According to Fox & Mathews (1981), there are basically three areas being investigated as possible sites of muscle fatigue: one, is fatigue at the neuromuscular junction; secondly, fatigue within the contractile mechanism; and thirdly, fatigue that may be caused by the central nervous system.

Fox & Mathews (1981) state that fatigue at the neuromuscular junction is probably due to a decrease in the release of the chemical transmitter acetylcholine. In 1972, Stephens & Taylor studied the effects of fatigue with isometric contraction. The study was conducted on a group of eight volunteers, and the muscle chosen was the first dorsal interosseus of the dominant hand. It was observed that in maximal isometric contractions, the force generated by the muscle started to fall within a few seconds, reaching 50% maximal voluntary contraction strength (MVC) in 1 minute and 25% in 2 minutes. It was shown that in submaximal efforts by the subject the force was maintained constant for a longer time but then fell similarly. As stated by Stephens & Taylor,

In the first phase, lasting about 1 min, there is a loss of some 50% of strength. During this time, natural e.m.g. activity falls linearly with the same slope with respect to force as in the nonfatigued muscle. In the second stage,

force continues to fall and reaches a plateau at about 25%. Electrical activity also continues to fall, but now less rapidly than does force. The ratio of electrical activity to force (E/T ratio) is normal or reduced in the first phase, but is increased in the second. The simplest interpretation of these results is that, at maximal contraction strength, fatigue arises initially from NMJ failure, but later, contractile element failure becomes progressively more important (p. 14).

The authors also concluded that neuromuscular junction fatigue is believed to be most marked in high threshold motor units (fast twitch or type II), while contractile element fatigue tends to affect low threshold units (slow twitch, or type I).

Merton (1954) found no changes in electromyogram (EMG) tracings during maintained maximal contractions and therefore he postulated that fatigue was originating from the contractile processes in the muscle itself. Research by Nilsson, Tesch, & Thorstensson (1977) agreed with Merton (1954). Results of their study done on 12 healthy subjects for fatigue of the left quadriceps muscle showed that peak torque values declined progressively to reach a stable level after about 50% of the initial value following approximately 50 contractions. The decline in peak torque was shown to correlate with the percentage of fast twitch FT fibers in the contracting quadriceps muscle. Although there was a rapid decline in peak torque, there was no corresponding decrease observed in the EMG. According to the authors, there was a slight increase in the EMG output during the first 25 contractions.

This may have been due to an additional recruitment of motor units (with a decreased ability to produce force) as the active FT units decreased in contractile ability. The researchers, concluded that the probable cause was a local factor in the muscle itself and not the neuromuscular junction. This hypothesis was supported by the fact that during the testing the EMG tracings remained relatively constant, while peak torque, work and power decreased. As a result of the decrease in peak torque an increase in the EMG/torque ratio was observed.

Similar testing done by Clamann & Broecker (1979) looking at muscular fatigue of the biceps brachii, triceps brachii and adductor pollicis showed fatigue to be distal to the neuromuscular junction, as recorded by the EMG. However, the first dorsal interosseus did show changes in the EMG as a result of fatigue, therefore demonstrating an effect at or proximal to the neuromuscular junction with central nervous system fatigue as a possible cause.

Fatigue in the contractile portion of the muscle may be due to several possible causes. One possibility is the accumulation of lactic acid (Fitts & Holloszy, 1976; Karlsson & Saltin, 1970; Tesch, Sjodin, Thorstensson, & Karlsson, 1978). Lactic acid decreases the pH level which increases calcium binding capacity of the sarcoplasmic reticulum and also reduces the calcium's binding ability with troponin. With reduced calcium available to the myofibrils, the actin

and myosin cannot interact effectively and muscle fatigue occurs. Additionally, the enzyme phosphofructokinase is inhibited by a decrease in pH which is important in anaerobic glycolysis (Fox & Mathews, 1981). Anaerobic glycolysis is necessary for food energy to be converted into adenosine triphosphate (ATP) energy which can then be used by the muscles for contraction. Therefore with reduced availability of ATP as a fuel source the muscles lose their ability to contract and fatigue results. This is especially prevalent during fast muscular contractions when the predominant ATP supply is from anaerobic glycolysis.

Another possible cause of contractile mechanism fatigue may be the actual depletion of ATP and phosphocreatine (PC) stores within the contractile element. Research by Fitts and Holloszy (1976) reported that a decrease in PC concentration followed a different time course than did the decrease in muscle contractile force, thus indicating no correlation between the two variables. Karlsson and Saltin (1970) studied exhaustive exercise performed on the bicycle. Through their biopsies done on the quadriceps femoris muscle, they concluded that low ATP and PC stores were not the reason for muscular fatigue.

Fox and Mathews (1981) still do not dismiss the possibility of ATP and PC involvement in fatigue. Fatigue may be due to a selective myofibril reduction in ATP, which may be more than ATP reduction of the muscle as a whole. This

reduction would depend on the type of muscle fibers involved whether slow or fast twitch, during the fatiguing exercise. Another reason for fatigue is the possibility that there may be a reduction in ATP energy yield rather than a decrease in the amount of ATP.

Muscle glycogen depletion has also been studied as a possible cause of contractile unit fatigue. A study by Thompson, Green, and Houston (1979) looked at muscle glycogen depletion in slow twitch (ST), FTa, FTb fibers. Each type of fiber showed a specific depletion pattern of glycogen. With submaximal bicycle work, glycogen was depleted the most in ST fibers and least in FTb fibers. During supramaximal work, FTb fibers were depleted the most, with little loss of glycogen from ST fibers. FTa fibers in both submaximal and supramaximal work showed intermediate loss of glycogen compared to ST and FTb fibers. Other research also has confirmed similar results that differential rates of glycogen depletion occur in ST, FTa, and FTb fibers of skeletal muscle during exercise. Since muscle glycogen is a major energy substrate, especially during aerobic exercise workouts (high VO_2), it may be a primary means by which contractile mechanism fatigue is retarded (Gollnick, Armstrong, Saubert, Sembrowich, Shepherd, & Saltin, 1973; Gollnick, Armstrong, Sembrowich, Shepherd, & Saltin, 1973).

The central nervous system is also a possible site for fatigue. Interesting work has been done by Asmussen & Mazin

(1978a,b) with diverting activities (physical and mental) during the rest phase following fatigue. They found that more work could be performed following a pause with a diverting activity than after a passive pause. Other studies by Asmussen and Mazin (1978a,b) showed that the amount of physical work a subject could do before exhaustion was more than if the subject was told to shut his/her eyes and work towards exhaustion. Also, upon working to exhaustion with the eyes shut and then opening the eyes, there was a return of working capacity from 15 to 30 percent of that already performed. This suggests that the central nervous system when stimulated by visual input is able to retard the effects of fatigue.

Many factors can thus be said to influence muscle fatigue, none of which give conclusive evidence as the sole influence on the skeletal muscle of man. Though not knowing the exact determinates of muscle fatigue, it is still observed that when a person exercises to fatigue muscular coordination tends to become impaired. However, little has been done to address the question of the effect that muscle fatigue may have on proprioceptive accuracy. If muscle receptors are in fact major contributors to kinesthetic and proprioceptive sense, it seems logical to postulate that muscle fatigue or the possible factors causing muscle fatigue (e.g. lactic acid, glycogen depletion, ATP and PC depletion, central nervous system activity) may have an influence on the muscle receptors responsible for kinesthetic sense. In 1983, Turner

did a study investigating fatigue and physical activity on kinesthetic and proprioceptive awareness of the knee. She found that regardless of the subject's activity level there was a decrease in proprioceptive awareness of the knee during post-exercise. Physical activity level did not have any effect on proprioceptive accuracy. Also, exercising to fatigue did not cause a greater deficit in awareness than did walking.

Summary

At present, the literature expresses support away from articular mechanoreceptors and towards a more intramuscular receptor mechanism as responsible for conveying proprioceptive awareness. Articular mechanoreceptors are, however, still supported by the literature in regards to their importance in muscle reflexes, tone, and sensory input at the extremes of joint range. Although research has not addressed the effect of knee injury and surgery with muscle fatigue on kinesthetic and static position sense, it seems possible that if a decrease in joint sense due to injury or surgery does occur, with or without a fatiguing exercise, then the risk of re-injury may be higher than for an individual who has no injury.

CHAPTER III

METHODS

This study was designed to examine the effect of muscle fatigue on proprioceptive accuracy of knee injured and surgically repaired individuals. The purpose of this chapter is to present methods used in the study. The following areas will be discussed: pilot study, subjects, testing procedures, and statistical methods.

Pilot Study

A pilot study was conducted on six volunteers to evaluate the design of the testing procedures and length of time of the test. These volunteers were residents from the County of La Crosse, Wisconsin. The test consisted of determination of the subject's dominant leg, teaching of the knee joint angles and pre-exercise (or rest) angle replication, exercising to fatigue on the Cybex II isokinetic dynamometer or a resting session, and measurement of the knee joint angles post-exercise (or rest). Results of the pilot were satisfactory and minimal changes were necessary prior to actual subject testing.

Subjects

Seventeen non-surgical, knee injured individuals, 14 knee injured with surgical repair individuals, and 18

control individuals served as subjects for the study. There were 6 male and 12 female control subjects, 6 male and 11 female non-surgical knee injured subjects, and 6 male and 8 female surgical repair subjects tested. Subjects were selected by availability and willingness to participate.

An explanation of the study and testing procedures were presented to each subject, with those willing to participate signing an informed consent form (see Appendix A). Subjects serving as controls completed a preliminary questionnaire (Appendix B) to eliminate any subject having a history of knee injury. The mean age of the control individuals was 23.2 years, with a range of 20 to 31 years of age. The knee injured subjects also filled out a preliminary questionnaire to obtain the history of knee injury and knee rehabilitation status (Appendix B). These subjects were selected on the criteria of ligamentous injury to the medial collateral, lateral collateral, anterior or posterior cruciate ligaments. Meniscus injury, muscle trauma, subluxation, and possible combinations of these type of injuries were also included in the study (see Appendix C). The non-surgical knee injured subjects were at least 5 months but no more than 19 months post trauma, with a mean of 11.3 months. The mean age of these subjects was 24.4 years, with a range of 19 to 49 years of age. The surgically treated knee injured subjects were at least 6 months but no more than 18 months post surgery, with a mean of 11.5 months. The mean age of these surgical sub-

jects was also 24.4 years, with a range of 17 to 37 years of age. The time limits were established in order to eliminate any short or long term distortion to the proprioceptive kinesthetic mechanism that may occur after trauma or surgery, and also to limit the extent to which the length of the injury had been sustained. The exact injury or surgery diagnosis was confirmed from the subject's physical therapy medical records.

Testing Procedures

Each subject, whether knee injured or control, was tested in the same manner. Leg dominance was determined for each control subject by having the individual walk up to a foam rectangle from a distance of 20 feet and kick this object with the leg which he or she thought they could kick it the farthest and hardest. This dominant leg then served as the leg for testing of the control subjects. Knee-injured subjects were tested on the injured extremity.

The determination of whether the subject received fatiguing exercise treatment or resting treatment first was done randomly. There also was at least 24 but no more than 48 hours between testing sessions, and therefore, following either fatigue or rest treatments, the subject was scheduled to come back for the other treatment. This was established in order that subjects receiving the fatiguing treatment first had sufficient time for muscle recovery before attempting the rest treatment.

The basic experimental design was the same for control, injury and surgical groups tested. It consisted of the following: a teaching session for the 30 and 60 degree angles, followed by a recording of these angles for pre-fatigue or pre-rest angle joint measurements; the treatment variable was next which was either a one minute rest or a fatiguing exercise on the Cybex II isokinetic dynamometer; and finally, post-fatigue or post-rest measurements were taken in a similar manner to pre-test measurements. The design was essentially a pre-test followed by treatment variables, rest or fatigue, and then post-test. Additional information was obtained by the use of moderator variables of knee injury without surgery and knee injury with surgical repair.

Cybex Set-up

The subject arrived at the testing room and was seated at the Cybex II isokinetic dynamometer. He/she was stabilized in the seat at the thigh and lower leg by velcro straps. All the straps were made as tight as the subject was able to comfortably tolerate. The thigh was secured at the distal end allowing for unrestricted knee movement, with the leg being stabilized to the Cybex lever arm shin pad proximal to the malleoli and below the bulk of calf musculature. The Cybex dynamometer axis for flexion/extension of the knee was adjusted for the individual subject and secured. Stabilization of the subject's upper body was not done, however,

he/she was instructed to not rock back and forth during the exercise or rest treatments and to hold onto the side hand grips. All subjects wore shorts to reduce the possibility of additional cutaneous input during testing.

The Cybex position angle channel on the recorder was used to teach and record the knee joint angles, 30 degrees and 60 degrees, which were given to the subject in a randomly determined order. These angles were chosen due to ease of observation and teaching from the dual channel recorder. Because of the restriction of the Cybex seat, subjects could not move their leg beyond 90 degrees of flexion without compressing the seat padding and, therefore, angles greater than this were not valid measurements.

Teaching Session

The subject was shown an illustration of one of the joint angles and explained that this was the angle to replicate. Subjects were then blindfolded and verbally cued to attain the desired angle. The angle was verified on the Cybex position angle channel and the knee angle was held for approximately 10 seconds. The subject was then allowed to relax and let the leg hang loosely over the edge of the seat.

Pre-Test Angle Measurements

Immediately following the leg relaxing to the neutral position (90 degrees), the subject was asked to replicate the angle taught without any visual or verbal cues. Knee joint angles, which served as the pre-fatigue/rest joint angle

measurements, were recorded on the Cybex II position angle channel. Both angles, 30 and 60 degrees, were taught and tested individually for angle replication in the same manner.

Resting Session

Each subject performed the resting session according to the following procedure. The subject was allowed to let the leg hang loosely over the edge of the seat for one minute following the pre-rest joint measurement. During the one minute rest, the subject was not blindfolded. The subject was then re-blindfolded and asked to replicate angles taught, without visual or verbal cues. Knee joint angles, representing the subjects's post-rest joint angle measurements for proprioceptive accuracy, were recorded on the Cybex II position angle channel (see Appendix D). The starting position for all angle replication was with the leg hanging loosely over the edge of the seat at approximately 90 degrees.

Fatiguing Exercise

For the fatigue treatment, a power-endurance test was done according to Cybex II testing protocol and speed was set at 180 degrees/second. Initially, the subject was allowed to get the "feel" of the machine by practicing three maximal repetitions followed by a one minute rest. He/she was considered fatigued when the peak torque of the quadriceps decreased to 50% of the maximum peak torque for at least three consecutive repetitions. The subject was not blindfolded during the fatiguing treatment. Following fatigue,

the subject was reblindfolded and the joint angles were reproduced without visual or verbal cues. These angle replications were recorded on the Cybex II dual channel recorder as the post-exercise knee joint angles for proprioceptive accuracy (see Appendix D). The starting position for knee angle replication was with the leg hanging loosely over the edge of the seat.

Statistical Methods

A 3 X 2 X 2 analysis of variance (ANOVA) was used to determine if there was any significant difference in proprioceptive accuracy between control, knee injury and knee surgical subjects for pre- and post-test mean angle measurements from fatigue and rest treatments given. Two ANOVA'S were done for the 30 and 60 degree angle replications. A Scheffe' post hoc would be performed to determine specific significant difference if the ANOVA'S proved to be significant. The independent variables for the study were the fatigue and rest treatments given. Moderator variables consisted of knee injury and surgery. The dependent variable of the study was proprioceptive accuracy measured by the subject's ability to accurately replicate knee joint angles. To determine the tenability of null hypotheses, the 0.05 level of significance was chosen.

CHAPTER IV
RESULTS AND DISCUSSION

Results

Two 3 X 2 X 2 analysis of variances (ANOVA) were computed for 30 and 60 degree mean angle measurements to compare pre- and post-mean angle differences between groups. Results of means and standard deviations for pre- and post-fatigue and rest treatments are presented in Table 1.

Table 1
Means and Standard Deviations of Knee Joint Angle

Variable	Measurements in Degrees					
	Control (n=18)		Injury (n=17)		Surgery (n=14)	
	mean	s.d.	mean	s.d.	mean	s.d.
Pre-Rest 30	30.00	4.72	31.76	6.14	30.71	6.19
Post-Rest 30	30.11	4.91	35.35	8.81	31.50	7.70
Pre-Rest 60	55.50	6.46	56.12	5.79	54.79	4.41
Post-Rest 60	53.78	7.03	54.76	10.76	53.00	8.51
Pre-Fatigue 30	31.94	10.13	30.59	3.50	29.93	5.15
Post-Fatigue 30	34.78	8.71	36.82	6.69	33.07	6.24
Pre-Fatigue 60	56.06	7.78	56.41	6.30	55.21	5.31
Post-Fatigue 60	54.28	9.40	57.94	8.44	52.36	8.30

Control

Control subjects' legs were tested for dominance, resulting in right leg dominance in 16 subjects and 2 subjects

with left leg dominance. Proprioceptive testing was done using the dominant leg. The preliminary questionnaire showed that most subjects considered their physical activity level at work to be classified as very light or light, however, they graded their physical fitness level to be generally good.

Figures 1 and 2 show pre- and post-means for fatigue and rest on control subjects. As can be seen by Figure 1, the post-rest or post-fatigue 30 degree angle replications were

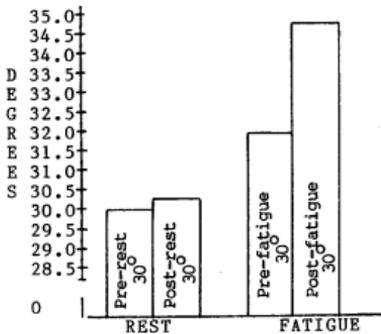


Figure 1. Control subjects' pre- and post-mean angle replications for 30 degrees

with the knee more flexed (i.e. greater than pre-rest degrees). The pre-rest and pre-fatigue mean angle measurements were closer to 30 degrees than post-rest and fatigue measurements. The results for mean angle replication following fatiguing treatment for 60 degrees were opposite, however

(see Figure 2). They showed the post angle replications to be more extended (i.e. less than pre-rest and pre-fatigue degrees). Pre-rest and pre-fatigue angle measurements, similar to 30 degree testing, were closer to 60 degrees than post-rest and fatigue measurements. Appendix D shows a sample recording of the data for the 30 and 60 degree angle measurements done in testing.

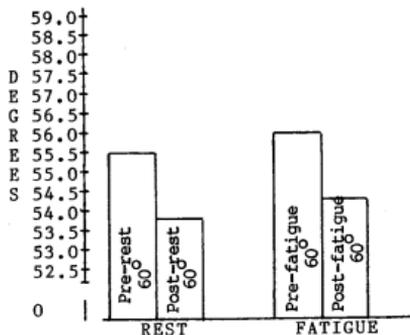


Figure 2. Control subjects' pre- and post-mean angle replications for 60 degrees

Injury

Injury subjects were tested on their involved side with the right leg being tested for 10 subjects and 7 subjects tested on the left. Physical activity level at work for these subjects was generally moderate, with physical fitness level being graded as good for most subjects. The majority of injury subjects also reported that they considered their

involved leg 80 to 100 percent healed. Figure 3 shows pre- and post-mean angle replications of knee injured subjects for 30 degrees. Post-rest and fatigue values were with the knee more flexed (i.e. greater than pre-rest degrees). Pre-rest and pre-fatigue mean angles were closer to 30 degrees than post-fatigue or rest mean angle measurements.

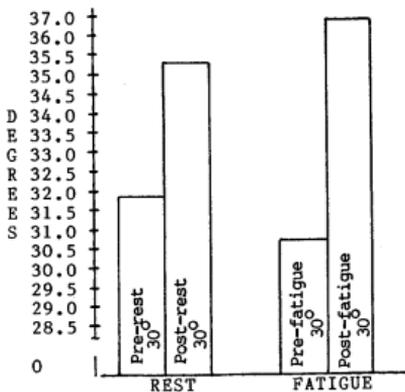


Figure 3. Injury subjects' pre- and post-mean angle replications for 30 degrees

Pre- and post-measurements for 60 degree mean angle values showed a reverse effect, when comparing mean angles from fatigue and rest treatments. The pre-rest 60 degree mean angles were with the knee more flexed, that is, they were greater than post-rest 60 degrees. However, for the fatigue treatment this was reversed, showing the post-fatigue

mean angles to be more flexed or greater than pre-fatigue mean 60 degree angles (refer to Figure 4). The pre-rest 60 degree mean angles and the post-fatigue mean 60 degree angles were closer to 60 degrees.

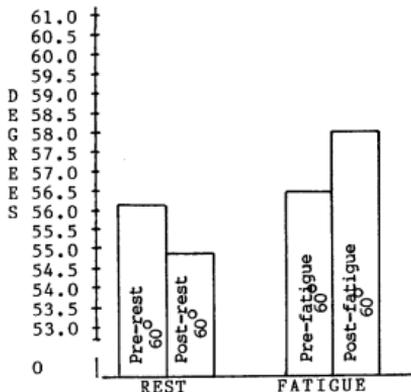


Figure 4. Injury subjects' pre- and post-mean angle replications for 60 degrees

Surgical

There were 6 right leg surgical subjects and 8 left leg subjects tested. The subjects' legs were tested on the involved surgical side without regard to leg dominance. The physical activity of these subjects centered around light or moderate levels, with the physical fitness levels predominantly being chosen as good or fair. The subjects' attitudes towards the percent of leg healing were varied from 40 up to 100 percent.

Pre- and post-test mean angle replications of surgery subjects for 30 degrees showed post-rest and fatigue mean values to be more flexed than pre-rest or fatigue values. Again, as in injury and control comparisons, the pre-rest and pre-fatigue mean angle measurements were closer to 30 degrees than post-rest and fatigue measurements (refer to Figure 5).

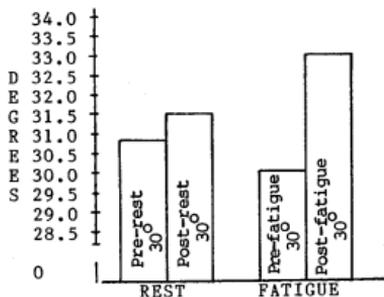


Figure 5. Surgery subjects' pre- and post-mean angle replications for 30 degrees

The results for mean angle replications for 60 degrees of surgical subjects can be seen in Figure 6. They showed the post-rest and fatigue mean angles to be more extended than pre-rest or fatigue values. Pre-rest and fatigue values were closer to 60 degrees than post mean values.

A 3 X 2 X 2 analysis of variance (ANOVA) to compare pre- and post-mean angle differences between control, knee injured and knee surgical groups for fatigue and rest treatments at

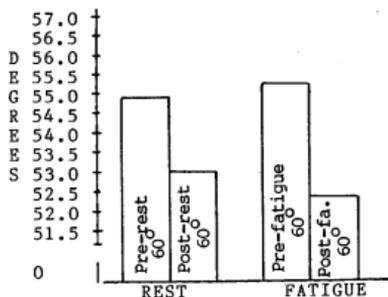


Figure 6. Surgery subjects' pre- and post-mean angle replications for 60 degrees

30 and 60 degrees showed no significant difference. The ANOVA performed for both 30 and 60 degree mean angle measurements showed F test values to be non-significant at the .05 level when comparing pre- and post-mean angle differences between groups (refer to Table 2 and Table 3).

DISCUSSION

From the statistical data computed with respect to the rest or fatigue treatment, all three groups (surgical, injured, and control) showed no significant difference between pre- or post-treatment 30 and 60 degree mean angle measurements. The rest treatment of subjects for all groups studied was done essentially to control for the time lapse which the subjects underwent between pre- and post-test knee angle measurements. The reasoning for this was that the fatigue treatment itself may not influence the post-treatment knee

Table 2
 3 X 2 X 2 Analysis of Variance by Group
 for 30 Degree Mean Angle Measurements

VARIANCE BETWEEN GROUPS	SS	DF	MS	F	TWO-TAIL PROB.
RG	104.31	2	52.15	1.12	0.3340
ERROR	2136.08	46	46.44		
SG	116.00	2	58.00	1.78	0.1806
ERROR	15011.35	46	32.64		
RSG	0.23	2	0.11	0.01	0.9937
ERROR	826.77	46	17.97		

RG= variance between groups (rest vs. fatigue treatment)
 ERROR= error variance within group
 SG= variance between groups (pre- vs. post- differences)
 RSG= variance between groups (interaction of rest and fatigue treatments and pre- to post- differences)

angle reproduction but the time delay could possibly have an effect by itself, such as subject's memory loss of the 30 or 60 degree angles. Interestingly, all but once (see Figure 4), the pre-mean angle replication values were closer to the angle undergoing replication thus indicating a memory interaction.

The ANOVA showed that the rest or fatigue treatments did not cause significant differences between injured, surgical and control groups for pre- and post- mean angle comparisons between groups. The potential damage, therefore, to the joint mechanoreceptors and their respective afferent innervation, for injury and surgical subjects, suggests the possibility that either not enough damage was done to cause a

Table 3
 3 X 2 X 2 Analysis of Variance by Group
 for 60 Degree Mean Angle Measurements

VARIANCE BETWEEN GROUPS	SS	DF	MS	F	TWO-TAIL PROB.
RG	23.84	2	11.92	0.20	0.8169
ERROR	2699.00	46	58.67		
SG	57.01	2	28.50	0.91	0.4086
ERROR	1436.66	46	31.23		
RSG	22.48	2	11.24	0.48	0.6204
ERROR	1072.01	46	23.30		

RG= variance between groups (rest vs. fatigue treatment)
 ERROR= error variance within group
 SG= variance between groups (pre- vs. post- differences)
 RSG= variance between groups (interaction of rest and fatigue treatments and pre- to post- differences)

discrepancy in proprioceptive feedback or that other areas such as the muscles with their muscle spindles were able to compensate for the potential loss of proprioception from the joints during the rest or fatigue treatment. Or, there is the possibility that proprioception itself may not be dependent upon the receptors in the injured, scarred, or recovered tissue thus allowing a normal proprioceptive feedback mechanism. Also, the method of testing might not have been sensitive enough to show differences between control, injured or surgical subjects.

Other considerations for no statistical significance in the results include the specificity of the range of motion in which the knee joint was tested. This implies that other

knee angles may have experienced a decrease in proprioception while the 30 and 60 degree angles tested were not affected. Burgess et al. (1982) showed similar results to support this hypothesis, i.e. reduced afferent discharge of joint mechanoreceptors during mid-range, with experiments on joints of the cat. He did not take into account, however, the potential muscular component to proprioception which may or may not be functioning throughout part or all of the joint's range of motion.

Lastly, consideration must be given to the possibility of statistical error resulting from the testing of the dominant legs for control subjects (16 right and 2 left) and comparing them to the involved injury legs (10 right and 7 left) and involved surgical legs (6 right and 8 left). The right and left legs of the subjects may in themselves have possible proprioceptive differences resulting in an unequal comparison between the control, injury and surgical subjects. Therefore, the fact that there was an inconsistency between the control legs tested compared to the injury or surgical legs may have randomly resulted in no statistical significance.

In conclusion, all three groups (surgical, injured and control) showed no significant difference between pre- or post- treatment 30 and 60 degree mean angle measurements for the rest or fatigue treatments. Results such as this are encouraging when considering that surgery or injury will not

compromise the proprioceptive mechanisms of the individual allowing him or her maintenance of conscious proprioception. However, the results are by no means conclusive. Considerable research must be done to test angles throughout the knee joint's range-of-motion, i.e. other than 30 or 60 degrees, to see if conscious proprioception is preserved or compromised under variable treatment conditions. This information would be helpful in rehabilitation of knee injuries. Facilitating body awareness through the use of proprioceptive neuromuscular facilitation techniques (PNF) or the possibility of inhibiting proprioceptive awareness through the use of joint positioning and/or muscle fatigue, when a particular joint injury would warrant it, may serve as a great adjunct to physical therapeutics.

CHAPTER V
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to examine the effects of muscle fatigue on the proprioceptive accuracy of knee injured individuals. Subjects were from the County of La Crosse, Wisconsin with 18 control, 17 knee injured without surgery and 14 knee injured with surgery individuals participating. The surgical and non-surgical knee injured subjects were selected on the criteria of ligamentous injury to the medial and/or lateral collateral ligamentous, anterior and/or posterior cruciate ligaments, as well as meniscus injury, muscle trauma, subluxation, or combinations of these types of injuries. Average time post trauma for the non-surgical knee injured subjects was 11.3 months and 11.5 months for knee surgical patients.

All subjects were tested on two separate occasions consisting of either rest or fatigue treatments with at least 24, but not more than 48, hours between testings. One testing consisted of knee angle teaching followed by pre-rest angle measurements, the rest treatment and then post-rest angle measurements. The other test consisted of knee angle teaching followed by pre-fatigue angle measurements, the fatigue treatment performed on the Cybex II isokinetic dynamo-

meter and post-fatigue angle measurements. Two angles were tested for knee replication, 30 and 60 degrees. The subjects were blindfolded during knee angle teaching and also during pre- and post-angle replications to determine proprioceptive accuracy.

A 3 X 2 X 2 analysis of variance (ANOVA) was used to assess the difference in proprioceptive accuracy for pre- and post-rest or fatigue mean angle measurements between control, knee injury and knee surgical subjects. The ANOVA for the 30 and 60 degree mean angle measurements showed F values to be non-significant.

Conclusions

As a result of the statistical analysis performed, the following conclusions were made:

1. Proprioceptive accuracy before rest was not significantly different than after rest for each group considered (surgical, injured and control).
2. For control, injured and surgical subjects, the proprioceptive accuracy before fatiguing exercise was not significantly different from that determined after fatiguing exercise.

Recommendations

As a result of the work done on this study, the following recommendations are made:

1. A similar study should be conducted using more angles for the subjects to replicate to see if there are

specific angles or areas in the joint range of motion which might be affected by muscular fatigue. The literature does support the concept that articular mechanoreceptors are unable to provide steady-state position information over most of the working range of a joint. Other receptors may therefore be responsible for proprioceptive input, such as the muscles and their associated muscle spindles throughout a large part of the working range of the joints (Clark & Burgess, 1969, 1975). Thus, muscular fatigue may very well be an important variable influencing muscle spindle input for proprioceptive awareness throughout a considerable amount of the range of the joint.

2. This study should be replicated with a larger sample size and with better control for the knee diagnosis, that is, having all knee injury or surgery subjects with the exact same diagnosis. With greater consistency in knee injury and surgical diagnosis, the results of statistical comparisons may look quite different from those in this study.
3. A similar study should be done with the use of isometric or isotonic fatigue as opposed to isokinetic to see what affect different types of exercise-induced fatigue may have on proprioceptive accuracy.
4. A study similar to the present study could be conducted with the use of only male subjects and repeated with

female subjects to see if there is a difference with regards to sex.

5. A study should be done testing the subjects in a more functional position, such as standing, to see if body orientation may account for proprioceptive accuracy differences.

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APPENDIX A
INFORMED CONSENT

INFORMED CONSENT

YOU, HEREAFTER REFERRED TO AS THE SUBJECT, WILL BE TESTED ACCORDING TO THE FOLLOWING PROCEDURE. THE SUBJECT WILL BE TESTED FOR HIS/HER ABILITY TO REPRODUCE KNEE JOINT ANGLES. THIS WILL BE DONE BY TEACHING THE SUBJECT TWO JOINT ANGLES WHILE ON THE CYBEX II ISOKINETIC DYNAMOMETER. THE SUBJECT WILL THEN BE BLINDFOLDED AND ASKED TO REPRODUCE THE ANGLES TAUGHT. FOLLOWING THIS THE SUBJECT WILL UNDERGO A REST SESSION OR FATIGUING EXERCISE WHICH WILL BE DETERMINED RANDOMLY. AFTER THE REST OR FATIGUING EXERCISE THE SUBJECT WILL AGAIN BE BLINDFOLDED AND ASKED TO REPRODUCE THE KNEE JOINT ANGLES.

THE SUBJECT WILL THEN BE REQUIRED TO RETURN TO THE TESTING SITE BETWEEN 24 TO 48 HOURS FOR THE OTHER TREATMENT (FATIGUE OR REST SESSION). FOLLOWING THE FATIGUING EXERCISE THE SUBJECT MAY EXPERIENCE SOME SORENESS IN THE JOINT AND MUSCLES AROUND THE KNEE. THIS IS A NORMAL REACTION TO FATIGUING EXERCISE AND SHOULD NOT CAUSE ALARM.

BY ALLOWING THE FOLLOWING PROCEDURE TO BE DONE THE SUBJECT WILL PROVIDE THE INVESTIGATOR WITH DATA TO ASSESS THE SUBJECT'S KNEE JOINT PROPRIOCEPTIVE AND KINESTHETIC SENSE (ABILITY TO PERCEIVE KNEE POSITION IN SPACE WITHOUT THE AID OF VISUAL OR VERBAL CUES). THE PROCEDURE WILL BE DONE BY A LICENSED PHYSICAL THERAPIST. THE THERAPIST SHALL BE AUTHORIZED TO REVIEW SURGICAL OR P.T. REPORTS TO OBTAIN AN ACCURATE DIAGNOSIS.

PROJECT TITLE: THE EFFECT OF MUSCLE FATIGUE ON PROPRIOCEPTIVE
ACCURACY FOLLOWING KNEE INJURY.

PRINCIPAL INVESTIGATOR: BRENT GRIFFIN R.P.T.

I, _____, BEING OF SOUND MIND AND _____
YEARS OF AGE, DO HEREBY CONSENT TO, AUTHORIZE AND REQUEST THE
PERSON NAMED ABOVE TO UNDERTAKE AND PERFORM ON ME THE
PROPOSED PROCEDURE, TREATMENT, RESEARCH OR INVESTIGATION
(HEREIN CALLED "PROCEDURE"). I HAVE READ THE ATTACHED
DOCUMENT, AND I HAVE BEEN FULLY ADVISED OF THE NATURE OF THE
PROCEDURE AND THE POSSIBLE RISKS AND COMPLICATIONS INVOLVED
IN IT, ALL OF WHICH RISKS AND COMPLICATIONS I HEREBY ASSUME
VOLUNTARILY. I HEREBY ACKNOWLEDGE THAT NO REPRESENTATIONS,
WARRENTIES, GUARANTEES OR ASSURANCES OF ANY KIND PERTAINING
TO THE PROCEDURE HAVE BEEN MADE TO ME BY THE UNIVERSITY OF
WISCONSIN-LACROSSE, THE OFFICERS, ADMINISTRATION, EMPLOYEES
OR BY ANYONE ACTING ON BEHALF OF ANY OF THEM. I UNDERSTAND
THAT I MAY WITHDRAW FROM THE PROGRAM AT ANY TIME.

SIGNED AT _____ THIS _____ DAY OF
_____, 19___, IN THE PRESENCE OF THE WITNESSES WHOSE
SIGNATURES APPEAR BELOW OPPOSITE MY SIGNATURE.

(SUBJECT) WITNESSED BY:

APPENDIX B
PRELIMINARY QUESTIONNAIRE

PRELIMINARY QUESTIONNAIRE

1. NAME: _____.
2. SEX: M F (CIRCLE)
3. AGE: _____.
4. DATE OF BIRTH: _____.
5. OCCUPATION: _____.
6. DO YOU HAVE ANY KNEE PAIN AT PRESENT? YES _____ NO _____.
7. IF YES WHICH KNEE DO YOU HAVE PAIN IN? RIGHT _____ LEFT _____.
8. WHICH LEG DO YOU CONSIDER YOUR DOMINANT ONE? RIGHT _____
LEFT _____. (FOR EXAMPLE: WHAT LEG WOULD YOU USE MOST
OFTEN TO KICK A BALL?)
9. WHAT WOULD YOU CONSIDER YOUR PHYSICAL ACTIVITY LEVEL AT
WORK TO BE?
 VERY LIGHT _____.
 LIGHT _____.
 MODERATE _____.
 HEAVY _____.
10. WHAT TYPE OF PHYSICAL ACTIVITIES DO YOU PARTICIPATE IN
DURING RECREATION OR SPORT? _____
_____.
11. WHAT DO YOU CONSIDER YOUR PHYSICAL FITNESS LEVEL TO BE?
 EXCELLENT _____.
 GOOD _____.
 FAIR _____.
 LOW _____.
 VERY LOW _____.

APPENDIX C
CLINICAL DIAGNOSTIC SUMMARY
FOR INJURY AND SURGICAL SUBJECTS

CLINICAL DIAGNOSTIC SUMMARY
FOR INJURY AND SURGICAL SUBJECTS

INJURY GROUP	DATE OF INJURY	DIAGNOSIS
SUBJECT 1	1/10/83	2ND DEGREE SPRAIN OF L. M.C.L. (PROBABLE 1ST DEGREE SPRAIN A.C.L.)
SUBJECT 2	2/21/83	LONGSTANDING NICK, TEAR OR ROLL IN LAT. MENISCUS WITH POSSIBLE 1ST DEGREE SPRAIN TO A.C.L.
SUBJECT 3	8/22/83	RIGHT A.C.L. TEAR CHRONIC
SUBJECT 4	10/27/82	CHONDROMALACIA, BURSITIS, SECONDARY TO HYPERFLEXION INJURY
SUBJECT 5	2/1/83	1ST DEGREE MED. COLLATERAL SPRAIN
SUBJECT 6	8/20/83	+1 INSTABILITY OF RIGHT A.C.L., QUAD/HAM WEAKNESS BILATERAL
SUBJECT 7	11/16/83	2ND DEGREE M.C.L. SPRAIN
SUBJECT 8	4/16/83	1ST DEGREE SUBACUTE RIGHT M.C.L. SPRAIN AT PROXIMAL INSERTION
SUBJECT 9	8/23/83	HYPERFLEXION INJURY WITH VALGUS STRESS
SUBJECT 10	1/20/83	1ST DEGREE SPRAIN OF M.C.L. LEFT KNEE
SUBJECT 11	1/30/83	CONTUSION OF LEFT KNEE, NO INSTABILITY
SUBJECT 12	1/31/83	PATELLO-FEMORAL IRRITATION & INFRAPATELLA TENDON STAIN, ILIOTIBIAL BAND FRICTION SYNDROM

SUBJECT 13	12/4/83	1ST DEGREE M.C.L. SPRAIN POSSIBLE MENISCAL INVOLVEMENT
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SUBJECT 14	5/1/83	GASTROC-HAMSTRING STRAIN
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SUBJECT 15	6/20/83	ACUTE PATELLAR SUBLUX.
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SUBJECT 16	9/14/83	LEFT MED. COLLATERAL SPRAIN
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SUBJECT 17	11/14/83	QUAD SPRAIN
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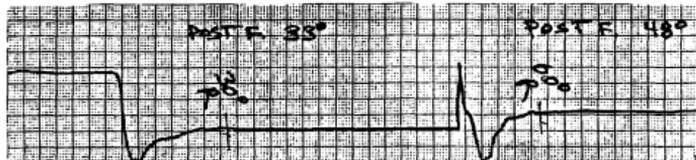
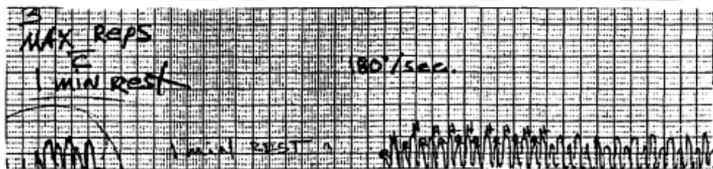
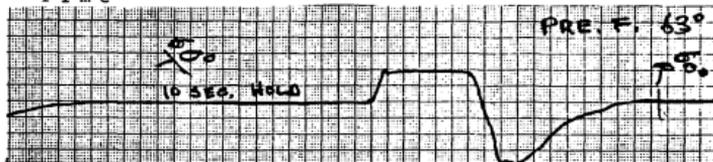
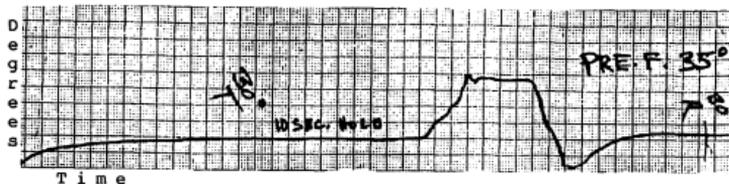
SURGICAL GROUP	DATE OF SURGERY	DIAGNOSIS
SUBJECT 1	10/1/83	ARTHROSCOPE WITH SUBTOTAL MEDIAL MENISCECTOMY
SUBJECT 2	1/19/83	V.M.O. STRAIN & MILD M.C.L. SPRAIN ARTHROSCOPIC SUBTOTAL MEDIAL MENISCECTOMY
SUBJECT 3	6/30/83	RECONSTRUCTION OF A.C.L. MED. & LAT. COLLATERAL LIGAMENT TIGHTING, SHAVED OFF BUCKET HANDLE TEAR OF MENISCUS
SUBJECT 4	8/20/83	POST ARTHROSCOPE WITH PARTIAL TEAR OF A.C.L. WITH MENISCUS INTACT
SUBJECT 5	6/23/83	RECONSTRUCTION OF A.C.L. WITH PREPATELLAR TENDON TENDON GRAFT, ALONG WITH SLOCUM PROCEDURE
SUBJECT 6	11/6/82	A.C.L. REPAIR WITH REINFORCEMENT OF MED. & LAT. ASPECT
SUBJECT 7	12/27/82	LAT. MENISCECTOMY WITH MILD CHONDROMALACIA AT SUPERIOR ASPECT OF PATELLA

SUBJECT 8	11/1/82	ARTHROSCOPE WITH NO FINDING OF SRUCTURAL DAMAGE
SUBJECT 9	3/14/82	ARTHROSCOPE MENISCECTOMY BUCKET HANDLE TEAR, TORN A.C.L.
SUBJECT 10	3/20/83	ARTHROSCOPE AND PARTIAL MED. MENISCECTOMY AND TORN A.C.L.
SUBJECT 11	WITHDREW FROM STUDY	
SUBJECT 12	5/21/82	LEFT ANT. CRUCIATE REPAIR
SUBJECT 13	6/20/83	PATELLAR TENDON TRANSFER, LAT RELEASE & SCRAPED OFF ARTHRITIS ALL 4 CONDYLES TIBIA AND FEMUR
SUBJECT 14	4/26/83	PARTIAL MED. MENISCECTOMY & RESECTION OF PLICA
SUBJECT 15	7/1/83	LEFT KNEE ARTHROSCOPIC REMOVAL OF PIECE OF LIGAMENT

APPENDIX D
SAMPLE CYBEX RECORD
WITH KNEE JOINT ANGLE MEASUREMENTS

SAMPLE CYBEX RECORD

FATIGUE TREATMENT



SAMPLE CYBEX RECORD

REST TREATMENT

