The effects of joint angle and reliability on knee proprioception

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ABSTRACT

PINCIVERO, D. M., B. BACHMEIER, and A. J. COELHO. The effects of joint angle and reliability on knee proprioception. Med. Sci. Sports Exerc., Vol. 33, No. 10, 2001, pp. 1708–1712. Purpose: The purpose of this study was to examine the reliability and effects of knee angle on the detection and subsequent response to passive knee movement. Methods: Twenty college-aged male and 20 female volunteers were evaluated for proprioception by a newly developed perturbation test. Subjects were in a prone position on an isokinetic chair with their right lower leg attached to a freely moving resistance adapter. The knee was placed in a starting position of 15, 30, or 60 degrees of flexion. While relaxed, the knee was dropped into extension, and the subjects were instructed to "catch their leg" when movement was perceived. Five trials were completed at each angle, in a random order. An electrogoniometer was secured to the lateral portion of the knee in order to measure angular displacement after perturbation in two specific phases: detection (displacement from leg release to movement cessation) and response (displacement from movement cessation to peak knee flexion). A three-factor ANOVA (two repeated factors (knee angle and proprioception phase) and one between factor (gender)) was performed on the average and standard deviation of the five trials for significant main effects and interactions. Results: The results demonstrated a significant phase by angle interaction, and no gender effect. It was shown that at a more extended knee joint position (15 degrees), significantly less knee movement occurred before perception, followed by a greater response, than in a more flexed position (30 and 60 degrees). Conclusion: The major findings of this study suggest that the detection of passive knee movement, and the subsequent voluntary response, may be dependent on joint angle. Considerations of the present method for proprioception assessment are warranted to enhance test-retest reliability. Key Words: KINESTHESIA, HAMSTRINGS, MECHANORECEPTORS, SENSATION, PERCEPTION

Proprioception can be defined as the conscious awareness of limb position and movement, and has given rise to a plethora of investigations aimed primarily at the effects of intervening factors, such as injury, fatigue, and training, on this perception (2,14). Although the functional role of proprioception as a mediator of joint injury and rehabilitation has been hypothesized, little evidence has supported this claim. Furthermore, the vast majority of studies examining proprioception have typically relied on methods involving the detection of passive joint movements at very slow angular velocities (0.1–0.5 degrees/s) (3,5,18), or replication of previously positioned joint angles (4,7). The development of a method to evaluate conscious movement awareness as well as a voluntary response may shed additional light on the importance of this sensory modality.

The conscious awareness of limb movement is mediated by a complex array of afferent input from peripheral muscle, tendon, articular, and skin mechanoreceptors (2,14,16). It has recently been stated that "the relative contribution of these different sensory channels may vary depending on the specific contexts of limb movement" (4). Arguably, one of the most important manifestations of proprioception is the generated motor response after passive joint perturbation. The generation of a motor response will be highly dependent on the relative weighting of the quality, and quantity, of this input as a function of the type of stimulus (i.e., movement) (9). The integration of converging input from centrally generated motor commands, as well as mono- and polysynaptic afferent signals onto homonymous alpha-motoneurons, will ultimately dictate the strength of the response under voluntary conditions. Specifically, changes in knee joint position will alter proprioceptive (afferent) feedback to the central nervous system through changes in ligamentous and capsular structure strain, and increases in musculotendinous tension through stretch (12,13,15). As a result, the perception of joint movement after perturbation, as a function of knee joint angle, may exert a significant influence on the subsequent motor response. The ability to voluntarily counteract a passively induced movement quickly, particularly involving an anterior cruciate ligament protagonist muscle (i.e., the hamstrings), may provide further insight into the mechanisms underlying "proprioceptive acuity." Therefore, the purpose of this study was to examine the reliability and effects of knee angle on the detection and subsequent response to passive knee movement.

MATERIALS AND METHODS

Subject characteristics. Subjects for this study consisted of 20 healthy male (mean age, 24.2 ± 2.7 yr; mean...
height, 178.1 ± 8.8 cm; mean mass, 83.2 ± 8.2 kg) and 20 healthy females (mean age, 25.2 ± 4.5 yr; mean height, 163.1 ± 8.6 cm; mean mass, 63.2 ± 12.5 kg) volunteers. Subjects were excluded from the study if they reported any previous history of musculoskeletal, cardiovascular, pulmonary, neurological, or systemic disease. All subjects provided written informed consent as approved by the Institutional Review Board at Eastern Washington University.

Procedures. To assess knee proprioception, the subjects were asked to lie in a prone position on the Accessory Chair of the Biodex System II Isokinetic Dynamometer (Biodex Medical, Inc., Shirley, NY). The lateral portion of the subject’s knee was visually aligned with the axis of rotation of the resistance adapter of the dynamometer. The lower leg was secured to the resistance adapter by adjustable Velcro straps below the muscle belly of the gastrocnemius muscle. The knee was then passively placed, by one investigator at one of three different starting positions: 15, 30, or 60 degrees of flexion. The investigator aligned the knee position with a standard goniometer (Jamar, Inc., Clifton, NJ) with reference made to the fully extended position as zero. The subjects were continually instructed to fully relax their muscles and to allow the resistance adapter to hold their lower leg in the fixed position. At a random point in time (approximately 5–10 s), the resistance adapter was released from the fixed position (release button on the control panel of the isokinetic dynamometer) and the leg was dropped into extension (Fig. 1). The subjects were instructed to “catch their leg when they feel movement, and to hold it.” The subjects were instructed to hold their leg for approximately 3 s. Before testing, subjects were provided with three familiarization trials at various angles that were randomly chosen. During the testing, the subjects wore a blindfold to remove any visual cues. Headphones were not used in this study, as depression of the button on the control panel of the isokinetic dynamometer did not produce an audible sound. The application of static noise through headphones to the subjects, as used in previous studies, was not used because it was thought that this may have distracted the subjects (22). A total of 15 trials were performed (five trials at each of the three starting knee angles) in a random order. The time in between each trial was approximately 1 min. The right leg of all subjects was tested. While in the prone position, the left leg was placed in a slightly flexed position (approximately 20 degrees) on a support. To address the

KNEE PROPRIOCEPTION AND JOINT ANGLE

Data analysis. The mean and standard deviation values for knee displacement for each phase was calculated for the five trials at each of the three starting knee angles. A three-factor ANOVA (two repeated factors (knee angle and proprioception phase) and one between factor (gender)) was performed on the average of the five trials in order to determine significant main effects and interactions. The average velocity of knee displacement after perturbation (i.e., during the detection phase) was calculated for each subject by dividing the change in displacement (degrees) by the change in time (seconds). A single-factor ANOVA with repeated measures was performed to assess differences in knee velocity after perturbation between the three starting angles. All tests of significance were performed at a preset alpha of $P < 0.05$. Test-retest reliability of mean knee displacement at each angle was determined through calculation of intraclass correlation coefficients (ICC = 2,1) and

FIGURE 1—Stick figure demonstrating subject position and experimental procedure.

FIGURE 2—Example electrogoniometer displacement tracing defining the 1) detection and 2) response phases at starting knee angles of (a) 15 degrees, (b) 30 degrees, and (c) 60 degrees (downward deflection of tracing illustrates knee extension movement).

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FIGURE 3—Mean knee joint displacement (mean ± standard error of mean, N = 40) from starting angles of 15, 30, and 60 degrees of flexion during detection and response phases (significant angle by phase interaction).

their associated standard errors of measurement (SEM) (19,21).

RESULTS

The results of the three-factor ANOVA for the mean displacement values revealed significant phase (F1,38 = 12.73, P = 0.001, $\eta^2 = 0.25, 1-\beta = 0.94$) and angle ($F_{2,76} = 5.84, P = 0.004, \eta^2 = 0.13, 1-\beta = 0.86$) main effects, and a significant phase by angle interaction ($F_{2,76} = 78.75, P < 0.001, \eta^2 = 0.68, 1-\beta = 0.99$). The results revealed no significant phase by gender ($F_{1,38} = 2.57, P = 0.12, \eta^2 = 0.06, 1-\beta = 0.35$), angle by gender ($F_{2,76} = 1.01, P = 0.37, \eta^2 = 0.03, 1-\beta = 0.22$), or phase by angle by gender ($F_{2,76} = 1.05, P = 0.35, \eta^2 = 0.03, 1-\beta = 0.23$) interactions. The significant phase by angle interaction is depicted in Figure 3. These results demonstrate that the shortest detection phase, observed at 15 degrees, was followed by a significantly greater response phase than at the other two knee angles. A shorter detection phase also preceded a significantly greater response phase at 30 degrees, as compared with 60 degrees.

The average velocity of knee displacement after perturbation at each starting knee angle was as follows (mean ± standard deviation): 15 degrees, 26.13 ± 9.47 degrees·s$^{-1}$; 30 degrees, 37.79 ± 9.09 degrees·s$^{-1}$; and 60 degrees, 46.80 ± 15.27 degrees·s$^{-1}$. The results demonstrated a significant overall difference in average knee velocity between the starting joint angles ($F_{2,78} = 66.05, P < 0.001, \eta^2 = 0.63, 1-\beta = 0.99$). Specifically, knee velocity was found to be significantly slowest at a starting angle of 15 degrees ($F_{2,76} = 109.69, P < 0.001, \eta^2 = 0.74, 1-\beta = 0.99$), followed in order by 30 degrees, and fastest at 60 degrees ($F_{2,76} = 21.15, P < 0.001, \eta^2 = 0.35, 1-\beta = 0.99$).

The results for mean knee displacement at each starting angle during each proprioception phase for the 15 subjects participating in the test-retest condition are presented in Table 1. These results demonstrate low test-retest coefficients for the detection phase at all angles, high coefficients for the response phases at 15 and 30 degrees, and a low coefficient at 60 degrees (Table 1).

DISCUSSION

The major findings of this study demonstrate that the perception of passive knee movement is a function of joint position. Specifically, the detection of knee movement occurred with lower joint displacement at a starting knee angle close to terminal extension (15 degrees) than at knee angles closer to midrange (30 and 60 degrees). A significantly greater response after detection was found at 15 degrees than at the other two joint angles. Similarly, detection occurred over a greater range of knee movement, followed by a significantly greater response, at 60 degrees than at 30 degrees. A secondary finding of the present study demonstrated no significant differences in proprioception between males and females, as a function of knee joint angle, proprioception phase, or both, as determined by the three-way factorial analysis.

Proprioception has long been known to be responsible for the detection of joint movement and position, through various mecanoreceptors housed in muscles (muscle spindles), tendons (Golgi tendon organs), skin (e.g., pacinian corpuscles), and articular structures (e.g., Ruffini endings) (10). The perception of joint movement, as assessed in the present study, involves well-understood neural pathways. Afferent signals, generated from mecanoreceptors, ascend through dorsal column nuclei and synapse onto second-order sensory neurons at the level of the medulla (2,14). Decussation of the second-order sensory axons through the medial lemniscus synapse onto thalamic relay nuclei (third-order sensory neurons) that terminate onto respective areas of the somatosensory cortex (13,14). As a result of subject positioning and the direction of knee movement, it can be reasonably speculated that proprioceptive input arose primarily from hamstring muscle stretching, posterior capsule tauntness, and possibly ligament strain. Such an assumption is derived from the response of muscle spindles to stretch as well as enhanced sensitivity of capsular and ligament mecanoreceptors at near terminal ranges of movement (6,11). It could be argued that the observation of the greater motor responses at decreased angles likely have been facilitated from enhanced sensitivity of these sensory terminals.

The results of the present study appear to be supported by others that demonstrated enhanced sensitivity to limb movement near the extremes of joint range of motion. Borsa et al. (5) demonstrated enhanced sensitivity of the knee joint in anterior cruciate ligament deficient athletes at a starting position of 15 degrees moving into knee extension at 0.5 degrees·s$^{-1}$, as compared with movement into flexion, or at a starting angle of 45 degrees of flexion. However, the differences in angular displacement between these variables were found to be much smaller than the differences in the present investigation. Specifically, the mean joint displacement of the 29 subjects before detection at 15 degrees was

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reported to be 0.92 degrees, and 1.10 degrees at a starting position of 45 degrees (5). Even though the present study yielded joint excursion values that were much larger (mean of 9.28 degrees at 15 degrees, and 18.09 degrees at 60 degrees), they support the notion of enhanced proprioceptive acuity at near terminal ranges of joints. Although muscle receptors are considered to be the dominant structures mediating proprioception (15.23), the present experimental design was such that angle specificity was the primary concern. In this manner, the manipulation of knee joint angle resulted in changes in hamstring muscle length, posterior capsule tautness, and ligament strain. This method, therefore, attempted to focus on a “functional” representation of proprioception that typically involves multiple input from afferent sources, and could not, therefore, isolate any particular input stimulus.

Numerous studies have examined joint movement sense as a function of articular injury (3.5.8), surgical reconstruction of ligaments (1.7), rehabilitation (7), and muscle fatigue (17.20). Underscoring the premise of such studies is an assumption of “functionality” of these various proprioception testing procedures to which a limited amount of evidence in the scientific literature presents conflicting findings (3.5). It is important to indicate that the perturbation used in the present study involved knee movement induced by gravity where angular velocity was not constant, resulting in much faster rates of limb displacement than those used in previous studies. The significantly higher angular velocity at the greater starting knee angle (60 degrees) is likely a function of the greater joint displacement that occurred following perturbation. In this context, the constant acceleration caused by gravity of the free-falling limb at the greater knee angles would have resulted in a much higher instantaneous velocity near the terminal portion of the detection phase. As a result, the higher average velocity observed during the 60-degree condition was likely skewed by these naturally higher instantaneous values. It is also important to note that the greater torque imposed by gravity at the lower knee angles may have also exerted a significant effect on the faster movement detection. In noting these biomechanical factors, in addition to the relatively small number of subjects undergoing the retest condition (N = 15), the low reliability coefficients for knee movement detection warrants further consideration if applying these methods. In light of the low test-retest reliability coefficients for the detection phase and the response phase at 60 degrees, application of this particular measure in future studies may be questionable. However, it is important to note that the test-retest errors demonstrate an absolute range of expected variability. Although the principal objectives of the present study did not focus on any temporally mediated factors (e.g., interventions such as training or rehabilitation), future research aimed at this must take into consideration such test-retest variability.

**CONCLUSION**

Evidence presented by this investigation demonstrates that knee movement detection is a function of knee angle. The ability to consciously perceive passive knee movement appears to be enhanced when the joint is near terminal extension and when muscles antagonist to the movement are stretched (i.e., the hamstring muscles). This earlier perception has been shown to facilitate a significantly greater motor response in a more extended knee position than at greater angles. As the present study (in addition to many others) operationally defines proprioception as a conscious awareness of joint movement, its functional relationship to injury mechanics must warrant future attention.

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**TABLE 1. Test-retest descriptive data (means, standard deviations, and standard errors of the mean, N = 15) for mean knee displacement (degrees) during the detection and response phases at starting angles 15, 30, and 60 degrees of flexion.**

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Day 2</th>
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<tbody>
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<td></td>
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<tr>
<td>Detection 30 degrees</td>
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<td>Detection 60 degrees</td>
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<td>Response 30 degrees</td>
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<tr>
<td>Response 60 degrees</td>
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**REFERENCES**

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