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For further information about this article or if you need reprints, please contact:

Dr. Asghar Akbari
Department of Physiotherapy,
Razmejo-Moghadam Central Laboratory,
Ayatoallah Kafami St.,
Zahedan, Iran

Tel/ Fax: (+98541) 3254207

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Comparison of the Effects of Open and Closed Kinematic Chain and Different Target Position on the Knee Joint Position Sense

Fateme Ghiasi and Asghar Akbari

The objective of this study was to compare knee joint position sense in weight bearing position with non weight bearing position and to determine the effects of target position and gender on joint position sense. This interventional cross sectional study was performed in Zahedan university of medical sciences in 2006. Forty-four healthy subjects (22 women and 22 men) were assigned through simple non-probability sampling. With their eyes closed, subjects asked to flex their knee joints in prone position, or flexed their knees in standing, attempting to replicate target angles (45°, 60° and 90° knee flexion). Angle matching error was measured using an electrogoniometer. Outcome was based on relative, absolute and variable errors. Data were analyzed using one way ANOVA, independent t-test and Pearson correlation. Angle matching error was lower in weight bearing position than non-weight bearing position ($p<0.05$). Target position, however, had no effect on angle matching error ($p>0.05$). No significant difference were seen between women and men in angle matching of three target positions ($p>0.05$). The results of this study showed that the subjects were more able to assist identification of the test positions during weight bearing position. Following three tests at approximately 45°, 60° and 90° knee flexion, position sense was found to be significantly more accurate and reliable following the weight bearing position. A larger volume of proprioceptive afferents information may have been derived from sources outside the examined knee and lower extremity.

Key words: Joint position sense, weight bearing, non-weight bearing, target position, angle matching error

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Faculty of Paramedicine, Zahedan University of Medical Sciences, Zahedan, Iran

INTRODUCTION

Proprioception is the sum of kinaesthesia and joint position sense. Kinaesthesia is defined as the awareness of joint movement and is dynamic. Joint position sense is restricted to the awareness of the position of a joint in space and is a static phenomenon (Grob *et al*., 2002; Lephart, 1992). Proprioception can also be defined as the cumulative neural input to the central nervous system from specialized nerve endings called mechanoreceptors. These are located in the joint capsules, ligaments, muscles, tendons and skin. Some of these receptors (for example, Pacinian corpuscles) are stimulated in the initial and terminal stages of the range of movement of joints as well as during rapid changes in velocity and direction (kinaesthesia). On the other hand, the Ruffini end organ-like receptors and Golgi tendon organ-like receptors have been associated with a response to the relative position of muscles and joints (joint position sense). However, in the literature the terms kinaesthesia, joint position sense and proprioception are often used synonymously (Grob *et al*., 2002, Joh; Lephart *et al*., 1997).

Knee joint proprioception is essential to neuro-motor control. Neuro-motor control of the knee involves the coordinated activity of surrounding muscles in particular, the quadriceps (Bennell *et al*., 2003). In recent years, increasing numbers of authors have recommended weight bearing tests of joint position or movement sense. They argue that weight bearing tests are more functional and involve all of the cutaneous, articular and muscular proprioceptors that act in concert during normal daily activities (Andersen *et al*., 1995; Bernier and Perrin, 1998; Kiefer *et al*., 1998). Hsu *et al.* (2006) found that joint proprioceptive inputs play a major role in joint position sense. Somatosensory inputs from weight bearing helped to increase the accuracy of ankle joint repositioning. Since some lower limb functions such as the swing phase of walking are non weight bearing, as are most upper limb functions, there is justification for both non weight bearing and weight bearing proprioceptive assessments. Kramer *et al.* (1997) compared non weight bearing with weight bearing tests of knee proprioception in patients with patello-femoral pain syndrome and asymptomatic individuals. This study did not indicate any clear differences between patello-femoral pain syndrome and asymptomatic subjects in the outcome measures. Callaghan *et al.* (2006) evaluated the effect of patellar taping on the proprioceptive status of patients with patellofemoral pain syndrome. The results showed that application of patellar tape did not enhance and in some cases worsened the joint position sense. Hazneci *et al.* (2005) demonstrated showed that using the isokinetic exercise in rehabilitation protocols of patients with patellofemoral pain syndrome not only improves the knee joint stabilization but also the proprioceptive acuity. Stillman and McMeeken (2001) assessed knee joint position sense in supine lying and in unilateral weight bearing stance. They showed that weight bearing and non weight bearing results were not correlated. One procedure cannot be used to predict results from the others. Also, predominantly unilateral weight bearing stance is often impractical for subjects with limited balance or weight bearing pain. Lonn *et al.* (2000) compared the effects of starting position, target position and various types of limb displacement on angle matching error. Lower repositioning errors occurred with active displacement procedures with compared to passive and with the intermediate starting position with compared to the extreme. Target position, however, had no effect on angle matching error. They recommended that starting position and type of displacement should be considered in interpretations and comparisons of data from clinical studies.

Although several studies comparing non weight bearing with weight bearing knee joint position or movement sense have been published previously, the main aspect of previous knee joint weight bearing studies which justify further research are: First, the obtained results were inconsistent-the authors report smaller errors during weight bearing (Birmingham *et al*., 1998a and b) larger errors during weight bearing (Andersen *et al*., 1995; Kiefer *et al*., 1998; Kramer *et al*., 1997); no significant difference (Taylor *et al*., 1998) and inconsistent differences (Marks *et al*., 1993), second, the previous researches allowed different types and amounts of weight bearing through the examined limb-unilateral standing with hand support (Marks *et al*., 1993); unilateral stance with some support from the opposite foot (Andersen *et al*., 1995; Kiefer *et al*., 1998; Kramer *et al*., 1997); and supine lying with 15 or 21% body weight transmitted through the examined limb (Birmingham *et al*., 1998a, b) and third, joint position sense was not compared between men and women in previous studies. Therefore, the aim of the present study were to compare knee joint position sense actively tested under two separate conditions: (1) prone lying with non weight bearing positioning of the whole limb and (2) standing position with full weight bearing positioning of the whole limbs. We want also to compare knee joint position sense between men and women and three target positions (45, 60, 90° knee flexion). It was hypothesized that error occurring, when subjects attempted to reproduce a criterion angle, in standing position would decrease and target position would effect on angle matching errors.

MATERIALS AND METHODS

Participants: A total of 44 subjects were recruited through simple non-probability sampling. The mean height, weight and Body Mass Index (BMI) of the men was 1.64±0.09 m, 79.1±12.9 kg and 29.3±4.2 kg m^{-2} and that of the women was 1.53±0.06 m, 72.1±10.9 kg and 30.8±4.0 kg m^{-2}, respectively. Subjects were selected according to the following inclusion criteria: (1) non-athlete, (2) age between 20-40 years old, (3) no history of knee pain, knee surgery, neurological and musculoskeletal or lower limb pathology and (4) the right lower limb be dominant (The dominant lower limb is that lower limb is the preferred limb for kicking a ball) (Verhoeven *et al*., 1999a). Subjects were excluded from the study if they had referred pain from the lumbar spine and hip joint. This interventional cross-sectional study was conducted at a Physiotherapy department, Razmejo-Moghadam outpatient's clinic, Zahedan University of Medical Sciences, Zahedan, Iran, in 2006. The purpose of the study and testing protocol to be used were explained to the subjects. The study was approved by the local ethical committee and all subjects gave their written voluntary informed consent before participation.

Procedures: The pilot study performed on ten subjects determined that a total of 44 subjects with confidence at 95% and power at 90% were necessary for each group. A brief questionnaire was used to obtain each subject's history. Knee joint position sense was examined under non weight bearing and bilateral weight bearing test conditions using validated and reliable protocols (Stillman, 2000). Position tests (non weight bearing and bilateral weight bearing) and target position (45, 60, 90° knee flexion) were randomly assigned. Randomization was carried out after the initial examination.

Assessment procedure: Joint position sense, defined clinically as the ability to reproduce joint angles, is one component of proprioception. Active ipsilateral matching is a commonly used and accepted method for measuring joint position test. Therefore, right knee joint position sense was assessed by active tests (Lonn *et al*., 2000; Stillman, 2000).

Non weight bearing joint position test: Participants were prone on a treatment couch with knees extended and the trunk supported (Olsson *et al*., 2004). The subjects moved the lower limb by active contraction at slow angular velocity and stopped when he/she perceived the target angle had been reached. The participant was instructed to hold the knee in the test position for four seconds and to concentrate on 'sensing' the knee position.

Weight bearing joint position test: For the bilateral weight bearing assessment, the feet were shoulder-width apart. For the standing assessments, minimum bilateral hand support was provided for balance. Subjects were requested to attempt to bear approximately equal body weight on both legs (Stillman and McMeeken, 2001). The subject with eyes closed moved the lower limb by active contraction at slow angular velocity and stopped when he/she perceived the target angle had been reached. The participant was instructed to hold the knee in the test position for four seconds and to concentrate on sensing the knee position.

Outcome measures: The angle of the knee in each test and match position was determined using electro-goniometer and knee joint position was observed by examiner. Three dependent variables were calculated for the non weight bearing and weight bearing assessments at each target position:

- **Relative error:** This was defined as the arithmetic difference between the test and response positions. Relative errors represent accuracy with directional bias. If the response position was closer to the starting position than the test position, then this was called an underestimation error and given a negative sign.
- **Absolute error:** this was determined as the difference between the test and response position without reference to whether it constituted under- or overestimation. Accordingly it is represented by a number without any sign. Absolute errors represent accuracy without directional bias.
- **Variable error:** this was defined as the standard deviation from the mean of each set of three relative errors. Variable errors represent the ability of the subjects to consistently sense each set of test positions.

Statistics: Data were analyzed using SPSS 11. Kolmogorov-Smirnov test for normality was performed for all outcome variables. Leaven's test was used for equality of variances. A one-factor analysis of variance was used to compare the results from the three procedures with respect to the relative, absolute and variable errors. Tukey post-hoc analysis was used to examine specific differences. Correlation was calculated using Pearsons' test. The level of significance was set at $p<0.05$. All data are presented as mean±SD.

RESULTS

A total of 44 subjects (10 pilot + 34 main trial subjects) met the inclusion/exclusion criteria and all of them were enrolled in the study. The mean age of women was 21.1±1.4 and that of men was 21.0±1.3. This study lasted for 6 months. The reliability of the chosen method of measuring joint position sense was established in 15 individuals (age 18-25 years) tested on two occasions one week apart. The results demonstrated well to excellent test-retest reliability with Interclass Correlation Coefficients (ICC) ranging from 0.91 to 0.99.

The mean of independent variables was compared between weight bearing position and non weight bearing position to determine the effects of both positions. A comparison of the non weight bearing position revealed significantly larger absolute error in the non weight bearing position at 60° and 90° target position ($p<0.05$). The mean absolute error for 60° and 90° target position in weight bearing position were 3.2±2.1 degree and 4.1±2.9 degree, respectively. Also, the mean absolute error for 60 degree and 90 degree target position in non weight bearing position were 4.6±3.8 degree and 5.5±3.5 degree, respectively. There were no significantly greater absolute errors at the 45° flexion in weight bearing position with compared to non weight bearing position. The mean absolute error for 45° target position in weight bearing position and non weight bearing position were 3.6±2.5 degree and 4.1±2.5 degree, respectively. Table 1 show that there were no significant differences between the subject groups with respect to the relative error for both weight bearing and non weight bearing assessments. However, the 45° of flexion in non weight bearing position produced significantly larger relative errors with compared to weight bearing position. There were no significantly greater variable errors at non weight bearing assessment than weight bearing assessment at three target positions. Table 1 summarizes the test positions and response errors from all subjects. Briefly, the non weight bearing procedures produced positive relative errors (over-estimation), whereas the weight bearing assessments produced negative relative errors (under-estimation).

A comparison of three target positions revealed no significantly absolute error in the non weight bearing position and weight bearing position ($p>0.05$). Target position had no effect on angle matching error (Table 2).

The mean of independent variables was compared between men and women to determine the effects of gender. There were no significantly greater errors at the three target positions in women with compared to men ($p>0.05$) (Table 3).

Finally, the relationship between knee joint position sense and height, weight and BMI score were not significant ($p>0.05$).

Table 1: Comparison of the relative, absolute and variable errors in three target position between weight bearing position with non-weight bearing position. Data are expressed as Means (SD) (N = 44)

Target position	Error	Weight bearing mean (SD) (°)	Non weight bearing mean (SD) (°)	Analysis of variance (p)
45°	Relative errors	0.5(4.4)	3.7(3.0)	0.000*
	Absolute errors	3.6(2.5)	4.1(2.5)	0.39
	Variable errors	0.4(0.4)	0.3(0.2)	0.21
60°	Relative errors	2.0(3.2)	2.1(5.7)	0.92
	Absolute errors	3.2(2.1)	4.6(3.8)	0.02*
	Variable errors	0.2(0.3)	0.2(0.2)	0.59
90°	Relative errors	1.8(4.7)	3.8(5.4)	0.06
	Absolute errors	4.1(2.9)	5.5(3.5)	0.04*
	Variable errors	0.3(0.3)	0.4(0.3)	0.42

*Significantly different from baseline p<0.05

Table 2: Comparison of three target position in weight bearing position and non weight bearing position

Position	Target position (°)	Target position (°)	Analysis of variance (p)*
Weight bearing	45	60	0.67
		90	0.66
	60	45	0.67
		90	0.20
	90	45	0.66
		60	0.20
Non weight bearing	45	60	0.67
		90	0.66
	60	45	0.67
		90	0.20
	90	45	0.66
		60	0.20

*Non-significant

Table 3: Comparison of the relative, absolute and variable errors between men (N = 22) with women (N = 22) in three target position and in both weight bearing and non-weight bearing position. Data are expressed as Means (SD)

Position test	Target position (°)	Error	Men mean (SD) (°)	Women mean (SD) (°)	Analysis of variance (p)*
Weight bearing	45	Relative errors	1.0(3.2)	8.6(5.4)	0.49
		Absolute errors	3.0(1.4)	4.3(3.1)	0.08
		Variable errors	0.4(0.5)	0.3(0.3)	0.56
	60	Relative errors	1.0(3.8)	3.0(2.1)	0.04
		Absolute errors	3.0(2.5)	3.3(1.6)	0.64
		Variable errors	0.2(0.3)	0.3(0.4)	0.16
	90	Relative errors	1.7(4.2)	1.8(5.3)	0.94
		Absolute errors	3.7(2.5)	4.5(3.2)	0.35
		Variable errors	0.3(0.3)	0.3(0.2)	0.92
Non weight bearing	45	Relative errors	1.0(3.2)	8.6(5.4)	0.11
		Absolute errors	3.7(2.4)	4.4(2.6)	0.34
		Variable errors	0.3(0.2)	0.2(0.2)	0.79
	60	Relative errors	1.0(3.8)	3.0(2.1)	0.74
		Absolute errors	5.6(3.8)	3.7(3.6)	0.08
		Variable errors	0.2(0.2)	0.2(0.2)	0.55
	90	Relative errors	1.7(4.2)	1.8(5.3)	0.79
		Absolute errors	5.1(3.7)	5.9(3.4)	0.45
		Variable errors	0.3(0.3)	0.4(0.4)	0.34

* Non-significant

DISCUSSION

The results showed that non weight bearing position revealed significantly larger absolute errors than the weight bearing position. The weight bearing assessments in the present study produced results which were significantly more accurate (in absolute terms) and more reliable than one of the non weight bearing procedures. Comparing the mean of absolute errors in weight bearing and non weight bearing did not show a significant difference between men and female. Also, there were no significantly differences at the three target position regarding absolute errors. The major finding was that weight bearing position had effect on angle matching error. Angle matching error was decreased in Weight bearing position with compared to non weight bearing position.

The non weight bearing knee repositioning procedure had the greatest potential for revealing the proprioceptive status of (only) the knee because it involved no resistance or weight bearing of or through adjacent joints (Lonn *et al*., 2000). Active limb movement to and from test positions is unavoidable in the weight bearing procedure, hence there was a greater potential for the standing subjects to use movement cues. On the one hand a simple active movement to a test position is arguably more functional because it corresponds to the usual circumstances of everyday proprioceptive function (Stillman and McMeeken, 2001). In the weight bearing procedure there was a relatively strong linear correlation between the concurrent hip and knee movements (R^2 = 0.69) and although the subjects were instructed otherwise, they could have reproduced the knee test positions by sensing and reproducing the hip movement. In contrast with the hip, there was no significant correlation between the ankle and knee position during either the non weight bearing (R^2 = 0.05) and weight bearing (R^2 = 0.09) limb repositioning procedures, hence substitution of ankle for knee repositioning seems unlikely (Stillman and McMeeken, 2001). Whole limb positioning also provides the opportunity for proprioceptive feedback from adjacent joints. Conceivably, the sensory regions of the cerebral cortex may aggregate this information in deciphering the location of the knee. Some previous human and animal studies of concurrent limb joint movements support this proposition (Abelew *et al*., 2000; Cordo *et al*., 1995; Verschueren *et al*., 1999b). A similar contribution to locating the knee joint position may stem from the skin of the weight bearing foot (Kavounoudias *et al*., 1998). In standing, proprioceptive information may be received through the compression of musculoskeletal structures in and about the knee and other joints throughout the weight bearing limb(s). Proprioceptive feedback may also be received from the compressed skin and subcutaneous structures of the sole of the weight bearing foot (Kavounoudias *et al*., 1998). Weight bearing may augment the afferent discharge from compressed mechanoreceptors in connective tissue structures distributed throughout the weight bearing joints (Stillman and McMeeken, 2001). Also, because of the foot dorsiflexion during both limb repositioning procedures, there is the possibility that calf (especially gastrocnemius) stretch may also be influential (Refshauge and Fitzpatrick, 1995). The finding in the present study of smaller absolute errors during the weight bearing as compared with the non weight bearing limb repositioning procedure tends to support this view.

In a specific study of weight bearing versus non weight bearing procedures, Refshauge and Fitzpatrick

(1995) examined the threshold for detection of low velocity passive ankle movements. With the knees straight and the feet dorsiflexed in weight bearing standing compared to the same joint positioning in non weight bearing sitting, no significant difference was found between the two sets of results. However, when the knees were flexed in non weight bearing sitting, the perception threshold increased approximately twofold. Refshauge and Fitzpatrick (1995) concluded that the foot and knee postures, including calf stretch, were the major determinants of the weight bearing test results and not weight bearing as such. The weight bearing procedure of the present study would also have involved calf stretch than the non weight bearing limb repositioning procedure. Thus, although the results from the present study are not conclusive, they do not contradict the findings of Refshauge and Fitzpatrick (1995). Nade *et al.* (1987) and Burke *et al.* (1988) showed that the proprioceptive afferent output from capsular, ligamentous and muscular mechanoreceptors increases exponentially as these structures are lengthened. Thus, even in normal joints proprioception might become more acute as the articular and surrounding structures are progressively tightened. Loudon (2000) used protractor goniometry to measure knee extension in standing subjects. Position sense was then tested actively with the subjects lying supine, using a device which transmitted an estimated 30% body weight through the limb. At test angles between 10° and 60° flexion, absolute errors were greater in the group whose standing knee extension exceeded 5° beyond straight. A weak positive linear correlation ($R^2 = 0.23$) was also demonstrated between knee mobility and absolute position sense following the tests at 10° flexion. The different results may signify that perhaps the subjects in the study by Loudon (2000) had different types of movement (knee extension) and different amounts of weight bearing (30%) and different position (supine). Kramer *et al.* (1997), using both active non weight bearing tests and uni-lateral weight bearing tests, found no significant differences between the results from 24 subjects with bi-lateral patello-femoral pain syndrome and gender-matched control subjects. Their protocol included one repetition at four separate test angles that were averaged to produce a single (absolute) error measurement. By measuring only once at each of a number of widely spaced test angles, the resulting average is likely to be highly variable thus potentially masking any abnormality when compared to controls. Furthermore, their non-significant results may also reflect failure to have considered relative and variable errors. Stillman and Mc Meeken (2001) was assessed knee joint position sense by active tests with active limb matching responses in supine lying and in unilateral weight bearing stance using (re) positioning of the whole limb whilst focusing on the knee and in supine lying using (re) positioning confined to the knee. Position sense was found to be significantly more accurate and reliable following the weight bearing procedure.

There are other possible explanations for the differences, including the relatively greater and differently distributed muscular resistances in standing. The weight bearing procedure was associated with greater (body weight) resistance of muscles throughout the lower limb than the (limb weight) resisted non weight bearing limb repositioning procedure. Even less (leg-weight quadriceps) resistance was involved in the non weight bearing knee repositioning. On the one hand, even the slightest resistance substantially increases the afferent output from muscle spindles (Wilson *et al*., 1997). Thus, at present it can only be hypothesized that differences in the magnitude and distribution of resisted muscle contractions might affect weight bearing versus non weight bearing results.

All subjects in the present study required at least minimal bilateral fingertip support, in order to maintain stable test in bilateral weight bearing stance. Clapp and Wing (1999) and Rabin *et al.* (1999) demonstrated that even fingertip contact insufficient to constitute physical support significantly diminishes sway in unilateral and bilateral stance with eyes closed. They proposed that this arose from proprioceptive feedback from skin of the supporting fingertips and joints within the supporting limbs. The same mechanism probably applies if balance is maintained by light contra-lateral floor contact as in the weight bearing tests of Andersen *et al.* (1995). These findings showed that there were no significantly greater errors at the three target position in women compared to men. Rozzi *et al.* (1999) found that women had increased knee mobility and reduced position sense compared to men. The reduced position sense in women group may signify that perhaps the women in the study had general hypermobility. Although, Huston and Wojtys (1996) did not directly compare knee mobility with position sense, but not their finding of reduced knee position sense in women.

Present results indicated that active knee joint position sense assessments in weight bearing with eyes closed produced more accurate and reliable results than non weight bearing assessments in prone lying. Although weight bearing assessments are more functional, they may not represent a valid or reliable measure of joint position sense at any individual lower limb joint. This study did not reveal any association between proprioception and pain or disability in subjects with and without knee pathology. Further studies are required to demonstrate the relationship between pain and disability with joint position sense and role of proprioception training in the clinical assessment of joint position sense.

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