Scand J Rehab Med 27: 161–167, 1995

SENSORY CHANGES ASSOCIATED WITH SEVERE ANKLE SPRAIN

Joanne E. Bullock-Saxton, PhD., B.Phty

From the Department of Physiotherapy, The University of Queensland, St. Lucia, Australia

ABSTRACT. An intact afferent nervous system is important in providing the feedback necessary for effective motor control. Joint injury may influence afferent feedback and, if the lower limb is involved, lead to a decrease in stability. Accordingly, the association between severe ankle sprain and local sensory deficit was examined. Measurements of vibration perception, two point discrimination and balance in one legged standing were made in subjects who had sustained a previous severe unilateral ankle sprain and in subjects with no history of lower limb injury. Comparisons between the two groups showed that subjects with previous severe ankle sprain had sensory deficits in all measured variables between the injured and non-injured sides. Such differences between sides was not apparent in the non-injured group. This study highlights that local sensory deficits are associated with severe ankle sprain.

Key words: ankle sprain, afferent sensation, vibration perception, two point discrimination, balance.

Ankle sprain, involving ligamentous and/or capsular injury is relatively common in people of all ages. Ankle instability and consequential recurrence of ankle sprain appears to be not uncommon. Indeed, in a survey of 265 patients with ankle sprain, 22% were found to have experienced a later ankle sprain on the second side, while 47% suffered further ankle sprains on the same side (2).

An intact sensory motor system is important for movement control and co-ordination and the existence of a complicated feedback system between muscles and joints and the central nervous system is well recognised. Previous research has highlighted the importance of feedback from capsular and ligamentous mechano-receptors to the reflex stabilisation of the joint (5, 6, 7), perception of joint position and movement (24), muscle activation (17), and the control of the gamma muscle spindle system (11) influencing the stability of the joint. These articular sensory receptors, or mechano receptors, are located within joint capsules, ligaments and joint structures and are considered damaged during joint injury (15).

Freeman et al. (6) have proposed that the basic mechanism of ankle instability following injury develops due to the lesion of mechano-receptors in the joint capsule and ligaments and that these endings are stimulated both by the static position and by motion of the joint. Freeman (5) has also suggested that the afferent nerve fibres in the capsule and ligaments of the foot and ankle subserve reflexes which help to stabilise the foot during locomotion, that a sprained ankle can be considered as a partial deafferented joint and that the "clumsiness" or "give-way foot" is a result of impaired reflex stabilisation of the foot.

The wider ramifications for limb movement of single joint injuries have been stressed by Wyke (24) who stated that "interruption of the flow of impulses from the mechano-receptors in a joint capsule into the central nervous system should result in clinically evident disturbances of perception of joint position and movement and of the reflexes concerned with posture and gait". The impairment of balance and the loss of a smooth, co-ordinated gait pattern following ankle sprain are features often observed clinically and they have implications for therapeutic management.

It is apparent that changes in the sensory input can cause alterations in muscle function. The likelihood that changes in sensory information contribute to damage or degeneration of a joint has also been supported (1). The role of proprioceptive information in the initiation and progression of joint disease is suggested by Barrett and coworkers' (1) research of joint position sense in people with and without joint degeneration. The possible effects of sensory deficits on joint degeneration and altered muscle function support the need to learn more about the relationship of sensory deficits and joint damage.

Table I. *The incidence and cause of injury*

Trauma	Obstacle course	Running/football	Jumping from a height to unknown surface	Walking on uneven ground
3	5	8	3	1

When considering a sprained ankle, it is reasonable to assume that a complete rupture, or repeated ruptures of the talo-fibular ligament would result in damage to the receptors in the ligament and capsule, and that such damage would be likely to influence the afferent input from that region (15). The problems associated with recurrence of injury are considerable. Little has been reported which can explain causation, although Glencross & Thornton (8) have pointed out that even months after injury, foot functioning during skilled activities is likely to be inadequate due to distortion of proprioceptive signals. The nature of any sensory function deficit which may be associated with joint injury needs to be understood. Such information would provide a basis for the development of appropriate preventative and therapeutic programmes which could be instituted to control repeated injury incidence.

A number of variables may be used for assessment of sensory function. Vibration perception, assessed at frequency intervals of 50 Hz between 50 and 450 Hz, and two point discrimination have been considered to provide sensitive measures of sensory perception. Vibration perception combines both superficial and deep sensations from joint mechano-receptors as well as the intact function of cortical sensory association areas (16) and it is a sensation which is vulnerable to change. It is likely that capsular tears, rupture of small nerve branches and joint oedema following ankle sprain could cause alterations of discharge from mechano-receptors, such as Pacinian corpuscles sensitive to vibration stimuli (23). Vibration perception at various frequencies can be measured sensitively by a mechanical oscillator connected to a power oscillator, for which voltage and thus amplitude of the oscillator head can be progressively increased (2).

Testing two point discrimination would address the extent of changes in perception to some other afferent stimuli (e.g. cutaneous receptors) following a period of pain (3, 9, 14) associated with damage to ligamentous and capsular receptors.

Postural stability in standing on one leg has been shown to be significantly decreased in untrained subjects following ankle sprain (18) and evaluates the capacity of proprioceptors to monitor peripheral change.

To shed more light on the effect of ligamentous/capsular injury on the sensory system, an experimental study was carried out, in which the differences in sensory perception and the integrity of the sensory motor system between the injured and uninjured sides of subjects with unilateral ankle sprain were compared with the side-to-side differences in a matched control group.

MATERIALS AND METHODS

For this study, the injured group (I) comprised 20 men aged between 18 and 35 years, who had sustained a unilateral severe ankle injury (grade II^+ and or III) which was severe enough to have caused pain, marked swelling at the time of injury and moderate anterior draw signs indicating a tear to the lateral ligaments of the ankle. All injured subjects were assessed no sooner than 2 months and no later than 18 months post injury to allow healing and the oedema and pain associated with trauma to subside. As far as possible, only those subjects whose cause of injury appeared to have been related to a traumatic incident were included in the study. The incidence of particular causes is shown in Table I. Subjects were excluded if they were still experiencing pain in the ankle during walking at the time of testing, or if they had had a significant injury to any other lower limb joint either on the side of the sprain or on the non-injured side. For this project 361 potential subjects were screened to meet these criteria listed.

Eleven men, matched as closely as possible for age, height and weight and who had no history of musculoskeletal injury to the lower limbs or neurological disorder comprised the control group (C). In addition to the criteria outlined above, subjects were included in the study only if they showed no history of diabetes or of clumsiness or inco-ordination.

Measurements

For each subject, measures of vibration perception, two point discrimination and balance in one legged standing were taken.

In each case, the order of limbs tested was selected randomly. The same researcher conducted all tests.

Vibration perception. For vibration perception measurement it is desirable to ensure that frequency and amplitude of vibration can be varied, a consistent pressure of application be maintained throughout the entire experiment, and that the subject is alert and co-operative. In clinical testing with tuning forks at 120 and 250 Hz, most of these criteria cannot be adequately satisfied.

To meet the requirements of this study, a mechanical oscillator connected to a power oscillator was used. This allows variation of both frequency and voltage, the latter being directly related to the amplitude of displacement of the oscillator head. The suspension of the oscillator from one end of a system of pulleys and of a mass of equal weight from the other as a counter balance ensured a constant pressure of the device on the subject's skin (Fig. 1*a*).

With the subject lying on the untested side, the tested leg was secured in a lower leg rigid support to control the degree of ankle dorsi-flexion, and placed on a higher density foam cushion. The oscillator was suspended directly over and so that it just touched a marked point on the lateral malleolus (Fig. 1*b*). The weight on the counter balance was then reduced by 50 gm, so that the head of the oscillator made contact with the fibular head with an applied force of 50 gm by gravity. Its position was monitored throughout the series of tests.

Vibration sense was assessed at a range of frequencies between 50 and 450 Hz at 50 Hz intervals. It was considered important to assess frequencies either side of 250 Hz, as previous research (12, 21, 23) has indicated vibration perception threshold to be most sensitive in this range. In each case, the amplitude of the oscillator was increased slowly until the subject stated that he perceived vibration, and this point was recorded as the vibration perception threshold (VPT) (10). This procedure was followed twice at each frequency level on the fibular heads of both lower limbs, a systematic order of rotation being used for testing of sides and presentation of frequencies.

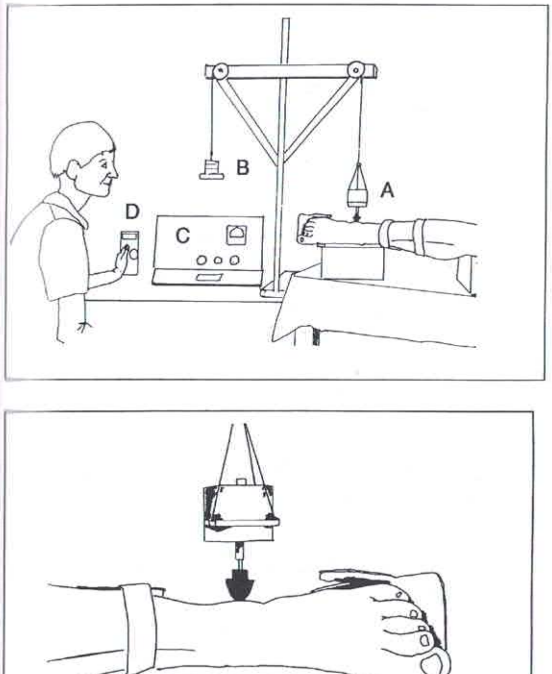

Fig. 1. (*a*) Subject and equipment positioning for Vibration Perception Testing. A = Mechanical oscillator, B = Counter balance weights, C = Power oscillator, D = Voltmeter. (*b*) Application of the mechano-oscillator to the inferior fibular head, and the stabilisation of the lower limb.

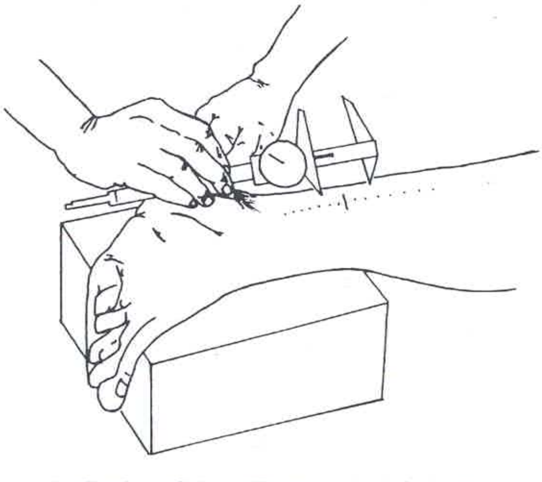

Fig. 2. Application of the callipers to the inferior lateral aspect of the lower limb.

As an initial experiment, to determine whether a person's VPT at each frequency is consistent, a repeatability test was carried out in which 10 repeated measures of vibration perception for each frequency were recorded.

Two point discrimination. Two point discrimination was measured using a set of dial callipers accurate at 0.1 mm (Fig. 2). These had two pointed ends which could be positioned a variable distance apart. Using the approach of other researchers (13), a leg area relevant to the site of injury was selected for testing, i.e. the distal end of the lateral aspect of each lower limb. With the subject in side lying, the skin was marked at a point 60 mm from the lateral malleolus, on a line running along the fibula. This represented the centre of the two point discrimination test. The subject, who kept the eyes closed, was instructed to tell the assessor if two or one points could be felt. To ensure that the subject could initially determine two points easily, the examiner started with a large separation between the two points of the calliper ends, calculated to be greater than the average distance plus one standard deviation for two point discrimination on the lower limb recorded in the literature (16). This gap was progressively reduced for each contact, when the subject perceived only one point instead of the two, the gap (measured in mm) was determined as the "threshold".

Balance in one legged standing. Some researchers concerned with standing balance on one leg have used a force platform to obtain quantitative measures of stability (18, 20). However, in this experiment it was considered preferable and sufficient to record the period (in seconds) for which the subject could stand on either leg with eyes closed, as the interest was in side-to-side differences in the ability to maintain balance in one-legged standing rather than on patterns of balance. The subjects were asked to stand with arms crossed in front of their chests, to raise one leg so that hip and knee were each in 90° of flexion and to close their eyes. They were told in advance that they were not to hop on or move the supporting leg, nor rotate their flexed leg over

Table II. *Mean vibration perception thresholds (VPT) for groups C and I at a range of frequencies*
Control (C) $n = 11$ (left and right sides)
Injured (I) $n = 20$ (injured and uninjured sides) (m/s2)

Frequency Hz	Control group (C)		Mean difference L-R
	Mean of left side	Mean of right side	
50	0.936	0.792	0.144NS
100	0.395	0.399	−0.004NS
150	0.299	0.317	−0.018NS
200	1.051	0.495	0.556*
250	1.664	0.978	0.686NS
300	2.177	2.300	−0.123NS
350	3.613	3.269	0.344NS
400	5.064	4.310	0.754NS
450	5.713	5.513	0.200NS

Frequency Hz	Injured group I		Mean difference of injured-uninjured sides
	Mean of injured side	Mean of uninjured side	
50	1.310	1.270	0.04
100	0.867	0.824	0.043
150	1.400	0.918	0.482*
200	2.243	1.273	0.970*
250	3.924	2.324	1.600*
300	6.299	4.133	2.166*
350	9.965	3.588	6.377*
400	17.508	5.962	11.546*
450	21.119	8.614	12.505*

* Significantly different ($p < 0.0005$).

their supporting leg to maintain balance. Subjects were informed that as soon as they felt that they were about to lose their balance they should place their flexed leg on the floor. The researcher recorded with a stop watch the period of time between the subject's assuming the starting position and lowering the flexed leg. This procedure was repeated five times on each leg with a short period of rest between trials. The two longest balance times recorded for each leg were used for analysis.

Analyses

An analysis of variance for unequal numbers, the general linear model (GLM) was applied to each set of data to determine the influence of injury on sensory perception. For each sensory assessment, and for vibration at each frequency, two measures were used for the statistical analysis, providing an estimate of error between repeated measures.

RESULTS

Vibration perception

Vibration perception was assessed in terms of the strength of vibration necessary for the subject to perceive the vibration stimulus and this was directly related to the acceleration (m/s2) of the vibration head, which was altered with each change of voltage.

For the initial repeatability test, the analysis of results showed that the mean confidence interval limits and the standard deviations of the "within-subject-between-replication" variable for each frequency were within the same range. This indicated that for normal subjects and for those with previous ankle injury, the VPT at each frequency was repeatable and consistent.

Data acquired for groups I and C were subjected to statistical analyses.

Table II provides a comparison between the two groups, of the mean levels of vibration strength necessary for perception on each side, as well as the mean side-to-side differences at each of the 9 frequencies. As Table II shows, for group C, a significant difference between sides existed only at 200 Hz. However, for group I, significant differences between injured and uninjured sides existed at 7 of the 9 frequencies, the exceptions being at 50 and 100 Hz.

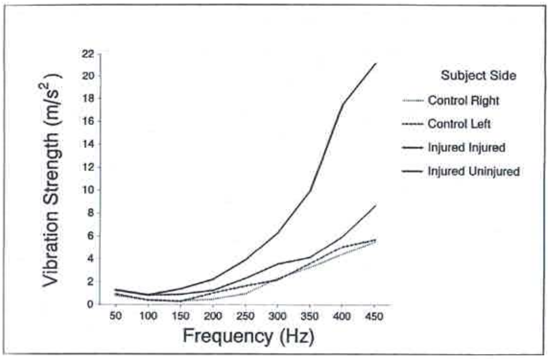

Fig. 3. Graph of frequency Vs vibration for both sides of C and I.

As Fig. 3 illustrates, while there was no apparent relationship between frequency and vibration perception at the low frequencies of 50–150 Hz for either group I or group C, from 150–450 Hz, there was a positive relationship between frequency and threshold vibration perception for both groups, that is, the higher the frequency, the lower the level of perception (or the greater the strength of vibration necessary for perception).

However, the consistent level of change evident on both sides of group C was not reflected in the uninjured side of group I, where a more marked increase in vibration strength was required for perception at the highest frequencies.

Examination of the means of threshold perception for each of the two sides of group I revealed that at every frequency, a greater strength of vibration was necessary on the injured side to reach the threshold of perception. The difference in perception between the two sides became increasingly more marked, the higher the frequency, as Table II and Fig. 3 illustrate.

The application of a Student's *t*-test revealed that significant differences between the side-to-side differences for groups C and I occurred at frequencies of 150–450 Hz ($p < 0.05$).

Table III. *Two point discrimination perception for groups C and I*

Control (C) $n = 11$ (left and right sides)
Injured (I) $n = 20$ (injured and uninjured sides) (mm)

Group C			Group I		
$\bar{x}$L	$\bar{x}$R	$\bar{x}$L-$\bar{x}$R	$\bar{x}$I	$\bar{x}$U	$\bar{x}$I-$\bar{x}$U
57.3	56.9	0.4NS	65.6	58.3	7.3*

* $p < 0.0005$.

Table IV. *Balance in one legged standing for groups C and I*

Control (C) $n = 11$ (left and right sides)
Injured (I) $n = 20$ (injured and uninjured sides) (seconds)
L = Left; R = Right; I = Injured; U = Uninjured

Group C			Group I		
$\bar{x}$L	$\bar{x}$R	$\bar{x}$L-xR	$\bar{x}$I	$\bar{x}$U	$\bar{x}$I-$\bar{x}$U
21.9	23.9	2.0NS	15.9	21.6	5.7*

* $p < 0.05$.

Two point discrimination

A comparison of the left–right differences for two point discrimination of group C and the injured–uninjured differences of group I revealed that whereas for group C, in whom there were no significant differences between sides, for group I, significant differences existed, as shown in Table III. It can be seen that the ability to discriminate between two points was considerably less on the injured side of group I. A Student's *t*-test determined that there was a significant difference ($p < 0.05$) between the side-to-side differences of groups C and I.

Balance in one legged standing

In one legged standing test of sensory integration, the time for which the subject could stand on each leg in turn was recorded. Table IV presents the means of those times for groups C and I. Analysis showed that significant differences existed between injured and uninjured sides of group I, where time spent in standing on one leg was 5.7 seconds less on the injured side than on the uninjured side. In contrast, the difference of 2.0 seconds between left and right sides for group C did not reach significance.

DISCUSSION

The results of tests for sensory function demonstrated that in subjects of the control group (C), apart from a significant side-to-side difference at a vibration frequency of 200 Hz there was no significant difference between sides for vibration perception, two point discrimination or balance in one legged standing. The results of the tests for vibration perception and two point discrimination for the injured group revealed a significant deficit in sensory perception on the injured side. The ability to maintain balance on one leg was also significantly impaired on the side of injury in this group, implying some loss of integrity of the sensory motor system.

Such results confirm the assumption that a ligamentous/capsular injury is associated with significant deficits in local sensory receptor function. The question of whether subjects in group I had a basic neurological deficit which contributed to their ankle sprain may well be asked. Certainly other authors have raised the possibility of a "predisposition" to injury (19).

Initial screening of subjects was aimed at ensuring that those included in the study had no history of incoordination and it has been assumed that the differences in group I from group C occurred as a result of injury. Nevertheless, it is appreciated that the origin of differences cannot be determined conclusively in a retrospective study. The question of cause and effect can only be answered in a prospective study and this is presently in progress. Regardless of the origin of deficits, the existence of a deficit in sensory function on both the injured and uninjured limbs in patients with unilateral severe ankle injury demands that the clinician pay due attention to its improvement. The result also has implications for the use of a non-injured limb as an internal control for future experimental data acquisition.

The likelihood that a sensory deficit may be associated with muscle function changes and with further joint damage, as suggested by earlier mentioned research (1, 5–8, 17–20) highlights the importance of normalising afferent input from a joint. It is possible that the rehabilitation of muscle function and co-ordinated activity about a joint may not be complete until this has been done.

CONCLUSIONS

The measurements of vibration perception, two point discrimination and balance in one-legged standing in subjects who had previously sustained a severe, unilateral ankle injury, have revealed significant differences between the injured and uninjured sides of subjects in the experimental group. The fact that the side-to-side differences in the experimental and control groups were significantly different, suggests that sensory changes are consequential on ankle injury. In view of the likely effect on the afferent system and the interference with the feedback process, motor control is likely to be affected in such circumstances. It is important, therefore, that such deficits in sensation and in sensory integration be addressed by the physiotherapist. Such a focus could help to prevent the ankle instability and recurrence of ankle sprain which has been observed so often, clinically.

ACKNOWLEDGEMENT

Thanks are extended to The Australian Defence Forces for providing access to their members as subjects for this study.

REFERENCES

1. Barrett, D. S., Cobb, A. G. & Bentley, G.: Joint proprioception in normal, osteoarthritic and replaced knees. J Bone Joint Surg [Br] *73:* 53–56, 1991.
2. Bullock-Saxton, J. E.: Changes in remote muscle function and local sensation following joint injury. PhD. Thesis. The University of Queensland, 1992.
3. Coderre, T. J. & Melzack, R.: Cutaneous hyperalgesia: contributions of the peripheral and central nervous system to the increase in pain sensitivity after injury. Brain Res *404:* 95–106, 1987.
4. Dyck, P. J., Karnes, J., O'Brien, P. C. & Zimmerman, I. R.: Detection thresholds of cutaneous sensation in humans. *In* Peripheral Neuropathy, Vol 1 (ed. P. J. Dyck, P. K. Thomas & E. H. Lambert), 2nd Ed., Saunders, Sydney, 1103–1138, 1984.
5. Freeman, M. A. R.: Instability of the foot after injuries to the lateral ligament of the ankle. J Bone Joint Surg [Br] *47:* 669–677, 1965.
6. Freeman, M. A. R., Dean, M. R. E. & Hanham, I. W. F.: The aetiology and prevention of functional instability of the foot. J Bone Joint Surg [Br] *47:* 678–685, 1965.
7. Freeman, M. A. R. & Wyke, B.: Articular contributions to limb muscle reflexes. Br J Surg *53:* 61–68, 1966.
8. Glencross, D. & Thornton, E.: Position sense following joint injury. J Sport Med *21:* 23–27, 1981.
9. Grubb, B. D., Stiller, R. U. & Schaible, H.-G.: Dynamic changes in the receptive field properties of spinal cord neurons with ankle input in rats with chronic unilateral inflammation in the ankle region. Exp Brain Res *92:* 441–452, 1993.
10. Goldberg, J. M. & Lindblom, U.: Standardised methods of determining vibratory perception thresholds for diagnosis and screening in neurological investigation. J Neurol Neurosurg Psychiatry *42:* 793–803, 1979.
11. Johansson, H., Sjölander, P. & Sojka, P.: Receptors in the knee joint ligaments and their role in the biomechanics of the joint. Biomed Eng *18:* 341–368, 1991.
12. Mountcastle, V. B., Lamott, R. H. & Giancarlo, C.: Detection thresholds for stimuli in humans and monkeys: comparison with threshold events in mechanoreceptive afferent nerve fibres innervating the monkey hand. J Neurophysiol *35:* 122–136, 1972.
13. Nolan, M. F.: Clinical assessment of cutaneous sensory function. Clin Management Phys Ther *4:* 26, 1984.
14. Roberts, W. J.: A hypothesis on the physiological basis for causalgia and related pains. Pain *24:* 297–311, 1986.
15. Shutte, M. J. & Happel, L. T.: Joint innervation in joint injury. Clin Sports Med *9:* 511–517, 1990.

16. Schmitz, T. J.: Sensory assessment. In Physical Rehabilitation: Assessment and Treatment (eds. S. B. O'Sullivan & T. J. Schmitz), 2nd Ed., FA Davis Co., Philadelphia, 1988.
17. Stokes, M. & Young, A.: The contribution of reflex inhibition to arthrogenous muscle weakness. Clin Sci *67:* 7–14, 1984.
18. Tropp, H.: Stabilometry in functional instability of the ankle. Med Sci Sports Exerc *16:* 64–66, 1984.
19. Tropp, H., Odenrick, P. & Gillquist, J.: Stabilometry recordings in functional and mechanical instability of the ankle joint. Int J Sports Med *6:* 180–182, 1985.
20. Tropp, H.: Stabilometry for studying postural control and compensation in vertigo of central and peripheral origin. Electromyogr Clin Neurophysiol *27:* 77–82, 1987.
21. Talbot, W. H., Darian-Smith, I., Kornhuber, H. H. & Mountcastle, V. B.: The sense of flutter vibration: comparison of the human capacity with response patterns of mechanoreceptive afferents from the monkey hand. J Neurophysiol *31:* 301–334, 1968.
22. Van Der Graff, K. M.: Human Anatomy, 2nd ed. WM C Brown Publishers, Dubuque, 1988.
23. Verillo, R. T.: Vibrotactile sensitivity and the frequency response of the pacinian corpuscle. Psychonomic Sci *4:* 135–136, 1966.
24. Wyke, B.: The neurology of joints. Ann R Coll Surg Eng *41:* 25–50, 1967.

Address for offprints:

Dr. Joanne E. Bullock-Saxton, PhD, B.Phty
Lecturer
Department of Physiotherapy
The University of Queensland, St. Lucia
Queensland, 4072
Australia