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THE SENSATION OF PASSIVE MOVEMENT AT THE METATARSO-PHALANGEAL JOINT OF THE GREAT TOE IN MAN

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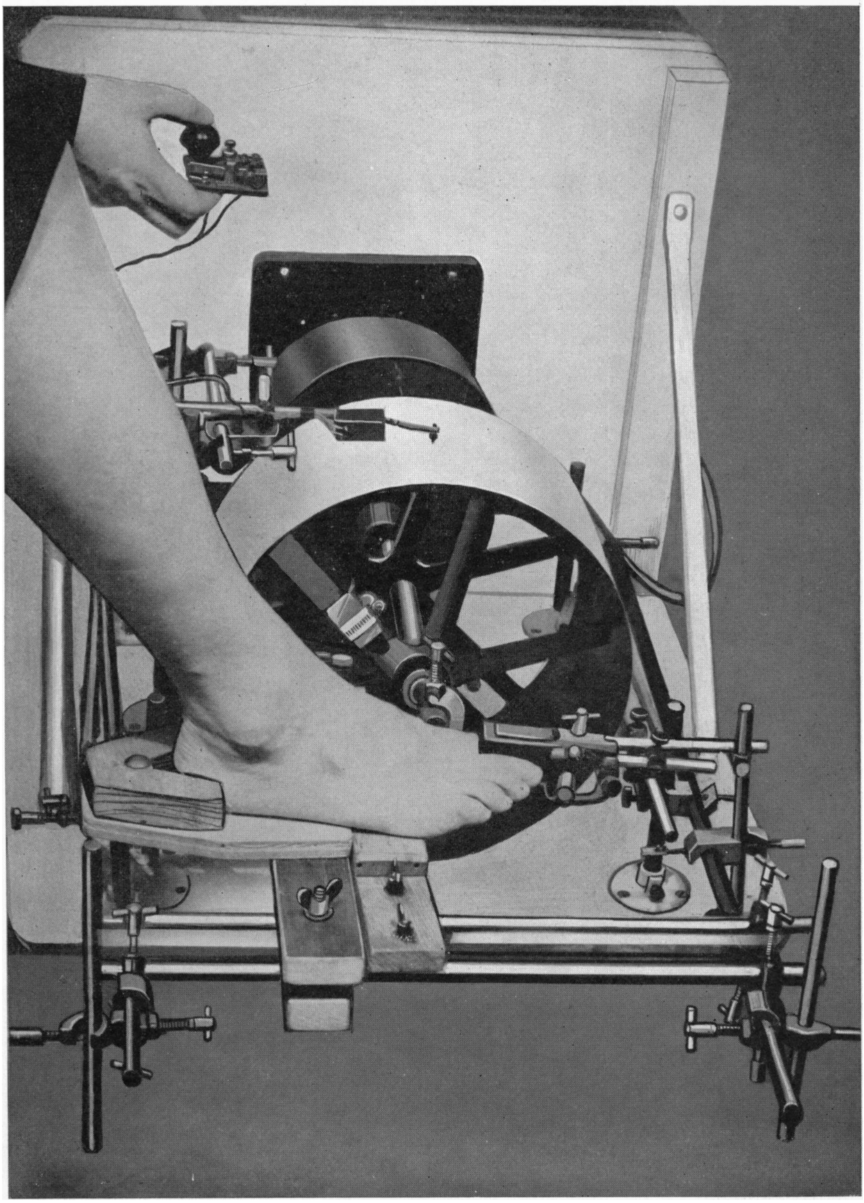
This work was begun as an investigation into the characteristics of passive movement sense at the metatarso-phalangeal joint. Since the original work of Goldscheider (1889), other investigators (Winter, 1912; Laidlaw & Hamilton, 1937 *a*, *b*; Cleghorn & Darcus, 1952) have investigated joint sensation in normal subjects by measuring the response to a continuous movement. Their work established the existence of threshold speeds of movement, varying with different joints in different subjects, below which sensation of movement in a relaxed limb was either absent, or present irregularly and inconstantly.

In the present investigation speeds were used considerably above the threshold values, but not so fast as to introduce complications resulting from variations in reaction times. The toe was displaced at a uniform angular rate and the subject responded as soon as the sensation of displacement was appreciated. The results were expressed in degrees of joint rotation, hereafter called the reaction angle. The experiment was carried out on eighty-four volunteer subjects, all medical students, in an endeavour to establish a normal range for sensation of passive movement.

An initial investigation was carried out to test whether the reaction angles did in fact represent a true sensation and were not distributed at random. An analysis of variance carried out on the data left no doubt that the reaction angles represented a real measurement; some variability was shown within the scores for each foot of each subject and between the averages of the two feet of the same subject, but far greater variability was present between average scores for different individuals. Further, this initial investigation revealed no significant differences between reaction angles for the same subject at the three different speeds used (0·2, 1 and 2°/sec), although, at the slowest speed, judgement of the moment at which unequivocal sensation of movement



The apparatus for measuring the reaction angle. The clamp which grips the great toe rotates with the drum about the axis of the metatarso-phalangeal joint.

To face p. 449

occurred caused considerable concern to the subjects. In the main investigation this speed was therefore omitted.

During the course of measuring the normal range for sensation of passive movement, certain facts emerged tending to support the conclusion that the source of the sensation measured was located in the capsule, and that muscles and tendons did not play a significant part. It was therefore decided, in addition, to investigate the effects of anaesthesia of the joint capsule upon this sensation.

METHODS

The metatarso-phalangeal joint of the great toe was used in all experiments; the basis of the determination was that the joint was rotated by an electric motor from an arbitrary position of rest, the subject indicating when movement was appreciated by means of a signal. The angle through which the joint was rotated was graphically recorded.

The subject to be tested was seated in a chair, his foot placed on a foot rest in such a way that the muscles of the leg could be relaxed. The axis of rotation of the metatarso-phalangeal joint was set in the same horizontal axis as the spindle of a balanced cylinder 12 in. in diameter. The toe was grasped firmly on dorsal and ventral aspects by a clamp with rubber-lined jaws so that the interphalangeal joint was fixed. All joint rotations started from the normal position of rest of the joint (see Plate). Throughout the experimental procedure the subjects' eyes were closed and signals were given by a key actuating a pen on the paper of the cylinder. On being told to prepare for movement the subject pressed the key and a mark was made on the paper. After a varying interval the motor moving the toe was started by a noiseless switch. When the movement was appreciated by the subject, the key was released, again marking the paper. The angle of displacement was derived from these two marks.

It was found that when the joint was moving the subjects began, after a varying period of time, to experience a feeling of uncertainty as to whether the toe was being moved and that this feeling gradually developed into certainty. Subjects were instructed not to register sensation until the period of certainty was reached. After two trial movements to accustom the subject to the machine three consecutive measurements were recorded for each speed (1 and 2°/sec). The average of these three measurements expressed in degrees was taken as the reaction angle for that speed.

The motor produced a very small amount of noise and vibration which under the conditions of the experiment was just perceptible to a majority of the subjects. In order to eliminate unreliable responses due to this, a control procedure was used. This consisted of the introduction of a number of dummy runs at selected intervals in which the normal procedure was used except that the driving clutch was disengaged. The motor could thus be started but no joint rotation occurred. Under these conditions only two subjects gave unreliable responses at both speeds, and a further two failed at the slower speed (1°/sec). The former were therefore excluded from further investigation, while the latter were only included in the averages for the faster speeds.

In order to assess the accuracy of the measurement of joint movement as indicated on the cylinder record, in four cases movements were verified radiographically. It was found that for an angular displacement of 10° from the position of rest the indicated angular displacement was within $\frac{1}{2}$° of that shown radiographically; from 10 to 20° the error was within $+1\frac{1}{2}$ to $-\frac{1}{2}$°.

In the experiment involving anaesthesia of the metatarso-phalangeal joint the following procedure was used: the metatarso-phalangeal joint was identified by palpation, and at four points around the circumference of the joint, skin weals of 1% procaine and 1 in 50,000 adrenaline were raised. A needle was introduced through each area of skin anaesthesia in turn, and carried down to the level of the capsule. The local anaesthetic was introduced in and around the capsule; from 8 to 12 ml. being required to encircle the joint completely.

With this procedure, a radio-opaque solution (Neo-Hydriol, May and Baker) was injected into the great toe of a freshly amputated limb. Subsequent radiographs showed that the viscous iodized oil was distributed in the pericapsular region.

Injection of procaine was found to produce a variable loss of skin sensation, and therefore the contralateral great toe, with skin alone anaesthetized, was used as a control. Each foot was tested in the usual clinical fashion for sensation of toe position, and also in the machine to determine the effect upon the reaction angle.

In nine subjects the whole of the capsule and pericapsular tissue was infiltrated, and in a further two only the dorsal aspect was anaesthetized.

RESULTS

Appreciation of passive movement

The results of the initial investigation showed that there was no statistically significant difference between any of the measurements for the same foot at the same speed taken on the same occasion, and therefore in the main investigation these three readings were averaged. Frequency distributions plotted for average reaction angles of each subject (each foot and each speed being taken separately as well as the averages of both feet and both speeds taken together) all gave parabolic curves with a very marked positive skew (Text-fig. 1). This suggested that it would be more appropriate in such distributions to use the logarithm of the angle (Text-fig. 2), a finding which is to some extent in accordance with theoretical expectations of stimulus and sensation.

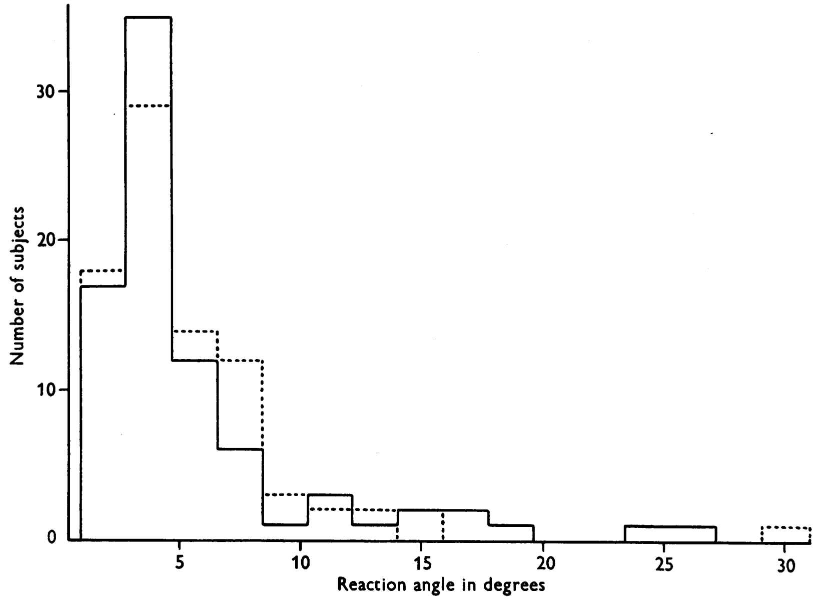
Calculations made on the data gave average reaction angles (at the speed of 2°/sec) of 4·5 and 4·3° for left and right feet respectively, with standard deviation of log 0·28° for each foot. No significant difference was found between the averages for the two speeds, 1 and 2°/sec, or between male and female subjects. Similarly no significant difference was found between the averages for right and left feet, or between the dominant and the other foot. Substantial differences did, however, exist between the scores of the two feet in a small minority of subjects.

Repetition of measurements. Of these original eighty-two subjects a stratified sample of forty-four, including subjects representing the whole range of reaction angles, was recalled at later dates for further measurements. The following procedures were adopted:

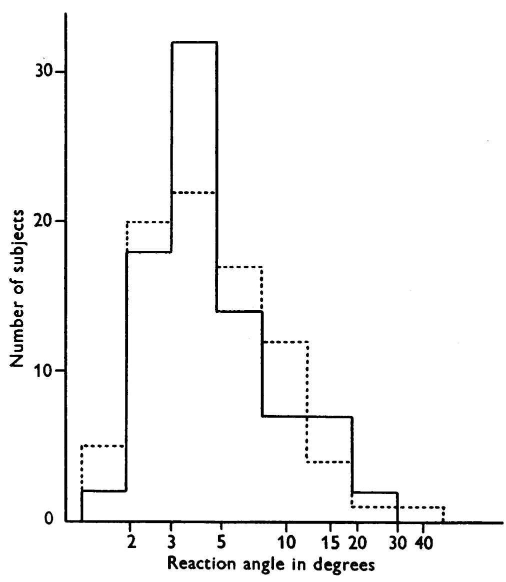
(1) On all subjects the original measurement was repeated at the fastest speed (2°/sec).

(2) On thirty of these subjects reaction angles were measured when the toe was moved upwards as well as downwards at the same joint, the fastest speed again being used.

(3) A small number of subjects at the extreme end of the range, i.e. those with the largest reaction angles, were given a more detailed clinical examination and some attempt was made to estimate their reaction angles merely by moving the toe by gripping it with the fingers.

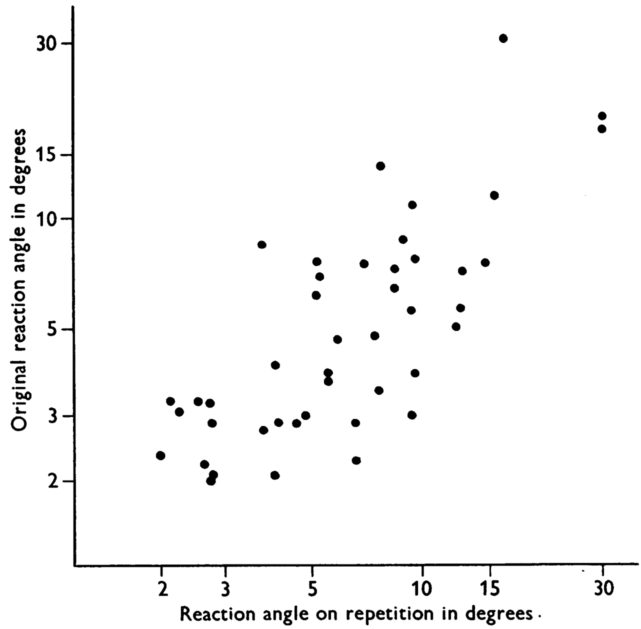


Text-fig. 1. Frequency distribution of reaction angles in eighty-two subjects. ——, right foot; ......, left foot.



Text-fig. 2. Frequency distribution of the logarithms of the reaction angles included in Text-fig. 1. Eighty-two subjects. ——, right foot; ......, left foot.

The results of the repetition confirmed that individual scores were reproducible to within a reasonable margin. Text-fig. 3 shows that a good correlation exists between original scores and repeats (the average of the three scores at the faster speed being taken in each case), the correlation coefficients being 0·74 and 0·66 for left and right feet respectively. Table 1 shows that the average reaction angle was slightly greater on repetition but the difference was not significant.



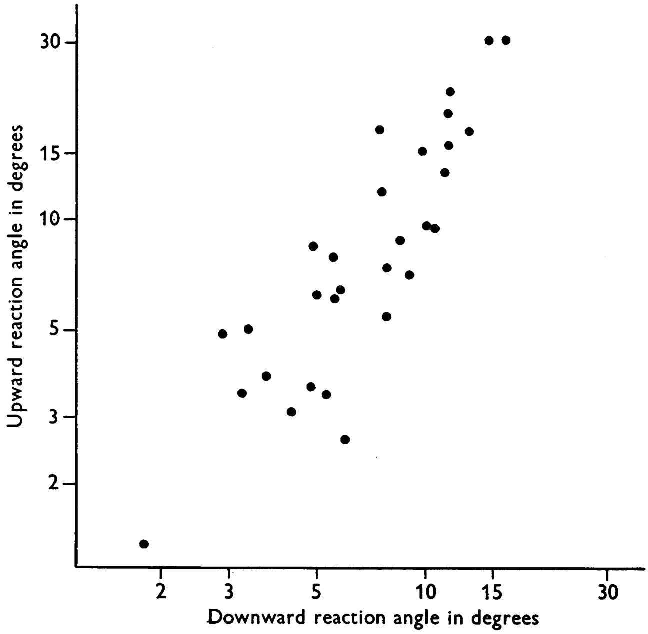
Text-fig. 3. Scatter diagram, showing correlation between the reaction angles originally recorded and those yielded by the same subjects 4–8 weeks later. Reaction angles expressed as the logarithm. Forty-four subjects. Left foot; speed 2°/sec; $r = 0{\cdot}74$.

TABLE 1. Average reaction angles. Sample of forty-four subjects. Rotation speed 2°/sec

	Original measurement		Repeat	
	Angle	Standard deviation	Angle	Standard deviation
Left foot	5·0°	log 0·28°	6·2°	log 0·29°
Right foot	5·1°	log 0·28°	6·4°	log 0·29°

Measurements of reaction angles for movements in the upward direction were found to be very highly correlated with downward movements of the same toe taken at the same time, the correlation coefficients being 0·81 and 0·86 for left and right feet respectively (Text-fig. 4). The average reaction angle shown in Table 2 was slightly greater for upward than for downward movements but the difference was once again not significant. In view of the considerable individual variability present in all the movements the high degree of correlation found was a somewhat unexpected but certainly interesting finding.

It will be seen from the frequency distributions that there was a group in which passive movement was not appreciated until the joint had been moved through a considerable angle. Examination of individual scores shows that



Text-fig. 4. Scatter diagram, showing correlation between the reaction angles for upward and downward movement. Reaction angles expressed as the logarithm. Thirty subjects. Right foot; speed 2°/sec; $r=0\cdot86$.

TABLE 2. Average reaction angles. Sample of thirty subjects. Rotation speed 2°/sec

	Downward movement		Upward movement	
	Angle	Standard deviation	Angle	Standard deviation
Left foot	6·5°	log 0·23°	8·2°	log 0·28°
Right foot	6·8°	log 0·23°	7·9°	log 0·33°

while the average reaction angles were 4·5 and 4·3° for left and right feet respectively, ten subjects, i.e. approximately 12% of those examined, registered an average of 15° or more, five of these with both feet and the remaining five with one foot. Moreover, of these ten subjects, three allowed the toe of each foot on at least one occasion to be moved through 20° or more before registering that any sensation had been felt, while a further three subjects allowed this to happen to one foot.

The repetition of measurements on a sample of the original subjects gave an opportunity to examine more carefully those whose original reaction angles were at the extreme high end of the range, and most of these were included among the subjects recalled. Among these subjects one (female) had no sensation at all when either toe was moved passively upwards by hand until an angle of about 50° was reached; appreciation of downward movement was not so markedly impaired. A clinical examination of this subject showed that there was marked impairment in the appreciation of passive joint movement in most of the peripheral joints, associated with a considerable increase in the range of joint movement, but active joint sense was normal. No evidence of any other abnormality in the central nervous system could be found. Another subject (male) allowed the toe of each foot to be moved through a distance of 40–50°, either up or down, before he appreciated that it had been displaced. In a second male this angle averaged over 20°, and in a third male downward movement was only appreciated when the limit of movement had almost been reached. The general distortion of tissues and the consequent introduction of other sensations when such large movements are made must be borne in mind.

Two other subjects were found who seemed quite unable to relax and allow passive movement of the joint to be carried out. In both cases the attempt to sense the position of their toes evoked tensing of muscles. It emerged from these observations that subjects with very high reaction angles to passive movements were immediately brought within the normal range when allowed to tense their muscles (Browne & Lee, 1953).

The effect of anaesthesia on the appreciation of passive movement

Simple clinical testing showed that after joint anaesthesia eight out of nine subjects were no longer able to determine the position of the great toe until the extreme range of movement was reached, when they found that skin stretching on either the upper or lower aspect of the joint gave them sufficient information. On the control side there was no impairment of the sense of joint position.

These eight subjects, when tested as described in the machine, showed a complete loss of appreciation of joint movement. The great toe could be passed through its full range of movement either upwards or downwards, the subject failing to detect movement even when the joint had been moved through its full range. Occasionally it was found that subjects could appreciate joint position and movement by stimuli arising from skin stretching, or from uneven pressures on upper and lower aspects of the foot. On being questioned at the conclusion of the experiment, several volunteered a statement couched in almost identical terms 'instead of feeling the joint moving it felt as if the toe was being pulled away from me'. These subjects, who were all familiar with the apparatus and with the sensations which arose when the joint was moved normally, agreed that sensations arising in the joint had been completely abolished by infiltration of the capsule. One subject who had the whole of the capsular region infiltrated showed only an impairment of appreciation of passive movement; at the extreme range of movement the sensation was appreciated. Failure to abolish perception of passive movement completely in this case might have been due to an error in injection technique.

In two of the nine subjects the procedure of anaesthesia of the whole capsule was carried out in two stages. When the dorsal aspect alone was anaesthetized, the response to passive movement was measured and found deficient in a downward direction only. Completion of the injection abolished all sensation of movement. In an additional two subjects, only the dorsal aspect of the capsule was infiltrated. Considerable delay in the appreciation of joint movement in a downward direction was observed. In one subject the reaction angle increased from 2 to 16°, and in the other subjects, from 4 to 18°. Appreciation of upward movement was, however, unimpaired (Lee & Ring, 1954).

DISCUSSION

It is a matter of some interest that out of eighty-two, ten subjects (approximately 12 %) had an average reaction angle of 15° or more, compared with the overall average of 4·4°. It has been shown that passive joint sense may deteriorate with age (Laidlaw & Hamilton 1937 *b*), but these subjects were all below the age of 25 years. Five of the subjects would probably be classified as having impaired joint sense on clinical examination but none of the 'abnormals' had any difficulty when walking. Further, one subject (female) who had impairment of the sensation of passive displacement of most of the peripheral joints of the body was completely unaware of this defect until examined.

It is noteworthy that the frequency distributions of the reaction angles show a skewness even when plotted on a log. scale (Text-fig. 2). Whether this skewness is due to the inclusion of what may be termed 'abnormals', or to a datum distribution of unexpected shape in a normal population, is a matter of interpretation. The skewness is unlikely to be due to individual variations of judgement as to when a doubtful movement becomes certain, since these should be distributed normally. Individual reaction times can only alter the response by a fraction of a degree, as the fastest speed of angular rotation was only 2°/sec.

It is usually stated that the appreciation of passive movement is dependent on information derived from muscles, tendons and joints. That movement of the joint capsule does stimulate nerve endings has been shown in the cat (Gardner, 1948; Andrew & Dodt, 1953; Boyd & Roberts, 1953). McCouch, Deering & Ling (1951) have shown that the tonic neck reflexes are not dependent on afferents from the muscle, or cutaneous tissue, but probably originate from the joints. Stopford (1921) showed that in peripheral nerve injuries of the upper limb in man which did not appear to involve muscles of the hand, there was loss of passive movement sense at the joints of the fingers.

Goldscheider (1889) was of the opinion that, in man, the source of the sensation of passive movement resided in the capsule and attempted to prove this by using induced currents to impair sensation. His results, however, were not conclusive and were criticized by Winter (1912) who upheld an origin from muscles and tendons upon equally inconclusive evidence. The more convincing evidence indicating a capsular origin was obtained by Stopford (1921). His findings are, however, open to minor criticisms; for example, all the cases with impairment of passive movement had anaesthesia of the skin and the patients' previous ability to appreciate passive movement was not known.

That sensation from the joint area itself may be important in the appreciation of passive movement was suggested by two observations. First, in two of the subjects examined, mild unilateral hallux rigidus was found to be present. In both these cases the reaction angle was significantly smaller on the affected side. The capsule in this condition is thickened and fibrosed and might be expected to have an increased sensitivity to deformation. Secondly, one of the subjects who recorded very large reaction angles was also found to have large reaction angles, assessed approximately by manual movement, in many other joints; and at all these joints there was evidence of laxity of the capsules, as revealed by an abnormal range of movement.

In the present work the injection of the capsule and pericapsular tissues with local anaesthetic resulted in a loss both of appreciation of passive movement and of position sense in the relaxed toe. This finding, together with other observations made during the work on measurement of reaction angles, indicated that this sensation is normally due to afferents arising in the capsule or the pericapsular tissues. Moreover, since the appreciation of downward movement could be grossly disturbed by anaesthesia on the upper aspect of the capsule alone, it would appear that the end-organs concerned are of the stretch-receptor type.

These results are in close accord with the work of Boyd & Roberts (1953) on end-organs in the capsule of the knee-joint of the cat. These workers recorded afferent discharges of a slowly adapting nature which showed characteristic frequencies for particular positions of the joint and increased frequencies of discharge originating from sense-organs apparently of the stretch-receptor type.

Measurements obtained from our subjects related to the sensation of passive movement. This sensation is sometimes distinguished from the sensation of position. No evidence has emerged from this work, however, to suggest that these two sensations are mediated by different mechanisms since joint anaesthesia abolished both sensations. It may be noted that the sense-organs in the joint capsule of the knee of the cat examined by Boyd & Roberts appear capable of providing accurate information about the relative position of the bones forming the joint as well as about their movements.

The conclusions are that appreciation of passive movement at the metatarso-phalangeal joint of the great toe is dependent on receptors in the joint capsule region. The sensitivity of these end-organs will depend in part on the anatomical arrangement of the joint capsule which is subject to individual variation. Appreciation of passive movement might therefore vary and so account for the high proportion of subjects with impairment of appreciation of this sensation.

It was found that impairment of appreciation of passive movement was not associated with any defect of appreciation of active movement; if those subjects with apparent impairment of appreciation of passive movement voluntarily produced a tonic contraction of the muscles of the lower leg the impairment disappeared. It would therefore appear that a distinction must be made between appreciation of passive movement and of position in the limb with muscles relaxed, and of active movement and of position in the limb with muscles tensed. Corresponding with these two types of sensation, two sensory mechanisms appear to be involved. Passive movement is appreciated as a result of alterations in tension of the joint capsule, whereas active movement would appear in addition to be indicated by impulses from muscles and tendons. The latter is capable of providing information of a remarkable degree of precision, while the former has been shown above to be comparatively insensitive for one peripheral joint at least; and since Laidlaw & Hamilton (1937*b*) have indicated that thresholds of appreciation of this joint do not differ markedly from those of other limb joints it is possible that a similar insensitivity to passive movement also exists elsewhere.

The findings indicate that passive proprioceptive sensation at the metatarso-phalangeal joint is subject to wide variation even in healthy subjects and is not a reliable method of testing for a loss of proprioceptive sense, unless a normal reaction angle has been recorded previously. Measurements of an individual's reaction angle taken successively over a period of time might conceivably provide useful information about changes in the appreciation of sensation. Such changes might, however, be associated with changes in the joint region and not in its innervation.

SUMMARY

1. A method of measuring the appreciation of passive movement at the metatarso-phalangeal joint in man is described.

2. It was found that whilst the average reaction angle was 4·4°, ten out of eighty-two subjects yielded average reaction angles of 15° or more. Appreciation of active movement, however, was unimpaired.

3. Complete anaesthesia of the joint capsule resulted in a loss both of appreciation of joint movement and of position sense in eight out of nine subjects.

4. Anaesthesia of the dorsal aspect of the capsule resulted in a loss of appreciation of downward movement only.

5. It is suggested that the sensation both of passive movement and of position sense arises in the region of the joint capsule. The stimulus for these sensations is probably stretch of the capsule.

6. A distinction is made between appreciation of passive and active movement; and the location of the peripheral receptors of each is indicated.

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