# Discrimination of active plantarflexion and inversion movements after ankle injury

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To assess active ankle function in normal weightbearing after injuries, with a task that required discrete movements, 40 ankles were tested from subjects who had previously injured both ankles, injured one ankle only, or had never injured an ankle. Tests to assess discrimination between the extent of movements, in a range around 12 degrees off horizontal, were made in standing and carried out on both ankles, in plantarflexion and inversion directions. Subjects were found to have a greater ability to discriminate between movements in plantarflexion (a just noticeable difference of 7.5 per cent) than in inversion (10.4 per cent). Never injured subjects had better overall discrimination (7.3 per cent) than previously injured subjects (9.7 per cent) and there was no significant difference between the average discrimination score for both ankles from subjects with previous bilateral or unilateral injuries. This result is consistent with earlier findings on the bilateral associations of unilateral lower limb injuries. **[Waddington G and Adams R: Discrimination of active plantarflexion and inversion movements after ankle injury. *Australian Journal of Physiotherapy* 45: 7-13]**

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## Introduction

Many sport and work activities involve high physical demands on the lower limbs, and injuries to the foot and ankle are common (Waddington and Shepherd 1996). A variety of techniques have been used to assess the effects of injury on proprioception and function at the ankle, some of which involve application of forces to non-weightbearing ankles (Forkin et al 1971, Garn and Newton 1988, Lentell et al 1995). Other techniques involve active use of the ankle joint in balance tasks (Cornwall and Murrell 1991, Hamer et al 1992, Leanderson et al 1996, Tropp et al 1985).

Both of these techniques have problems with respect to what is being assessed and its relation to ankle function. The passive stimulation methodology, with its requirement that muscles be relaxed, focuses on only the afferent aspect of the perceptual-motor loop, and therefore may not enable the subject to demonstrate how good (or bad) their ankle is in a more functional movement. Balance tasks involve more joints than the ankle and may also involve social factors (Carron 1968) and relaxation issues (French 1978, Maki and McIlroy 1996) which confound these measures as clear tests of ankle function.

Accordingly, we have developed an apparatus for evaluating performance at the ankle which incorporates the following components: an upright, non-restrained, full weight-bearing stance, with the subject producing discrete, active movements that result in a functional interaction with the environment. Movements made by the subject are discrete, self-initiated and self paced, and thus are different from the continuous adjustment movements made to maintain upright stance in balance tasks. With discrete movements to defined locations, it is possible to adapt methods from perceptual threshold and discrimination testing as performance measures. Magill and Parkes (1983) have proposed a way of measuring the discrimination ability of subjects making limb movements using classical psychophysical techniques (Kling and Riggs 1971). This involves constructing a psychophysical function from the outcome of the comparative judgments involved in the method of constant stimuli. Their method involves the calculation of a discrimination measure from judgments comparing two separate movements, where subjects simply have to say which movement of the two was the longer. This methodology is the same as that used by a number of authors to examine discrimination of arm movements (Carlton and Newell 1985, Choi and Meeuwsen 1995, Meeuwsen et al 1992).

The discrimination measure obtained is closely related to the "just noticeable difference", or smallest amount by which a stimulus must be increased before the changed value can be discriminated. With respect to movements, this means the smallest difference in movement extent that can reliably be discriminated. Subjects with good discrimination for movements about the ankle can detect only small differences, whereas subjects with poor discrimination require a much larger difference before they can tell. Further, if old ankle injuries do have lasting effects (Goldie et al 1994), this discrimination measure should reflect such effects.

Because the typical mechanism of ankle injury involves a plantarflexion/inversion movement, both movement directions were tested (Waddington and Shepherd 1996).

## Method

The method of constant stimuli was used to estimate the discrimination threshold of two movements of the lower limb. With this method, the subject judges pairs of movement stimuli, then tells the experimenter which of the two was the greater.

Forty ankles were tested from 10 male and 10 female subjects, who had a mean (SD) age of 28 (13) years, weight 70.2 (11.4) kg and height 172 (8.9) cm. All subjects used their right foot by preference when kicking a ball, and were a sample of convenience comprising academic colleagues and athletes on teams available to the first author. Subjects were interviewed, and answered questions about any ankle injuries they had previously experienced. A three-part classification was used in relation to their reports. To be classified as an injury for this study, any previous sprain of the lateral ligaments to the ankle had to have caused disruption of a week or more to training or work activities. Events that were less disruptive than this were classed as "no injury". On the basis of their responses, subjects were allocated to one of the following injury status categories: no ankle injury; unilateral ankle injury only; or bilateral ankle injury. No subjects had any history of musculoskeletal injury to the lower limb or back, any ankle pain within six weeks prior to entering the study, or any history of visual or vestibular disturbance affecting balance. Approval to undertake this project was obtained from the Human Ethics Committee of The University of Sydney prior to commencement and each subject signed a consent form, indicating their willingness to participate.

The Ankle Movement Extent Discrimination Apparatus (AMEDA), purpose-built for this study, is shown in Figure 1. Subjects stood with one foot on a fixed platform and the other on a square plate with the pivot axis always through the centre of the footprint. The plate could be unbolted to allow either a frontal or lateral pivot axis, that is, movement from the horizontal into either inversion or plantarflexion directions at the ankle. Identical platform bearings allowing movement in the plantarflexion and inversion directions were used and the torque required to initiate movement of the platform in either direction was found to be 0.01Nm. Nine wooden stop blocks of different height provided the end stops to platform movement. Manually interchanging the stop blocks under the edge of the platform allowed nine different ranges of motion for the platform from horizontal. Subjects faced in one direction for both plantarflexion and inversion movements of one ankle and reversed the direction for testing of the contralateral ankle. The AMEDA was calibrated by measuring the total range of motion of the platform from horizontal to a given wooden stop with vernier calipers, then the corresponding angular range was calculated using trigonometry. Platform ranges of motion are described in Table 1.

**Table 1.** Ranges of movement of the AMEDA platform which corresponded to the sets of variable stimuli in the plantarflexion and inversion directions. The central position (standard) was presented on each trial randomly as the first or second of the two movements being compared.

| Block number | Plantarflexion stops degrees from horizontal | Inversion stops degrees from horizontal |
|---|---|---|
| 1 | 14.44 | 14.52 |
| 2 | 13.22 | 13.47 |
| 3 | 13.10 | 13.27 |
| 4 | 12.72 | 12.88 |
| Standard | 12.49 | 12.55 |
| 6 | 12.02 | 12.08 |
| 7 | 11.72 | 11.84 |
| 8 | 11.41 | 11.54 |
| 9 | 10.28 | 10.49 |

Two end stimuli (wooden blocks numbers 1 and 9 in Table 1), which were a double increment from the closest ones to them, were included. This ensured that subjects with particularly poor movement discrimination ability would still experience some movement comparisons where they were mostly accurate, thereby permitting a good estimate of their discriminability to be obtained. Presentation of the eight movement ranges to be discriminated was according to the method of constant stimuli, whereby a variable and a standard stimulus together constitute a trial, ie the standard block presented with one of the other blocks. Each of the stopped ankle movements were presented

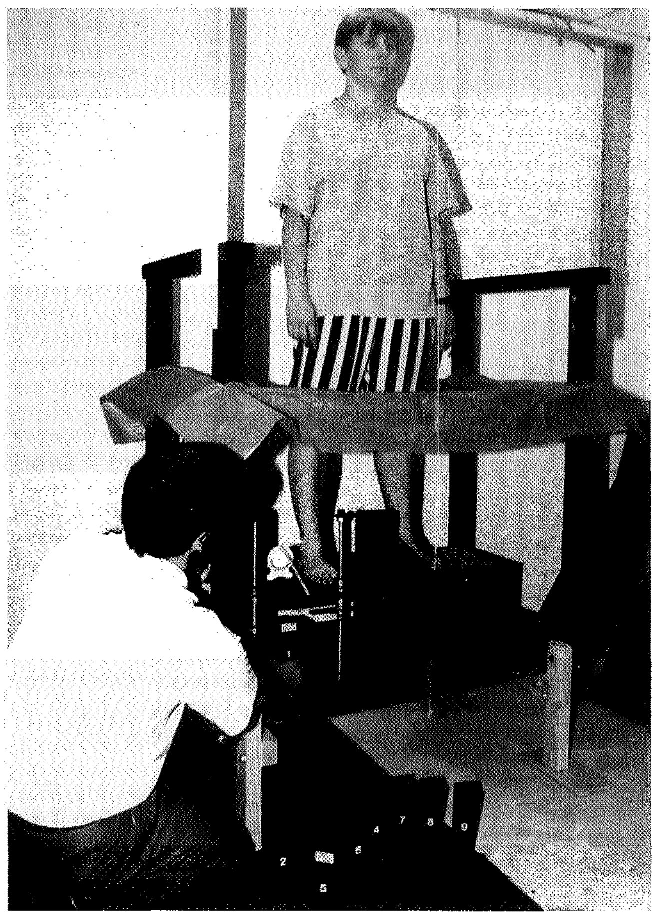

**Figure 1.** A subject standing on the purpose built ankle movement extent discrimination apparatus, AMEDA.

in pairs, with the time between movements being constrained by the necessity of removing the first stop block and replacing it with the next appropriate block to stop the second movement. Subjects were asked whether the second movement of each pair was closer to, or further from, horizontal than the first movement. A pilot study was conducted beforehand to determine, by trial and error, a set of movement stops which were difficult, but not impossible, for subjects to discriminate. The eight movement stops presented to the subjects ranged from 10.28 degrees to 14.44 degrees of plantarflexion from the horizontal, ie from 82 per cent of the standard to 116 per cent of the standard of 12.55 degrees. Inversion movement stops ranged from 10.49 degrees to 14.52 degrees from the horizontal, ie 84 per cent of the standard to 116 per cent of the standard of 12.55 degrees.

***Data collection*** Random allocation was made for each subject to a sequence of the four conditions: left or right foot, inversion or plantarflexion. Before testing began with a given foot and movement direction, subjects were asked to move the plate in that direction until they felt that they could move no further without their foot slipping off. This angle was recorded as their end of comfortable range for the movement. No value recorded was less than 20 degrees from horizontal in plantarflexion or inversion, so testing in the range between 10 and 14.5 degrees then proceeded. Subjects were asked to maintain a relaxed standing posture, approximately 60cm above the floor, with the foot of the limb being tested centred over the axis of movement of the movable base plate and their head aligned with a plumb line suspended directly in front of them (Figure 1). Each subject was allowed a brief series of trial movements on the device. This allowed them to familiarise themselves with the device prior to data collection, after which the eight pairs of stimuli plus standard were presented 10 times in random order to each subject, with no feedback on results being given as to the outcome of each performance. A movement to the standard block was presented first on half of the trials. Only one completed attempt at each movement was allowed, and subjects were simply asked to move down and back up to the horizontal stop at a steady pace. After each pair of movements, the subject was asked if the second movement was "closer to" or "further than" the horizontal (resting position) than the first movement. Each subject undertook 80 comparisons for each movement direction, ie a total of 160 comparisons (or 320 movements) per ankle. The experimenter changed the stop blocks between each movement, then recorded the subject's response after each movement pair.

***Data analysis*** Raw scores for "closer to" or "further than" were collated on score sheets for each subject. An example of a fitted stimulus response curve (Kling and Riggs 1971, Maher and Adams 1995), in which the percentage of "further than" responses is plotted against variable stimulus values, is presented in Figure 2. Data were analysed using Probit analysis (Finney 1971). This is an SPSS-Windows sub-routine, which calculates the parameters of the best-fitting cumulative normal curve. Each subject's performance on a discrimination task employing the method of constant stimuli can be characterised by three components (Maher and Adams 1995). These are: i) the point of subjective equality, PSE, which is the point judged both greater than and less than the standard on 50 per cent of occasions; ii) the stimulus point that is just noticeably greater, JNG, than the standard, ie judged to be greater than the standard on 75 per cent of the trials; and iii) the just noticeably less, JNL point, judged to be less than the standard on 75 per cent of trials. The smaller the distance between the PSE and the JNG and JNL points, the smaller the

**Table 2.** Injury Status group means and standard errors for each of the four ankle movement conditions.

| | Right Side | | Left Side | |
|---|---|---|---|---|
| | Plantar-flexion | Inversion | Plantar-flexion | Inversion |
| Uninjured group | 6.62 (0.88) | 7.92 (1.23) | 5.88 (0.68) | 8.90 (0.90) |
| Unilateral injury | 6.73 (0.90) | 11.99 (1.54) | 8.28 (0.68) | 11.61 (1.40) |
| Bilateral injury | 9.25 (1.38) | 10.37 (1.65) | 8.17 (1.24) | 10.85 (0.96) |

standard deviation of the underlying distribution. Halving the interval between the JNG and JNL gives the average just noticeable difference, JND, which describes an interval of uncertainty within which the two stimuli cannot be discriminated reliably. The JND expressed as a percentage of the standard is known as the Weber fraction (after the physiologist EH Weber). A three-way analysis of variance, ANOVA, with injury status a between-groups factor and side and movement direction repeated-measures factors, was conducted on the Weber fractions. Within the injury factor status, two planned orthogonal contrasts (Winer 1971) were written which compared firstly all injured subjects with uninjured and secondly, unilaterally with bilaterally injured subjects. Significance was set at the 0.05 level.

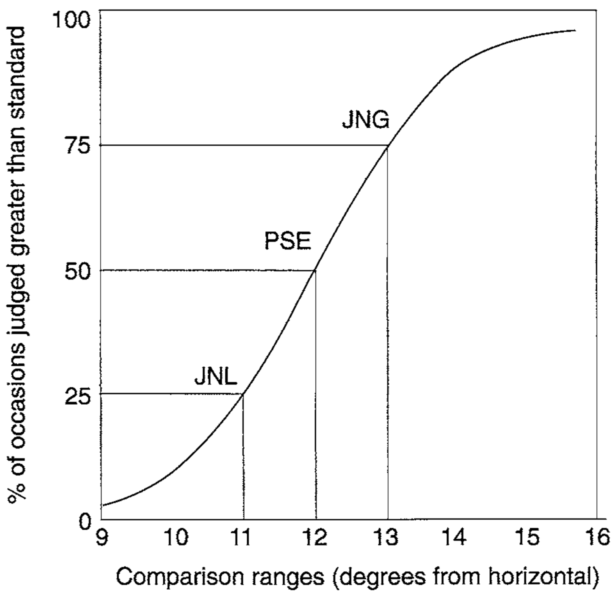


**Figure 2.** Percentage of occasions on which the comparison stop is judged greater than the standard plotted against the comparison stimulus value (Standard stop is 12.55 degrees from horizontal). The three points (JNG, PSE, JNL) that are used to describe stimulus discriminability are shown. The point of subjective equality (PSE) is the stimulus value that is judged greater than the standard on 50 percent of occasions. The just noticeably less (JNL) stimulus is the comparison value that is judged less than the standard on 75 percent of occasions. The (JNG) or just noticeably greater stimulus is the comparison stimulus value that is judged greater than the standard on 75 percent of occasions.

## Results

The mean Weber fraction for plantarflexion movements was 7.5 per cent and for inversion movements 10.4 per cent (Table 2) and this difference was found to be significant, $F_{(1,17)} = 16.63$, $p = 0.001$ (Figure 3). The ANOVA also showed an effect for injury status, whereby the comparison between uninjured and all injured subjects was significant $F_{(1,17)} = 5.47$, $p = 0.032$ (Figure 4). Better movement discrimination was recorded for uninjured (7.3 per cent) in comparison with injured subjects (9.7 per cent). No significant difference was found between the mean discriminability for unilaterally injured subjects (9.65 per cent) versus that for bilaterally injured subjects (9.66 per cent), or between tests on the right foot *vs* the left foot. There were no significant interactions between the two repeated measures factors, movement direction and side, and the injury status factor.

## Discussion

In this study, prior unilateral ankle injury was found to be associated with a mean ankle movement discrimination score that was the same as subjects who had previously injured both ankles. Both these groups were significantly worse at movement discrimination than subjects with no history of ankle injury. Further, the absence of interaction effects with the direction and side factors indicated that this result held for inversion and plantarflexion movement directions, and for right and left ankles. These findings are consistent with the Gauffin et al (1988) proposal that unilateral injuries have bilateral consequences which, they argue, occurs through alteration to the central programs for motor control.

In separate studies of patients with ankle and knee injuries respectively, Gauffin et al (1990) and Tropp et al (1985) have argued that the observation of poor

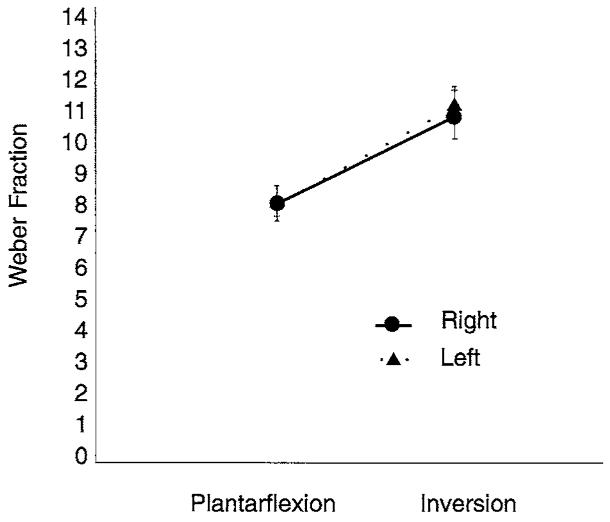


**Figure 3.** The effect of ankle movement direction and side of body on movement discrimination expressed as Weber fraction. The group means for the Weber fractions for the two tested movements of both ankles are shown, with bars representing the standard errors.

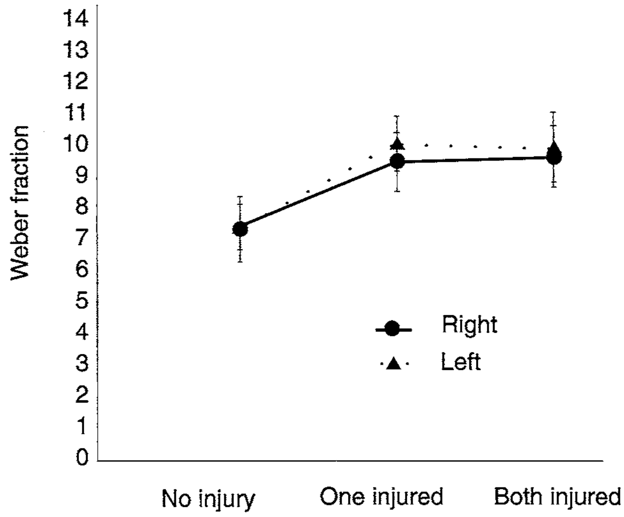


**Figure 4.** The effect of ankle injury status and side of body on movement discrimination expressed as Weber fraction. The combined group means of both inversion and plantarflexion movements for the Weber fractions for the three injury conditions are shown, with bars representing the standard errors.

performance, even in the uninjured limb, favors a central motor program view of injury effects on lower limb motor control.

The concept of a motor program, or a stored, generalised, representation of a class of movements was first put forward by Schmidt (1975). In extending this notion, Schmidt (1988 and 1991) has proposed that it is not information about how to control each of the variants of a movement class that is stored cortically, but a general rule or schema for the whole class of movements. Under the motor program view of motor control, it is argued that, for reasons of efficiency in memory storage and operation, only the one central motor program is employed. An implication of this is that, for persons who have injured only one ankle, common central programs are used for both injured and uninjured limbs, rather than separate ones for each limb, even though this leads to a lowest common denominator performance.

Kelso et al (1979) have provided evidence for this account from a study of subjects using their upper limbs to make bimanual movements to targets of different distances and sizes. Paradoxical poor performance from a limb that could do better was observed. Evidence from studies on bilateral transfer of the motor components of skilled tasks is also consistent with this hypothesis (see Magill 1993 for a review). Gauffin et al (1988) demonstrated positive transfer of a motor skill when they reported a performance improvement for the untrained foot when it was tested after ankle disk training with the injured foot. Transfer in the other direction was shown when, in a later study, Gauffin et al (1990) found a negative transfer effect. Their patients with old anterior cruciate ligament ruptures showed bilateral impairment in postural control as compared with a reference group. A similar finding of bilaterally impaired stabilometry values during single leg stance was reported by Tropp et al (1985) for soccer players with functional instability in one ankle. These latter results are paradoxical in that they show the use of the poorer motor program by both limbs after injury to only one limb, but they are still consistent with the view that, for a given task, the one central program is used for both limbs. This effect, now established in the present study with a method different from that used in the original reports, raises interesting questions about the possibilities for post-injury movement education.

An alternative account of the data reported here can be found in the literature. Goldie et al (1994) note that there is a view that sees subjects with a unilateral ankle injury as bilateral injuries waiting to happen, because they have "a pre-existing global deficit" (p. 970). The two theoretical accounts outlined above differ with respect to the time at which the poor performance on the uninjured limb occurs. The Gauffin et al (1988) central motor program account has the quality of the central programs for movement control at the ankle deteriorating when the lower quality programs constructed for use by the injured limb are also adopted for the uninjured limb. However, the pre-existing global deficit hypothesis states that the poor performance pre-dates any injury. By testing movement discrimination ability at other joints, it should be possible to clarify which of these accounts is more accurate. If discrimination scores at, say, the ankle, hip, shoulder and wrist are all significantly correlated, the level of ability that a person has to discriminate between movements could be seen as biologically determined. If these correlations were absent, the central motor program view becomes the more likely. Another way of differentiating between theories would be to test a group of athletes at the beginning of a season, then after any ankle injuries. Whichever theoretical account is best supported by future studies, both would seem to have opened the possibility for some kind of specific training to 'tune' movement sensitivity at any joint which subjects wished to train.

The second major finding from the current data was that showing superior movement discrimination in the plantarflexion direction. For both plantarflexion and inversion directions of movement, a subject's Weber fraction represents the relative change needed for 75 per cent detection of the movement extent as being different from a standard movement made to 12.5 degrees below horizontal. On average, a difference of 0.9 degrees could be detected in plantarflexion, as compared with 1.3 degrees difference from the 12.5 degrees standard in inversion. This represents a 70 per cent superior discriminability for plantarflexion movements, (with relatively large muscle groups functioning) than inversion movements (with comparatively small muscle groups functioning). Such a result is consistent with the hypothesis that degree of movement sensation associated with a given movement is a function of the total available muscle fibres on stretch during the movement (Refshauge and Fitzpatrick 1995). Refshauge and Fitzpatrick (1995) have reported that detection of passive movement in the lower limb is most acute when the muscles of the hip and knee are in a stretched position, irrespective of whether the subject is in sitting or standing. If the total physiological volume of muscle available is compared between the two actions, the muscle volume involved in plantarflexion is significantly greater than that involved in inversion (Harter 1996). The implication of this result is that when assessing movement system function in the lower limbs, tasks involving an upright stance will permit best performance, in addition to having greater face validity due to their better approximating normal movement conditions.

***Conclusion*** The current findings extend the original effect reported by Gauffin et al (1988) to task situations requiring discrete movements rather than the continuous movements involved in balancing. While the results about unilateral and bilateral ankle injury effects are consistent with the Gauffin et al (1988) motor program account of the movement control consequences of ankle injury, they could also be explained as by-products of a biologically determined ability to discriminate different movements. Clinically, the important issue now is whether movement discriminability as measured by the Weber fraction is improved by training.

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