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Research article

Position-specific deficit of joint position sense in ankles with chronic functional instability

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Abstract

The present study was aimed to test a hypothesis that individuals with functional ankle instability (FAI) underestimate the joint angle at greater plantarflexion and inversion. Seventeen males with unilateral FAI and 17 controls (males without FAI) consented for participation in this IRB-approved, case-control study. Using a passive reproduction test, we assessed ankle joint position sense (JPS) for test positions between 30 and -10 degrees plantarflexion with an inclement of 10 degrees with or without 20° inversion at each plantarflexion angle. The constant error (CE) was defined as the value obtained by subtracting the true angle of a test position from the corresponding perceived angle. At plantarflexed and inverted test positions, the CE values were smaller in negative with greater in the FAI group than in the control group. That is, in the FAI group, the FAI group underestimated the true plantarflexion angle at combined 30° plantarflexion and 20° inversion. We conclude that the ankle with FAI underestimate the amount of plantarflexion, which increases the chance of reaching greater planterflexion and inversion than patients' intention at high risk situations of spraining such as landing.

Key words: Functional ankle instability, lateral ankle sprain, proprioception, joint position sense, constant error.

Introduction

Lateral ankle sprain (LAS) is among the most common injuries in sports (Jackson et al., 1974; Han and Muwanga, 1990; Wilkerson, 1992), accounting for 15-30% of all sports injuries (Garrick and Requa, 1988; Adamson and Cymet, 1997). More than 23,000 LAS's have been estimated to occur daily in the United States, which equates to one sprain per 10,000 people (Kannus and Renstrom, 1991; Soboroff et al., 1984) reported that the cost of treating these injuries ranged from $318 to $914 per sprain, with an annual aggregate cost in the United States of $2 billion. The recurrence rate of LAS among athletes has been reported to be as high as 70-80% (Smith and Reischl, 1986; Yeung et al., 1994). Functional ankle instability (FAI) is a sequelae frequently associated with acute inversion ankle sprains and was first described by Freeman (Freeman, 1965). Functional ankle instability (FAI) is characterized by recurrent ankle sprains and sensations of "giving way" at the ankle joint during physical activity with or without mechanical instability (Freeman, 1965; Goldie et al., 1994; Tropp et al., 1985). FAI becomes evident in 10 to 60% of the patients with an acute ankle injury (Itay et al., 1982; Peters et al., 1991).

A few studies have proposed, as a possible cause of FAI, mechanical instability (Freeman, 1965, Lentell et al., 1995), weakness of the peroneal muscles (Tropp, 1986; Wilkerson et al., 1997) and proprioceptive deficit (Boyle and Negus, 1998; Glencross and Thornton, 1981; Konradsen and Ravn, 1990; Tropp et al., 1984; Willems et al., 2002). The role of FAI on proprioceptive deficit is controversial; a few studies proposed that FAI negatively affects joint position sense (JPS) (Boyle and Negus, 1998; Glencross and Thornton, 1981, Jerosch and Bichof, 1996), while others denied it (Gross, 1987; Holme et al., 1999). Furthermore, previous studies showed mixed results regarding the direction of error in JPS: Willems et al. (2002) claimed that the error was usually negative and that all subjects (both healthy subjects and those with ankle instability) tended to underestimate the test position. In contrast, Feuerbach et al. (1994) found that the exact error was not significantly different from zero for subjects without injuries. Thus, there exists a clear knowledge gap as to whether or not recurrent ankle sprain in FAI is associated with underestimation of the joint position. If individuals with FAI underestimate the joint position, they may place their foot and ankle joints into greater plantar flexion and inversion positions than they perceive. This misperception may place the ankle joint in a vulnerable position that increases the risk of reinjury during activity.

Most LAS occur during foot contact on landing or locomotion associated with either unanticipated foot placement on a sloped surface (e.g. someone's foot) or inappropriate positioning of the foot in space before foot-contact with the surface (Robbins and Waked, 1998). In both cases, humans perceive the amplitude of inversion less than the true position (Bahr et al., 1994; Robbins et al., 1995). In addition, excessive inversion and plantarflexion at the landing are considered a major cause of LAS (Tropp et al., 1985; Wright et al., 2000). If individuals with FAI do tend to underestimate the joint position, the ankle may be placed into a high risk position or a greater plantarflexed and inverted position than it actually is perceived.

The present study was aimed to test a hypothesis that individuals with functional ankle instability (FAI) underestimate the joint angle at greater plantarflexion and inversion as compared with healthy individuals. The results of this study will lead us to understand JPS deficits

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in FAI more clearly as to the direction of the joint position error. This case control study will test the hypothesis by comparing the direction and amount of error in JPS between FAI and healthy groups.

Methods

Participants

The study protocol was approved by the Ethics Committee of the Nagasaki University School of Health Sciences. Participants were recruited at local clinics and the University campus. All subjects were informed of the procedures and signed an approved consent form prior to the enrolment.

Inclusion criteria for the FAI group were: (1) males aged between 18 and 22, (2) at least one episode of major inversion sprain (Grade II or more severe) of the right ankle, followed by (a) subsequent difficulty in standing on the right foot immediately following the injury; and (b) recurrent sprains (more than 3 times) of the right ankle and continuous feeling of “giving way” in daily activities or during exercises. Exclusion criteria for the FAI group were: (1) any pain or stiffness in the right ankle during the previous three-month period of the testing, (2) positive result in the manual anterior drawer test or the inversion stress test, (3) general joint laxity, (4) any medical problems, (5) communication disturbance or mental disorder. Seventeen FAI patients (19.6 ± 2.1ys, 1.73 ± 0.08m, 66.4 ± 8.0kg) agreed on participating in this study after completing a screening questionnaire. The following signs were used to assess generalized joint laxity (GJL): passively dorsiflex the 5^{th} metacarpophalangeal joint to ≥90°, Oppose the thumb to the volar aspect of the ipsilateral forearm, hyperextend elbow to ≥10°, hyperextend knee to ≥10°, and place hands flat on the floor without bending the knees. Participants were considered to have generalized joint laxity (GJL) if they had at least four of these nine signs unilaterally or bilaterally (Beighton et al., 1973) . GJL score of FAI group was 4-8 points (mean ± SD; 5.1 ± 1.1).

Selection criteria for the control group were: (1) male with the case matched by age, height and body mass, (2) current medical problems, (3) no episode of sprain in the right ankle, (4) no unstable feeling of the right ankle, (5) absence of pain or stiffness in the right ankle during the previous three-month period of the testing. (6) any medical problems, (7) communication disturbance or mental disorder. Seventeen healthy individuals (20.4 ± 2.3ys, 1.71 ± 0.08m, 65.7 ± 9.7kg) agreed on participating in this study.

Instrumentation

Ankle joint angles were measured using a custom measurement device called "3D ankle position analysis system (3D-APAS) (Kang et al., 2003) (Figure 1)", comprising two digital cameras (Canon, PowerShot G5) and an angle measurement system. The digital camera is commercially available and the sampling rate was 25Hz. No data reduction or smoothing was utilized. The angle measurement system was attached on the platform and provides analogue data of the platform orientation which was used during validation and experimental measurements. A custom computer program was coded using Microsoft excel 2003 that minimize measurement errors and biases from image distortion as well as camera distance and orientation.

Figure 1. 3D ankle position analysis system. Measurements system using two digital cameras and a platform that allowa dorsiflexion, palantarflexion and inversion of the ankle.

The 3D-APAS was designed so that the axes of the testing device for planterflexion/dorsiflexion as well as inversion/eversion were designed so that the translation of the leg was minimal during passive ankle joint motion. The camera images allowed us to observe how far the lower leg moved during testing and we could not confirm that there were significant shank translations during the experiments. It was designed to stabilize the foot with the anatomical ankle position, which is equivalent to the ankle position during standing, was utilized as an initial testing ankle position. In addition, the 3D-APAS allows for locking the platform at 10 target positions utilized during the experiments.

Test procedures

Participants were placed in a seated position on a bench with the knees flexed at 90° and the lower leg positioned vertically. Before the testing, the long axis of the lower leg was placed perpendicular to the ground. During testing, the participants’ eyes were covered to eliminate any visual influence and their foot were bare. The lower leg was not immobilized during the test in order to minimize stimulus to the skin of the lower leg (Lentell et al., 1995; Lephart et al., 1998). The right foot was positioned and foot was placed on the platform of the ankle position measurement device with an abduction angle of 15°, so that the axis of rotation for inversion/eversion of the subtalar joint was aligned with the longitudinal axis of rotation of the platform and the excursion of the lower leg during passive ankle motion was minimal.

Once the foot and ankle were positioned and stabilized on the platform, two markers (a) and (b) on the lateral side of the participant’s lower leg and three markers (c), (d) and (e) on the platform were placed (Figure 2). The ankle planterflexion angle was defined as an angle between a line connecting markers (a) and (b) and a plane defined by the markers (c), (d) and (e). The two cameras were placed as far as possible to minimize camera distortion and capture all the markers within the central 2/3 of the images.

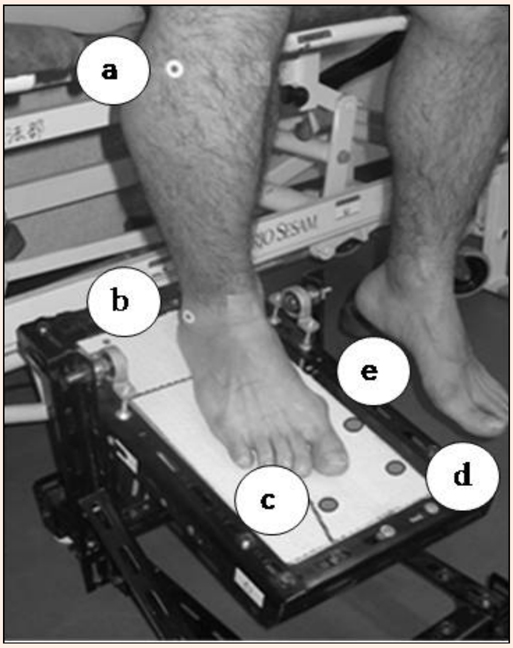

Figure 2. Positions of markers on the right foot and the platform. (a) head of the fibula, (b) lateral malleolus, (c) on the mid-line of the platform anterior to the toes, (d) on the medial edge of the platform anterior to the toes, (e) on the medial edge of the platform medial to the 1st MP joint.

Experimental protocol

Measurements of JPS during dorsiflexion and plantarflexion with or without inversion of 20° were performed. To eliminate the learning effects, the order of ankle positions were randomly selected from the 10 ankle positions; five plantarflexion angles between 30° and -10° with 10° intervals two inversion angles of 0° and 20°. First, the participant's ankle was held in one of the 10 test positions for 15 seconds. Then, the ankle joint was passively dorsiflexed until it reached 10° of dorsiflexion, then rested for 10 seconds. After this, the examiner manoeuvred the platform to return it at an angular velocity of 2-3° per second toward the original test position. This angular velocity was determined based on the literature (Gross, 1987; Willems et al., 2002) and the examiner practiced to maintain the designated angular velocity. Participants were instructed to say "stop" when the ankle reached the position where they thought was the original test position. The foot position at this point was photographed using the two digital cameras of the ankle position analysis system. One measurement for each test position was performed per each participant. In addition, subjects were not allowed to practice any of the testing position prior to the examination.

Analysis

Computerised three-dimensional analysis was performed to compute the participants' ankle positions using the images obtained using the two digital cameras. We obtained 3 dimensional coordinates of five markers (a) through (e) for each testing position. Then, the ankle position formed by the lines connecting markers (a) and (b) and the plane defined by markers (c), (d) and (e) was computed. The author defined the angle between the longitudinal axis of the lower leg and the platform in the saggital plane as plantarflexion angle of the ankle. For each test position, the angle calculated from the digital image is hereafter referred to as the "estimate angle" (i.e. the angle perceived by the participant). The value obtained by subtracting the correct angle provided by the hardware-locked position from the corresponding estimate angle was defined as the constant error (CE). When the estimated angle is in reduced plantarflexion compared with the correct angle, the CE was in negative. Analyses of the angles from the images were performed three times for each condition by a blinded examiner. An average for each condition was then calculated from these measurements.

Reliability

A preliminary study was performed to examine reliability of the measurement method. Three examiners measured joint position angle of -10°, 0°, 10°, 20° and 30° of plantarflexion at 0° and 20° of the ankle inversion, respectively. The platform of testing device was paced at the testing angles using hardware fixture, providing exactly the same and known platform positions. Each measurement was then repeated 3 times to calculate intra-and inter-rate reliability. The result showed that inter-rater reliability was good with ICC(3,3) and SEM resulted in 0.917, 0.50° , respectively for the joint position at 0° of inversion, and 0.747, 1.1°, respectively, at 20° of inversion. Similarly, ICC(1,3) of 0.825 and SEM of 1.05° for the joint position angles of plantarflexion at 0° of inversion, and ICC(1,3) of 0.624 and SEM of 1.07° at 20° of inversion for intra-rater reliability.

The accuracy and precision of the measurement system using 3D-APAS were obtained from the angles of the platform using the hardware fixture designed to lock the apparatus at exact 10 testing positions. Accuracy and precision of the testing device was within 2^o and 3^o, respectively.

Statistical analysis

All data were analyzed using SPSS for windows, version 10.0J (SPSS Inc, Chicago, IL). A three-way analysis of variance (ANOVA) for split-plot design was performed with group (FAI or healthy), inversion positions (0 and 20°), plantarflexion angles (-10, 0, 10, 20 and 30°). For significant main effects, the Tukey Honestly Significant Difference (HSD) post hoc test was used for pairwise comparisons. The level of statistical significance was set at p = 0.05. A priori power analysis was not performed due to a lack of reasonable assumptions for constant errors in different joint positions.

Results

Three-way ANOVA revealed that there were no significant three-way interactions (Table 1). There was significant two-way interaction between group and

Table 1. A summary table of 3 way analysis of variance.

		Main Effect			2way interaction			3way interaction
		Group	PF	Inv.	Group-PF	Group-Inv.	Inv.-PF	Group-PF-Inv.
CE	F	5.05	38.56	4.19	5.84	6.05	7.62	.80
	p	.032	.000	.049	.000	.020	.000	.525
	ES	.40	1.10	.36	.31	.29	.24	.16

PF= plantarflexion, Inv. = inversion, F = Fvalue, p = probability, ES = effect size.

plantarflexion angle (Table1). Tukey's HSD post hoc analysis revealed that the CE at 30° for 0° and 20° of inversion , respectively, when comparing CE between two conditions within FAI group date ($p < 0.05$ and $p < 0.001$, respectively) (Table 2). No significant differences were detected at any other pairwise comparisons ($p > 0.128$ and $p > 0.131$, respectively).

There was significant two-way interaction between group and inversion position (Table 1). Post hoc analysis showed there was significant difference in CE between 0° and 20° of ankle inversion for the FAI group, while no significant difference was observed for the control group. In addition, there were no significant difference in CE at 0° and 20° ankle inversion , respectively, between the FAI and control group ($p > 0.220$).

Significant effects of group, inversion position, and plantarflexion angle were noted, indicating that all of these factors affect the CE value (Table 1). These findings indicate that individuals in the FAI group were more likely to underestimate the plantarflexion angles than healthy individuals when the ankle was inverted and plantarflexed.

All 17 subjects in FAI group demonstrated difficulty standing on one foot and having experienced recurrent ankle sprain and giving way. Post-hoc power analysis for repeated measure ANOVA showed that the power exceeded 0.8 for intra-, inter-groups as well as mixed interactions.

Discussion

The aim of this study was to determine if patients with FAI underestimate the joint position when the ankle is placed in plantarflexion and inversion. The main findings of this study were that at plantarflexion 30°/inversion 20°, the FAI group underestimated the plantarflexion angle by a greater margin than the control group. Therefore, the study hypothesis was supported by the results of this study. This positive result suggests that the ankle position may be in greater planterflexion and inversion than the patients' perception.

The results of the present study are partially consistent with previous studies (Boyle and Negus, 1998; Feuerbach et al., 1994; Glencross and Thornton, 1981; Gross, 1987; Holme et al., 1999; Jerosch and Bichof, 1996). Glencross and Thornton (1981) reported significantly greater JPS errors as well as reduced ability of detecting active movement in the FAI compared with the uninvolved ankle. In the passive angle-reproduction test for ankle joint inversion, Jerosch and Bichof (1996) found that the estimate errors of individuals with FAI were significantly greater compared with the control. Boyle and Negus (1998) assessed the inversion JPS error for inverted ankles, and found that the JPS error was greater in the FAI group than in the healthy controls at all positions. On the other hand, Gross (1987) found no difference in the absolute values of the error of ankle inversion JPS between joints with and without FAI. Holme et al. (1999) failed to reveal any significant differences between injured and uninjured ankles in either active or passive joint position sense. Feuerbach et al. (1994) found that the exact error was not significantly different from zero for subjects without injuries. The result of the present study suggests the FAI plays a role in affecting proprioception of the ankle negatively only at combined plantarflexion 30° and inversion 20°.

Underestimation of joint position in FAI has been reported for both FAI and healthy ankles. Robbins, et al. (1995) reported greater underestimation of the joint position at greater plantarflexion in healthy ankles. Willems et al. (2002) similarly reported underestimation for both FAI and control groups when the ankle is in inversion. In contrast, the present study demonstrated a clear underestimation for the FAI group only with greater plantarflexion and inversion. Possible causes of underestimation may include disturbance of proprioception (Boyle and Negus, 1998; Glencross and Konradsen and Ravn, 1990, Tropp et al., 1984; Willems et al., 2002), decreased tension of peroneal muscles (Tropp, 1986; Wilkerson et al., 1997) and abnormal joint kinematics of both talo-crural and talo-calcaneal joints (Freeman, 1965; Lentell et al., 1995). Mechanoreceptors in ligaments and joint capsule, particularly the anterior talofibular ligament (ATFL), may be damaged during ankle sprain (Freeman, 1965; Saunders, 1980; Renstrom and Konradsen, 1997). The peroneal muscles reportedly suffer from proprioception deficits, weakness and the delay of the reaction time (Konradsen and Ravn, 1990; Tropp, 1986; Willems et al., 2002; Wilkerson et al., 1997). Furthermore, the lack of the afferent input from the joints may be caused by abnormal kinematics in FAI. For the knee joint, ACL deficient knees demonstrated greater deficit in JPS than ACL

Table 2. CE according to palantarflexion angle of the ankle. Data are means (±SD).

	Ankle Position	-10	0	10	20	30
FAI	Inversion 0°	.9 (2.6) ***	-.6 (2.6) ***	-1.6 (3.9) *	-.8 (3.5) **	-5.0 (3.0)
	Inversion 20°	.6 (3.2) ***	-.1 (4.0) ***	-2.9 (2.8) ***	-2.8 (3.3) ***	-9.6 (3.3)
Control	Inversion 0°	-.7 (2.9)	-.2 (3.1)	-.9 (2.6)	-1.2 (2.8)	-2.5 (2.6)
	Inversion 20°	.0 (2.9) ***	.5 (2.1) ***	.2 (2.9) ***	-.6 (3.1) ***	-4.7 (2.4)

*, **, *** denote $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively, compared with palantarflexion 30°.

reconstructed knees, which suggests that abnormal joint kinematics have a negative impact on JPS (Reider et al., 2003). Therefore, there is a need for more accurate kinematic studies to reveal abnormal ankle kinematics associate with FAI that may affect proprioception.

The present study was carefully designed to eliminate potential biases. First, the testing device, "3D ankle position analysis system" was designed so that the shank and above receives no skin sensation or any other mechanical input directly from the device. The measurement error of this device was less than 3°. This may have contributed to the smaller CE smaller than 3° in healthy subjects at 0° inversion as compared with the CE of 9-10° reported by Robbins et al. (1995). Second, strict selection criteria were utilized to eliminate potential confounding factors including aging, hormones, general joint laxity, and mechanical ankle instability. This should have allowed us to evaluate the role of FAI on proprioception. A post hoc power analyses revealed that the statistical power exceeded 0.80 when the CE value at combined plantarflexion 30° and inversion 20° in FAI group is compared with the control group for the inter-group comparison or the value at plantarflexion 20° with inversion 20° for the intra-group comparison. We utilized CE as indices for the assessment of proprioception and we believe the CE provides valuable information with regard to the overestimation and underestimation of the joint positions (Willems et al., 2002).

Generalizability of this study would not be limited to our study population of young, healthy individuals. JPS is affected negatively that error in JPS increases by 3º as age increases (Robbins et al., 1995), whereas the present study detected greater than 9° of underestimation for the FAI group. However, the present study would not be generalized conclusively to the individuals with general joint laxity who potentially have mechanical instability of the ankle joint, as a conclusion has not been reached as to the possible association between mechanical instability and functional instability (Richie, 2001). Another aspect of the limited generalizability is the static nature of this testing procedure. However, present study supports the idea that the joint position is underestimated at plantarflexion 30°/inversion 20° and the ankle joint may be at greater platnerflexion and inversion at landing. Considering landing with the ankle inversion and plantarflexion is the major cause of ankle sprain in sports (Tropp et al., 1985; Wright et al., 2000), revealing the mechanism of underestimation at plantarflexion and inversion would be the next step in this topic.

The strengths of this study lie in the high accuracy and reproducibility of the data produced by the measurement system, the careful performance of the examination procedures in accordance with approaches used in previous studies, and the low risk of measurement and selection bias. Statistical power was considered strong for the major results. Subjects were not allowed to practice prior to the testing which might have increased variability of the measurements. However, randomization of the testing procedure, sufficient statistical power and high intra-tester repeatability should have minimized the ordering bias. Weakness of this study would include insufficient statistical power to detect the differences between the positions of plantarflexion 30°/inversion 20° and plantarflexion 30°/inversion 0°, which may highlight the role inversion on the proprioceptive deficit.

The present study revealed underestimation of ankle joint position exists in FAI group at greater plantarflexion/inversion. Proprioceptive training may be useful for secondary prevention for patients with FAI after ankle sprain (Handoll et al., 2001; Michell et al., 2006; Wester et al., 1996). The authors suggest the accurate kinematic studies to reveal the mechanism of underestimation in FAI (Reider et al., 2003).

Conclusion

In the present study, we aimed to determine the effects of FAI on ankle JPS. We conclude that subjects with FAI underestimated the amount of plantarflexion. Future study may include accurate analyses of ankle kinematics to identify possible causes of underestimation.

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Key points

- Joint position sense (JPS) of the ankle with functional ankle instability was investigated utilizing a passive reproduction test.
- The FAI group demonstrated greater error of the joint position than the control group only when the ankle was positioned at combined inversion and plantarflexion.
- The FAI group underestimated plantarflexion angle when the ankle was placed at combined inversion and plantarflexion.

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