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The relationship between ankle joint physiological characteristics and balance control during unilateral stance

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ABSTRACT

Background: The role that the ankle's physiological characteristics play in maintaining balance during quiet stance has been well documented. However, the role of the ankle in maintaining balance during more challenging conditions is questionable. As such, the objectives of this study were to identify any significant relationships between the physiological characteristics of the ankle joint and the ability to maintain more challenging unilateral stance.

Participants: 21 healthy, adult athletes (age = 24.67 ± 5.42 years; height = 175.34 ± 7.48 cms; weight = 79.09 ± 14.07 kg).

Procedures: Passive resistance and joint position sense in the sagittal plane of the ankle, and active dorsiflexion range of motion of each subject was assessed, in addition to centre of pressure parameters during 20 s unilateral stance.

Results: Pearson's product moment correlation coefficient found significant positive correlations between $D_{\text{peak torque}}$ and sway area ($r = .554$); A_x range ($r = .449$); and A_y range ($r = .471$). Significant negative correlations were found between $P_{\text{peak torque}}$ angle and sway area ($r = -.538$, $p = .012$), A_x range ($r = -.590$, $p = .005$) and A_y range ($r = -.439$, $p = .046$).

Discussion: The results highlighted limited relationships between unilateral stance balance control and the ankle characteristics commonly associated with quiet stance balance control and has, thus, further questioned the role that the ankle plays during more challenging stance conditions. The majority of balance training protocols in the athletic community focuses on the distal joints, however, this needs re-addressing in order to maximise performance.

1. Introduction

Balance is the ability of the human body to maintain the position of its centre of gravity (COG) within the area of its base of support (BOS). If the COG is displaced out of the BOS, the body becomes unbalanced, senses this threat to stability and uses muscular activity to counteract the force of gravity in order to prevent falling [1]. Thus, a balance control system, which involves both the central and peripheral nervous systems constantly interacting, needs to be activated in order for stability to be maintained [2]. Decreased balance control has been associated with higher injury risk in sport [3] and can explain differences between individuals with and without functional ankle instability (FAI) [4].

In unperturbed, bilateral ("quiet") stance, the body has been considered as an inverted pendulum whereby the balance control system must contend with gravity as the largest destabilising force [5] and chooses patterns that require a minimal number of muscles [6]. It has been demonstrated that ankle mechanisms dominate in the sagittal plane with an almost synchronous sway of the body parts [7], and emphasises the theory of the "ankle strategy" as the balance control system during quiet stance [8]. Some of the physiological characteristics of the ankle in the sagittal plane, which have received consideration when trying to understand the ankle-strategy's role in quiet stance balance control, have included stiffness (passive resistance; PR), proprioception and flexibility [9].

However, both an ankle and a "hip strategy" have been described in more perturbed situations [10]. It has been suggested that during situations more challenging than quiet stance, the sways are too great for the ankle to act and, as such, the hip would

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respond to flex, thus moving COG posteriorly, or to extend to move the COG anteriorly [8]. However, research is still sparse when considering this strategy in challenging balance conditions. This is an important issue in sport as an athlete often undergoes situations of perturbed stance, for instance when coming into contact with an opponent, and unilateral stance conditions during all forms of locomotion, jumping, landing and striking an object with the foot. So it seems important to know what physiological contributing factors may be present that influence balance control during more challenging stance conditions.

The objectives of this study were to identify if any associations existed between stiffness, flexibility or proprioception of the ankle in the sagittal plane, and balance control during unilateral stance. The significance of this is to ascertain whether the ankle strategy has an influence during a stance more challenging and more common in the sporting realm than quiet stance or whether balance control can be attributed to other proposed mechanisms, thus potentially influencing future balance training protocols.

2. Methodology

2.1. Participants

Twenty-one university athletes ($n = 12$, males; $n = 9$, females; age = 24.67 ± 5.42 years; height = 175.34 ± 7.48 cm; weight = 79.09 ± 14.07 kg) competing within their respective sports, as part of the national university league, volunteered to participate in the study. All subjects gave their informed consent and the study was approved by the institute's review board and Ethics Committee. Subjects were assessed for suitability through a written questionnaire and those meeting any of the exclusion criteria featured in Table 1 were removed from the study.

Table 1
Participant exclusion criteria.

Current lower limb musculoskeletal injury
Incidence of minor head injury within the previous 6 months
Lower limb orthopaedic conditions, including a history of chronic ankle instability
Impairment of the visual system that could not be rectified with spectacles or contact lenses
Impairments of the vestibular system
Neurological conditions, which have a noticeable effect on tactile sensation
Any athlete who undergoes balance training as part of their training regimen

2.2. Procedures

Participants undertook 4 separate tests, within one testing session. The tests attempted to ascertain the following physiological parameters: stiffness, in the form of PR in the sagittal plane of the ankle joint; flexibility, in the form of active range of motion (AROM) in the sagittal plane of the ankle joint; proprioception, in the form of joint position sense (JPS) in the sagittal plane of the ankle joint; and balance control, in the form of centre of pressure (COP) parameters during unilateral stance. Due to the geographical location of the testing bays, the tests were not counterbalanced. The time between each test and their relatively distinct nature was deemed appropriate to minimise confounding effects; however, the authors are aware that these effects may still have been present. The right leg was assessed for each subject as differences between proposed dominant and non-dominant legs have not been found for these parameters [11]. Three trials for each test were administered in order to ascertain a mean value from which to use for data analysis.

2.3. Stiffness assessment

A fully calibrated KinCom AP2 isokinetic dynamometer (Chattanooga Group Inc.; California, USA; 1997) was used to measure PR during ankle dorsiflexion and plantarflexion in order to determine a measure of PR at 5°/s [12]. The angular range that the dynamometer took the ankle joint through was within 5° of subjective end-range dorsiflexion and plantarflexion. The primary investigator ensured participants sat with right knee fully extended [13], as this mimicked the unilateral stance condition, with the upper part of the right leg firmly secured to the dynamometer seat in order to limit any knee movement during the trials. The left leg was allowed to hang over the edge of the seat of the dynamometer, flexed at the knee joint, parallel to the right leg, whilst the dynamometer passively moved the ankle joint through dorsiflexion until end range, then through to plantarflexion end range, with the maximum peak torque values being recorded during each trial ('$D_{\text{peak torque}}$' and '$P_{\text{peak torque}}$', Nm) [14]. Torque and angular position (°) on the KinCom were sampled with a frequency of 100 Hz and data was transferred using the Shelton KinCom Data Transfer Programme v1.0.28 (Shelton Technical Ltd.; Milton Keynes, UK) to a Windows XP SP3 computer (Viglen Genie, 3.0 GHz Duo processor, 2GB Ram). The values for peak torque were normalised based on the angular displacement that occurred during the trials [15] ('$D_{\text{peak torque}}$ angle' and '$P_{\text{peak torque}}$ angle', Nm/°).

2.4. Flexibility assessment

Participants were asked to actively dorsiflex their ankle to its end range before relaxing to their neutral position. The primary investigator ensured participants lay supine on a fixed massage couch with their right knee extended and foot hanging over the edge of the couch [16]. Markers were placed at the lateral malleolus, head of 5th metatarsal and mid-way between head of fibular and lateral malleolus. Their left leg was flexed to 45° at the hip and 90° at the knee; so as to mimic the unilateral stance condition. Participants were then asked to actively dorsiflex their ankle to its end range before relaxing to their neutral position [16]. 2-D motion analysis was chosen to assess maximal AROM in dorsiflexion ('AROM',°) as it has low measurement error [17]. A Casio Exilim EX-FH25 high-speed camera (Casio Inc.; New Jersey, USA) was positioned level with the axis of rotation, in the sagittal plane, 1 m from the lateral malleolus and recorded all trials at 100 frames per second. Quintic Biomechanics v21 software (Quintic Consultancy Ltd.; Coventry, UK) was then used by the primary investigator to identify maximal AROM in dorsiflexion.

2.5. Proprioception assessment

The ipsilateral angle reproduction test used was "passive production, active reproduction" [18] which involved the active reproduction of a passively specified target position. The difference between the target position and the subject's estimated target position was the outcome measure, irrespective of directional difference, and was known as absolute error (AE). The participants were positioned by the primary investigator in a similar manner to the AROM measures, with the anatomical markers in the same locations and the Casio Exilim EX-FH25 high-speed camera located in the same place. The ankle was passively dorsiflexed from the relaxed starting position to a set, pre-determined target position and the participant was informed of this by the primary investigator using the word "target". The ankle remained in this position for 5 s and was then passively moved to full plantarflexion and returned to the starting position. After remaining in the starting position for 3 s, the participant was asked, through use of the word "reproduce", to actively move their ankle in an attempt to match the target position. When the participant considered the