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PLANTARFLEXOR FORCE PRODUCTION IN ISOMETRIC AND STRETCH-SHORTENING CYCLE TASKS

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The ankle joint and its surrounding musculature are vital in sprinting, and recent work has developed a method to isolate the plantarflexor muscle group for analysis of its force-producing capabilities. The aim of this study was to compare values for plantarflexor force obtained using isometric dynamometry and an adapted force sledge in twenty healthy subjects. Results showed low relationships between isometric and dynamic strength measures, probably because the dynamic test utilises a stretch-shortening cycle. No relationship was observed between isometric strength and the sledge foot plate height during the task with a moderate relationship observed between dynamic strength and plate height. This highlights the important role the Achilles tendon plays in dynamic tasks.

KEY WORDS: dynamometry, force sledge, musculotendinous mechanics, strength

INTRODUCTION: The ankle joint has been shown to be vitally important in all phases of the sprint, especially the start and acceleration phases. Its importance begins with the push-off from the blocks (Charalambous *et al.*, 2012). The ankle is the major power generator from the second step out of the block onwards (Johnson & Buckley, 2001; Bezodis *et al.*, 2008; Debaere *et al.*, 2012), highlighting the importance of conditioning and assessment of the force production capabilities and stretch-shortening cycle (SSC) function of this particular muscle group to both games players and track athletes.

The force production capacities of this muscle group have primarily been determined by dynamometry (Falkel, 1978; Maganaris, 2003). This methodology allows for isometric and isokinetic data to be collected in a highly controlled setting, but the ecological validity of these measures is questionable as these modes of contraction rarely occur in sport (Cronin & Sleivert, 2005). Recent work has isolated the plantarflexors for analysis of force production capacities and stretch-shortening cycle function (Furlong & Harrison, 2013). This methodology still isolates the muscle group and maintains control but greater ecological validity of the movement is maintained as it is a dynamic task with similar kinematics to that of running and hopping. It also results in similar reaction forces on the limb.

The aim of this study is to compare the isolated muscle strength of the plantarflexors using isometric dynamometry and an adapted force sledge to identify what relationship, if any exists between the two methods. A secondary aim of this study is to investigate if isometric or dynamic strength is a better predictor of the height the sledge plate reaches (performance) during the dynamic cyclical loading task on the sledge. This would aid practitioners in deciding appropriate sport-specific test protocols for this particular muscle group for their athletes.

METHODS:

Participants: Following university ethics committee approval, twenty healthy subjects gave written informed consent to participate in this study (age: 23.5 ±2.30 years, mass: 74.2 ±11.51 kg, height: 1.73 ±0.075 m). None had any history of lower limb surgery and all were injury free in the lower limb for the preceding 3 months.

Isometric dynamometry testing: Due to the nature of the sledge testing, the dominant leg was defined as the preferred hopping leg which also happened to be the preferred kicking leg. All isometric tests were conducted using a Contrex dynamometer (Duebendorf, Switzerland). Subjects lay supine on the dynamometer, with their knee bent to 135º. Knee angle was determined by goniometry and defined as the internal angle between the greater trochanter, estimated knee joint centre and the lateral malleolus. The joint axis was aligned manually with the dynamometer axis of rotation with the joint in a maximally contracted state, at the position of interest. As much restriction as possible was used to ensure the heel did not lift from the test plate, as this could result in misalignment of the axes which is known to affect the measured torque (Arampatzis *et al.*, 2007). Familiarisation consisted of a series of isometric contractions at 25%, 50%, 75% and 100% of maximum torque, and was completed until the subjects obtained 3 measures at the 100% loading which were within 10% of each other. Testing then consisted of three maximal efforts at least 90 s apart to ensure energy system recovery. Subjects were instructed to exert maximum force against the plate while keeping their foot on the plate and hold it for 3-4 s. The same protocol was used for dominant and non-dominant legs.

Sledge testing: A similar methodology to Furlong and Harrison (2013) was used in this study to determine the force production capabilities of the plantarflexors. 12 mm retro-reflective markers were placed on the sledge plate edge and the subject's knee joint centre, lateral malleolus and lateral 5^{th} metatarsophalangeal joint for tracking by a six camera 3D motion analysis system (500 Hz, MAC Eagle, Motion Analysis Corporation Inc., Santa Rosa, CA., USA). These markers were used to define the ankle angle.

Figure 1. Force sledge set-up showing the full sledge with subject secured in place.

Subjects were positioned supine at the base of the sledge as shown in figure 1 and the thigh was secured using Velcro straps. Subjects were instructed to strike the plate as rhythmically as possible while minimising plate contact time, using only their ankle joint. Familiarisation consisted of a total of approximately 25-30 impacts with no added mass where the subject initially pushed the plate away from them and struck it rhythmically and a second trial where the plate was released from 30 cm away from the foot. The protocol continued until the subject was satisfied that they were familiar with the task and the researcher deemed the subject was striking the plate as instructed. The same instructions were used for the test protocol. After successful completion of a trial, the plate was secured away from the foot and additional mass was added to the sledge. The test was administered similar to an 11 repetition maximum (11RM) strength test, with the researcher attempting to reach the maximum loading in as short a time frame as possible. A loading of 70% of this 11RM has been shown to be the most reliable loading therefore trials at this loading were used for analysis (Furlong & Harrison, 2013).

Data treatment: Residual analysis was conducted on the sledge data to identify what was the optimum cut-off frequency to ensure a balanced signal: noise ratio. Sledge marker position data was filtered using a fourth order, zero lag, low-pass Butterworth filter with a cut-off of 12 Hz. Plate acceleration was calculated as the second derivative of plate position, with force calculated using Newton's second law with a correction for the component of weight acting down the sledge rails since the sledge was angled at 30°. Frictional force was negligible (0.18%) so was omitted from the calculation. Peak force (F_P) was the maximum force developed during each contact time. Contact time (CT) was defined as the period when plate marker acceleration was greater than zero and flight time (FT) defined as the period when it was zero or less. Plate height (i.e. displacement from release to peak of flight) was calculated using the equations of motion and assumed equal periods of upwards and downwards flight. This was considered a measure of SSC function similar to jumping height.

Data analysis: Based on previous work, only the middle impacts (4 to 8) were used for analysis. All statistical analysis was completed in SPSS Statistics 19 (IBM, Armonk, NY, USA). Pearson's correlation was used to determine what relationship, if any, existed between measures of isometric and dynamic strength of the plantarflexors, and the height reached by the plate during the dynamic task.

RESULTS: Table 1 provides a summary of the bivariate correlations of dominant and non-dominant leg measures. Large correlations were shown between dominant and non-dominant legs for the same mode of contraction, but the relationships between the same leg and mode of contraction, and mode of contraction and plate height were moderate.

Table 4. Pearson's correlations between isometric and dynamic force production capabilities. ** indicates significance at the 0.01 level (two-tailed), * indicates significance at the 0.05 level (two-tailed)

	Dynamic (DOM)	**Isometric (DOM)**	**Plate height (DOM)**	**Dynamic (NONDOM)**	**Isometric (NONDOM)**	**Plate height (NONDOM)**
Dynamic (DOM)	1					
Isometric (DOM)	.590**	1				
Plate height (DOM)	.683**	.179	1			
Dynamic (NONDOM)	.836**	.630**	.464*	1		
Isometric (NONDOM)	.580**	.887**	.083	.651**	1	
Plate height (NONDOM)	.500*	.186	.638**	.646**	.123	1

DISCUSSION: The correlations between dominant and non-dominant legs in both modes of contraction were high. This is not surprising as all subjects were healthy and uninjured and therefore would be expected to have similar functional relationships in dominant and non-dominant limbs.

Correlations between isometric and dynamic strength, despite being significant, were not high (.59 and .63 for dominant and non-dominant legs, respectively). The R^2 values were also low for these measures (.34 and .42), which indicates a relatively large proportion of unaccounted variance in scores. One of the primary sources of variance is the utilisation of SSCs in the dynamic task. In isometric tasks, force is dependent on muscle mass and the force producing capabilities of these muscles. In a SSC activity, the storage and recoil of elastic energy and involvement of stretch reflexes allow for enhanced force production capabilities. The performance enhancing benefits of the SSC in power activities have been well documented (van Ingen Schenau *et al.*, 1997) and the results above clearly show measures of isometric strength have no link to performance-related measures in dynamic sports-specific tasks (correlations of .179 and .123 in the dominant and non-dominant legs respectively). In contrast to this, the measures of dynamic strength and plate height (performance) were moderately correlated most likely due to effective utilisation of the SSC and elastic recoil.

CONCLUSION: The results of this study show the isometric and dynamic force-producing capabilities of the plantarflexors are not related. Further study is required to determine the relationship between SSC function and force output during dynamic SSC tasks.

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