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LEG DOMINANCE AND PLANTARFLEXOR STRETCH-SHORTENING CYCLE FUNCTION

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Large ankle kinetic asymmetry has been observed during maximal velocity sprinting which is not related to observed kinematic asymmetries. This may be due to underlying physiological and mechanical differences. The aim of this study was to use a recently developed method of isolating the plantarflexors to examine leg dominance in mechanical and stretch-shortening cycle function. Significant differences were observed in the peak force generated, rate of peak force development and reactive strength index of the plantarflexors of nine recreationally active subjects during a cyclical sledge task. This may explain why differences are observed in ankle kinetics during sprinting but further research is needed looking at SSC function in elite sprinters to determine if these trends are also observed in that population.

KEY WORDS: dominant leg, muscle-tendon unit, sprinting, stiffness

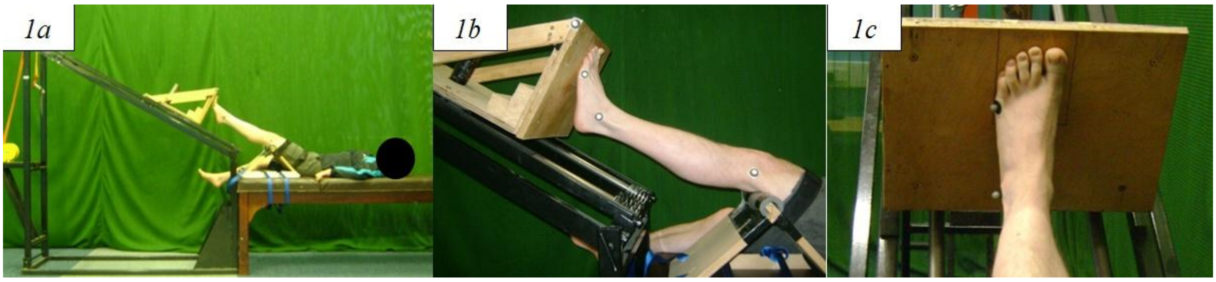
INTRODUCTION: Recent work has found large asymmetry in ankle kinetics during maximal velocity sprinting (Exell *et al.*, 2012) despite asymmetry not always being present in corresponding kinematics. This suggests different movement patterns and muscular control strategies may be employed by the dominant and non-dominant limbs to propel the body during running while maintaining cyclical rhythmical movement. These asymmetries may be the result of underlying physiological, muscle training related differences in the entire lower limb or in the plantarflexors which are the primary force generators around the ankle. In sprinting, fast stretch-shortening cycle (SSC) function is important. The SSC refers to a concentric contraction immediately preceded by an eccentric contraction (Bosco *et al.*, 1981). It is a mechanism to store elastic energy in the muscles and connective tissues during movement and its function is thought to be related to the level of musculotendinous stiffness present (Anderson, 1996). Fast SSCs are SSCs of less than 250 ms and occur continuously in sprinting. The reactive strength index (RSI), which refers to the ratio between a jump height and its preceding contact time, is regularly used as an assessment of SSC function (Comyns *et al*, 2007). Sprint athletes have been shown to have higher RSI and stiffness which relates to enhanced SSC function (Harrison *et al.*, 2004). Previous work using a force sledge has shown that in a cyclical loading task, there is no difference between lower limb peak force generation and SSC function (Flanagan & Harrison, 2007) despite the asymmetries observed in maximal velocity sprinting, but the sledge apparatus looks at the lower limb as a whole. Recent work by Furlong and Harrison (2013) has developed a reliable, valid method of isolating the plantarflexors for analysis of SSC function and musculotendinous mechanics. The aim of this study was to identify the differences, if any, in the SSC function of the plantarflexors as a possible explanation for ankle kinetic asymmetry in sprint performance. Since asymmetry has also previously been considered as a risk factor of injury, this may guide coaches and therapists in design of training protocols to optimise performance while simultaneously decreasing injury risk.

METHODS: Participants: Following university ethics committee approval, nine recreationally active healthy subjects gave written informed consent to participate in this study (age: 23.1 ±3.00 years; mass: 78.8 ±12.1 kg; height: 1.76 ±0.07 m). None had a history of lower limb surgery and all were injury free in the lower limb for the preceding 3 months.

Test protocol: A similar methodology to Furlong and Harrison (2013) was used in this study. One 12 mm retro-reflective marker was placed on the sledge plate edge for tracking by a three camera 3D motion analysis system (500 Hz, MAC Eagle, Motion Analysis Corporation

Inc., Santa Rosa, CA., USA). Subjects were positioned supine at the base of the sledge as shown in figures 1a, 1b and 1c 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.

All trials were completed using the dominant leg which was defined as the preferred hopping leg due to the nature of the task. For all subjects, this was also the preferred kicking leg. The plate began at a position 30 cm above the foot and was released after a ‘3, 2, 1’ countdown. The same instructions were given as in familiarisation. The plate was secured away from the foot after successful completion of each trial and additional mass added to the sledge. The test was administered similar to an 11 repetition maximum strength test, with the researcher attempting to reach the maximum loading in as short a time frame as possible. Furlong and Harrison (2013) showed that a loading equivalent to 70% of this 11RM produced the most reliable results so the trials analysed for this study used this loading. Mass added to the sledge has also been shown to affect measurements of F_P, RPFD and RSI obtained therefore the same mass was used for the non-dominant leg trial.



Figures 1a-c. Force sledge set-up. 1a) shows the full sledge set-up with subject secured in place. 1b) shows the motion analysis marker positions on the fifth metatarsophalangeal joint, lateral malleolus and knee joint centre, and 1c) shows the marked area which subjects were instructed to strike as rhythmically and continuously as possible.

Data treatment: Residual analysis was conducted to identify the optimum cut-off frequency to ensure the signal: noise ratio was balanced. Sledge marker position data was filtered using a fourth order, zero lag, low-pass Butterworth filter with 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 with rate of peak force development (RPFD) calculated as the peak force divided by the time in seconds it took to reach it. 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. Reactive strength index (RSI) was defined as the ratio between plate height and preceding CT.

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). Analysis of variance (ANOVA) was used to determine if between-groups differences existed for F_P, RPFD and RSI of the dominant and non-dominant legs. Effect size was calculated using partial eta^2 (η_p^2) using the formula $\eta_p^2 = SS_{effect}/(SS_{effect} + SS_{error})$, where SS_{effect} = effect variance and SS_{error} = error variance. The scale for classification of effect size was based on Hopkin’s scale (2002) and was based on *f* values for effect size. These were converted to η_p^2 using the formula $f = ((\eta_p^2/(1-\eta_p^2)))^{0.5}$. The scale for classification of η_p^2 was hence <0.04 = trivial, 0.041 to 0.249 = small, 0.25 to 0.549 = medium, 0.55 to 0.799 = large and >0.8 = very large (Comyns *et al.*, 2007). Observed power was calculated using the formula power = 1 – β, where β is the probability of a type II error (Vincent, 2005).

RESULTS: Significant differences of 12.4%, 19.8% and 20.9% were observed between the dominant and non-dominant limbs for measures of F_P, RPFD and RSI respectively. These resulted in medium to large effect sizes for the variables of interest.

Table 5. Descriptive and statistical results for peak force, rate of peak force development and reactive strength index of the plantarflexors in the dominant and non-dominant legs

	Dominant leg	Non-dominant leg	*p*	Effect size	Observed power
F_P (N)	526.7	461.3	0.011	0.628	0.837
RPFD (Ns^{-1})	8141.8	6531.4	0.034	0.496	0.618
RSI	1.15	0.91	0.018	0.577	0.754

DISCUSSION: Previous work has showed significant between-leg differences in maximum isometric plantarflexor torque and force production (Valderrano *et al.*, 2007), and the results of this study support those findings in a valid, dynamic test setting which includes a number of SSCs. Exell *et al.* (2012) reported asymmetry of up to 93% in work performed at the joint for eight subjects despite a lack of consistent corresponding kinematic asymmetries. Joint work is the product of joint torque (dependent on muscle group force production capabilities) and joint angular velocity (dependent on speed of muscular contraction, rate of force development and opposing co-contraction) therefore the results above may explain observed differences. Further study of plantarflexor F_P, RPFD and RSI in competitive sprinters is required to fully explain those results, but these preliminary findings would appear to provide some explanation.

Flanagan and Harrison (2007) previously showed no differences in measures of peak force generated and RSI of the entire lower limb during repetitive cyclical loading. The results above clearly show that the plantarflexors are different in terms of their force-production capabilities, how they develop this force and how they can apply this force. When Flanagan and Harrison's (2007) results are considered with the findings of this study, it appears that the hip, knee and ankle joints of the lower limb compensate for each other in order to maintain overall lower limb symmetry during cyclical activities such as running. These results would suggest that the two legs use different strategies to get off the ground. This appears to be a reasonable conclusion, as during a hopping or kicking task, the dominant and non-dominant legs perform different roles. The dominant leg is used in a quicker movement and has to develop force rapidly, while the non-dominant leg is more involved in leg stability and requires less dynamic, more isometric muscular contraction to maintain this. These two different roles could explain why the above results were observed.

Of further interest in these results is the much debated idea that limb symmetry reduces risk of injury. The results above were obtained from healthy, non-injured subjects who did not develop an overuse injury within the twelve months after the study. There appears to be a level of variation between the two limbs which naturally exists without causing any problems, but further work is required to compare these variables in injured and healthy populations before further conclusions can be made.

CONCLUSIONS: The results of this study would suggest that underlying differences in plantarflexor SSC function may explain the differences in ankle kinetic asymmetry previously observed and the joints of the lower limb may compensate for each other to maintain cyclical movement. Further study with competitive sprinters is necessary to identify if these results are repeated in that population. Interestingly for the practitioner, there appears to a natural level of between-limb difference in healthy individuals, suggesting that asymmetry may exist without causing any problems but further work with injured patients is required.

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