THE EFFECT OF INCREASED LOADING ON PLANTARFLEXOR FUNCTION DURING A STRETCH-SHORTENING CYCLE TASK

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Increasing loading is one of the most common methods used to increase exercise intensity but it is important to consider the influence of the increase on subsequent force output, rate of force development and, in the case of plyometric exercise, contact time. The aim of this study was to investigate the effect of altering loading on plantarflexor force and force production during a fast stretch-shortening cycle task. Results showed load increased force production and contact time and decreased flight time and reactive strength index. These results have important implications for practitioners in determining the optimal method of increasing training intensity in order to avoid negative training effects.

Keywords: intensity, muscle and tendon, mechanics, plyometrics, strength and conditioning, periodization

INTRODUCTION: Strength and conditioning coaches working with athletes can progress exercises by increasing the duration of time the exercise is performed for, the type of exercise, increasing intensity or increasing exercise frequency (Baechle & Earle, 2008). One of the most common ways of increasing exercise intensity is by increasing the relative load or mass moved by the athlete. For lower-body power exercises, this can be done through the addition of weights to a bar, use of weighted vests or attachment of weight to the ankle. While this additional weight has the effect of increasing the amount of force required to move the body, it may also affect the rate at which force can develop and in the case of plyometric exercises, the amount of time the athlete spends in contact with the ground.

Previous work has shown increased loading (from 20 to 60 and 100% of one repetition maximum) at the knee extensors during a stretch-shortening cycle task significantly influenced patellar tendon force, rate of force development, concentric joint velocity and vastus lateralis shortening velocity (Earp *et al.*, 2014). Ishikawa *et al.* (2005) showed that the catapult action of the Achilles tendon during a drop jump to be dependent on intensity of the preceding eccentric phase, which they manipulated by altering drop jump height. The plantarflexors have an important role to play during plyometric, fast stretch-shortening cycle exercises due to their importance in maintaining ankle stiffness (Hobara *et al.*, 2007). How plantarflexor function varies with increased intensity due to increased loading is unclear. It is important to determine the influence increased loading may have on this muscle group as during exercises where the primary aim is to move the added mass as rapidly and forcefully as possible, any effects may influence potential training benefits.

The aim of this study was to determine the effect of altering loading on measures of plantarflexor force, rate of force production and reactive strength index (RSI) during a fast stretch-shortening cycle task which isolates the plantarflexor muscles. This may aid practitioners in understanding the effect of increasing loading and subsequent potential training effects on this particular muscle group.

METHODS: Participants: Following institutional ethical approval and written informed consent, twenty healthy active participants participated in this study (11 males, 9 females, age: 23.5 ±2.3 years, height: 1.73 ±0.08 m, mass: 74.2 ±11.3 kg). All were active for at least 30 minutes, three days per week, had no history of lower limb surgery and were injury free for the preceding three months. All were advised to refrain from unaccustomed strenuous exercise for the 24 hours preceding data collection.

Sledge testing: All testing was performed using an adapted force sledge apparatus shown to be highly reliable (Furlong & Harrison, 2013). The preferred hopping limb was used for analysis. A 9.5 mm retro-reflective marker was placed on the sledge plate edge for tracking by three-dimensional motion analysis (500 Hz, MAC Eagle, Motion Analysis Corporation Inc., Santa Rosa, CA., USA). Participants were supine at the base of the sledge and the thigh was secured using Velcro straps so maximum knee angle during impact was between 140 and 160° (figure 1). Participants were instructed to strike within a marked area, to push the plate up the rails as quickly as possible and as high as possible using just their ankle joint. Familiarisation consisted of 25-30 impacts where participants rhythmically struck the plate and where the plate was dropped from 30 cm above the foot, until the researcher was satisfied the plate was being struck as instructed.

Figure 1. Adapted force sledge set-up, showing test limb position

During each trial, participants completed 11 impacts. Mass was added to the sledge between each effort. Trials were performed in a semi-randomised order, with the aim to reach an 11 repetition maximum (11RM) loading in as few efforts as possible and some of the lighter loads completed after the 100% 11RM effort. Trials were rated from 1-5 on the basis of perceived difficulty to complete the 11 impacts, where 1 was very easy and 5 was very hard. Subjects were allowed a minimum of 90 s break between trials to allow for recovery, but most participants took up to three minutes break between efforts. The loadings used for analysis were hence 1) 55.9 ±5.9% of 11RM, 2) 68.2 ±5.3% of 11RM, 3) 80.2 ±5.2% of 11RM, 4) 89.3 ±3.7% of 11RM and 5) 100% of 11RM.

Data treatment: Sledge marker position data was filtered using a fourth order, zero lag, low-pass Butterworth filter with a 12 Hz cut-off. Plate acceleration was calculated as the second derivative of plate position with respect to time, and force calculated using Newton's second law with a correction for the component of weight acting down the sledge rails as the sledge was angled at 30°. 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. Peak force (F_P) was defined as the peak concentric force exerted during each CT, with rate of peak force development (RPFD) calculated as F_P divided by the time in seconds it took to reach F_P from initial contact. The average of impacts five to seven were used for analysis. RSI was defined as the plate height divided by the preceding CT.

Statistical analysis: All analysis was conducted in SPSS Statistics 20 (IBM, Yarmonk, NY, USA). Analysis of variance with repeated measures was used to detect between-loading differences for each variable. Where data violated the assumption of sphericity, the Greenhouse-Geiser correction was used. Alpha was set at $p < 0.05$. The effect of load on each variable was determined using η_e^2. The scale for classification used was <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). Between-group effect sizes were determined using Cohen's d_z (Cohen, 1977) in Microsoft Excel (Microsoft Inc., Redmond, WA., USA). The scale of interpretation used for these values was 0.2 to 0.59 = small, 0.6 to 1.19 = medium, 1.20 and above = large (Hopkins, 2006). Observed power was calculated as power = 1 – β, where β is the probability of making a type II error (Vincent, 2005).

RESULTS AND DISCUSSION:

Table 1. The effect of increased loading on plantarflexor function during a fast stretch-shortening cycle task

	55%	70%	80%	90%	100%	Observed power	η_e^2
F_P (N)	481 ±163	528 ±193	559 ±167	617 ±184	629 ±173	1.000	0.626
RPFD ($N.s^{-1}$)	8170 ±3081	8290 ±3670	8637 ±2756	9087 ±3228	8745 ±3049	.534	0.088
CT (s)	0.143 ±0.024	0.159 ±0.031	0.168 ±0.026	0.173 ±.024	0.177 ±0.027	1.000	0.540
FT (s)	0.537 ±0.106	0.537 ±0.121	0.516 ±0.108	0.517 ±0.091	0.502 ±0.092	.819	0.187
RSI	1.28 ±0.49	1.17 ±0.54	1.02 ±0.43	0.99 ±0.35	0.91 ±0.32	1.000	0.449

A general trend of increased FP and CT and decreased FT and RSI was observed with increased loading. Observed power was high in all measures, but lower for RPFD. The small calculated effect sizes for this variable suggests the likelihood of type II error is low.
Similar to Earp *et al.* (2014) and Ishikawa *et al.* (2005), increased loading increased F_P. Statistically significant differences with moderate-large effects observed between all loads with the exception of 70-80% (small) and 90-100% (NS, <.2) with a large η_e^2. Force was calculated as the product of mass and acceleration therefore increased mass resulted in increased force provided acceleration remained constant or increased. This is of interest to the strength and conditioning coach aiming to increase strength, suggesting increasing loading acts to increase maximal strength.
Average values of RPFD were similar at 55 and 70%, increased at 80 and 90% but then decreased again at 100%. Only RPFD at the 90% load was statistically significant different to other groups with negligible or small effect sizes observed between it and other loadings. Loading was hence considered to have no effect on plantarflexor RPFD, in contrast to Earp *et al.* (2014). This may be due to differences in calculation as RPFD in this study was calculated as the quotient of peak force in Newtons and time to peak force in seconds. While timing of F_P as a percentage of CT was consistent across loadings, CT increased so bigger forces were divided by a bigger time, resulting in no observed difference. Analysis of measures such as rate of force development in the first 30 and 50 ms would give further insight into the effects of load on rate of force development.
CT was statistically significantly different between loads except between 70 and 80%, and 80 and 90%. The differences between 80 and 70, 90 and 100%, and 90 and 100% were small but all other differences were moderate or large. η_e^2 was medium tending towards large. Increased CT allows for increased time to develop force which may partly explain the observed increased force, and may also reflect the body's response to dissipate the impact force and reduce risk of injury. CT has previously been reported as an important measure for the strength and conditioning coach to monitor training specificity and effectiveness (Flanagan & Comyns, 2008), allowing classification of slow and fast SSC activities. This increase in CT is particularly relevant for training speed athletes who concentrate training on decreasing CT: for these athletes, concentrating on developing explosiveness at lower loadings may be more appropriate.
FT at 55% was significantly different to the 80 and 100% loading, at 70% it was different to the 80 and 100% loadings and 90% it was different to the 100% loading. η_e^2 was small, with small to medium differences observed between loads. The difference between 80 and 90% was negligible. This is of interest as despite the increase in concentric force, performance-

related output decreased suggesting a negative effect of increased loading. This decrease in performance may potentially be due to the protective nature of the Golgi tendon organs, which activate when excessive load is placed on the tendon (Flanagan & Comyns, 2008). They act to inhibit contraction, which may explain why FT was observed to decrease with the increase in loading.

Statistically significant differences in RSI with medium to large effect sizes were observed between most groups. Effect size was small between 55 and 70%, 80 and 90%, and 90 and 100%, and negligible between 80 and 90%. η_e^2 was medium. For the researcher, this result highlights the importance of standardising loading intensities to allow for between-group comparison of SSC function. Decreased RSI with increased intensity has previously been reported as a decreased ability of the body to utilise eccentric loading and a suboptimal training stimulus, but may also indicate a potential injury risk (Flanagan & Comyns, 2008). Further investigation of muscle and tendon mechanical behaviour with altered loading could provide further insight into the effects of increased loading on plantarflexor function during a SSC task.

CONCLUSIONS: Increased loading on the plantarflexors increases concentric plantarflexor force production and CT during a fast SSC task and decreases FT and RSI. This has significant implications for the strength and conditioning coach working with athletes, especially when the focus of training may be for power or improving fast SSC performance. Increased force production appears to come at the expense of improving fast SSC performance hence increasing intensity by increasing loading should be used by coaches with consideration to the desired outcome of the training programme.

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