“Effects of an Eccentric-Overload Training Intervention on Force-Time Characteristics of Drop Landing Tasks: A Case Study”

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Headline

Many critical sport tasks are characterised by the presence of very high forces and exchanges of mechanical energy, often reaching the body's biological limits (1). To meet these demands, the muscles and joints must serve multiple functions which can be characterised by their mechanical outputs such as acting as motors, dampers, struts or springs (2). One sport which tests the extremes of these varied functions is artistic gymnastics. Vertical ground reaction forces (vGRF) of 14.4x body weight (BW) have been reported during landings (3), reaching 3 meters above the landing surface (4). Tumbling involves vGRFs as high as 15.1x BW in 120-130ms (5), with sprint speeds of 9.95 m.s-1 reported while accelerating to the vault (6). A commonality between these tasks are large braking forces, with eccentric overload training potentially offering a promising method of stimulating adaptations here (7).

Aim

The aim of this study was to investigate the effects of a 3-week eccentric overload training phase on landing and drop jump force-time characteristics.

Methods

Participant

A 25-year-old international male gymnast who trained full-time participated in this study. The gymnast was 5 months post shoulder surgery with a good level of global function, providing an opportunity to explore training methods. He had been weight training for 5+ years and had attained high levels of global strength, e.g. isometric mid-thigh pull: 6.8xBW.

Design

Following familiarisation with the tests during normal training, the gymnast completed the drop landing and drop jump testing. Following this, 3 weeks of eccentric overload training for the leg extensors were completed before re-tests were completed. 3 weeks of traditional loading was then completed before further re-testing to assess whether potential changes would maintain or fluctuate.

Testing

A drop landing was performed from 100cm for 5 repetitions to characterise the capacity to attenuate force. The cues of “land as softly and quietly as possible” were used to emphasise energy dissipation over a longer duration. The gymnast was instructed to step off the platform without jumping up or lowering his centre of mass prior to leaving the platform. Arms were free to assist in balancing during the landing. The main outcome measures for the drop landing task were peak vGRF (first and second local peaks, Figure 1) and time to peak VGRF (TTPF). Lower peak vGRFs have been demonstrated to involve higher muscular contributions to energy dissipation with less energy required for dissipation by the remaining tissues such as the skeletal system (8,9). If forces can be distributed over a longer duration, lower peak force is required to perform the negative work to dissipate the energy.

A drop jump from 40cm for 3 repetitions was used to characterise leg spring stiffness, with the cues of “bounce as quickly as possible on the floor and jump as high as possible”. Step-off instructions were the same as during landings, but arms were placed on hips to minimise their contribution to the test. A force platform was used for both tests to measure ground reaction forces sampled at 1000Hz (Kistler 9286B). Vertical stiffness was the main variable used to characterise leg spring function, and was calculated by peak vGRF divided by negative of displacement of the COM. The reactive strength index (flight time/ground contact time) was also calculated to highlight temporal aspects of the jump.

Training

Table 1. outlines the exercise selection and progression throughout the 3-week eccentric overload phase for the leg extensors. A short-duration, high intensity-low volume programme was used which is in line with previous studies which reported adaptations using these variables (10,11). With the exception of the flywheel squat, all eccentric overload exercise were completed supramaximally by performing the concentric with 2 legs and lowering with 1. Supramaximal exercises were lowered for 3s, in line with previous studies which have demonstrated large increases in eccentric peak torque (12,13). The aim during each session was to work up to a maximal top set, this led to an average of 27% increase over the 3 weeks.

Statistical Analysis

The mean difference and 95% confidence interval of the mean difference between time points were calculated using Estimation Statistics ‘two groups’ analysis (14). A clear difference was interpreted when the 95% confidence interval of the mean difference did not overlap zero. When the 95% confidence interval did not overlap zero, magnitudes of Cohen's d effect size were calculated using the pooled standard deviation and interpreted as small ($0.2 \leq d < 0.6$), moderate ($0.6 \leq d < 1.2$), large ($1.2 \leq d < 2.0$), very large ($2.0 \leq d < 4.0$), and extremely large ($d \geq 4.0$) (equivalent scale used for negative values of d) (15). The direction of the mean difference and accompanying effect size indicated whether the post-measure (positive difference), or pre-measure (negative difference) was of larger magnitude.

Table 1: Exercise Selection and Progression

	Week 1			Week 2			Week 3		
Session 1	Sets	Reps	Load (kg)	Sets	Reps	Load (kg)	Sets	Reps	Load (kg)
Flywheel Squat (Eccentrix)	3	8	-	4	8	-	4	8	-
Alternating DB Press	3	5/5	-	3	5/5	-	3	5/5	-
TRX Row	3	8	-	3	8	-	3	8	-
Romanian Deadlift	3	5	-	3	5	-	3	5	-
Calf Raise (1 down, 2 up)	3	3/3	20	3	3/3	24	3	3/3	28
Session 2									
SL 45° Leg Press (1 down, 2 up)	3	6/6	250	3	4/4	270	3	2/2	310
Single Arm Cable Row	3	5/5	-	3	5/5	-	3	5/5	-
Elevated Press-up	3	8	-	3	8	-	3	8	-
SL Lying Leg Press (1 down, 2 up)	3	4/4	160	3	3/3	180	3	2/2	220
SL DB Calf Raise (1 down, 2 up)	3	5/5	22	3	5/5	26	3	5/5	30

Results

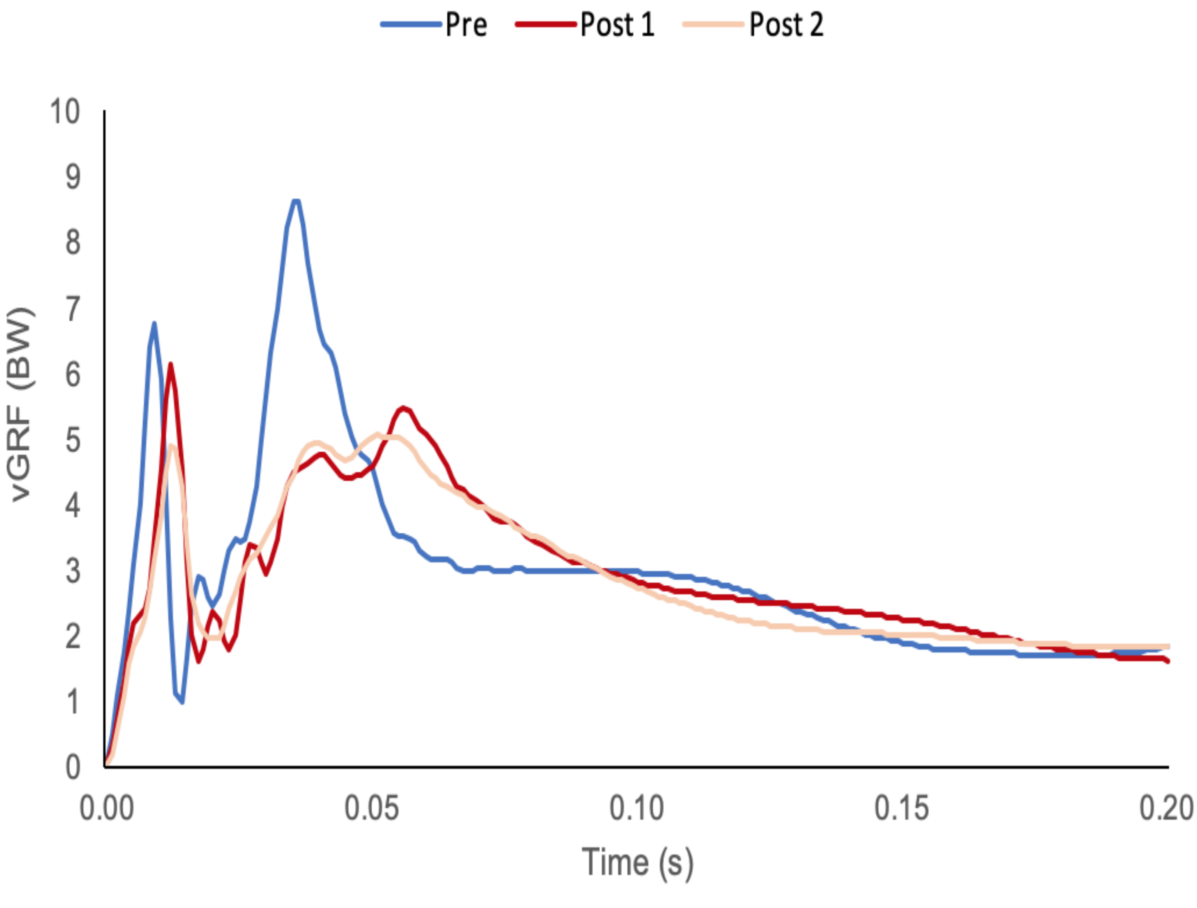

Fig. 1: Drop Landing vGRF Curves

Table 2: Drop Landing results

		Peak vGRF1 (BW)			Peak vGRF2 (BW)			TTPF 1 (s)			TTPF 2 (s)		
Pre		6.45	±	0.35	7.47	±	0.91	0.010	±	0.001	0.041	±	0.005
Post 1		6.00	±	0.40	5.32	±	0.74	0.013	±	0.001	0.053	±	0.004
Post 2		4.94	±	0.32	5.30	±	0.62	0.012	±	0.000	0.049	±	0.006
Pre vs.	mean diff		*-0.45*			*-2.15*			*0.002*			*0.012*	
Post 1	95% CI	-0.87	to	-0.05	-3.03	to	-1.18	0.001	to	0.004	0.007	to	0.017
	d		-1.20			-2.60			2.15			2.62	
Pre vs.	mean diff		*-1.51*			*-2.17*			*0.001*			*0.008*	
Post 2	95% CI	-1.89	to	-1.14	-3.01	to	-1.27	0.000	to	0.002	0.001	to	0.013
	d		-4.55			-2.80			1.40			1.42	
Post 1 vs.	mean diff		*-1.06*			-0.02			*-0.001*			*-0.005*	
Post 2	95% CI	-1.45	to	-0.63	-0.80	to	0.72	-0.002	to	-0.001	-0.011	to	0.000
	d		-2.95			-0.03			-1.49			-0.93	

Note: *Underlined and italic text* indicates a clear difference between means (95% CI does not overlap zero)

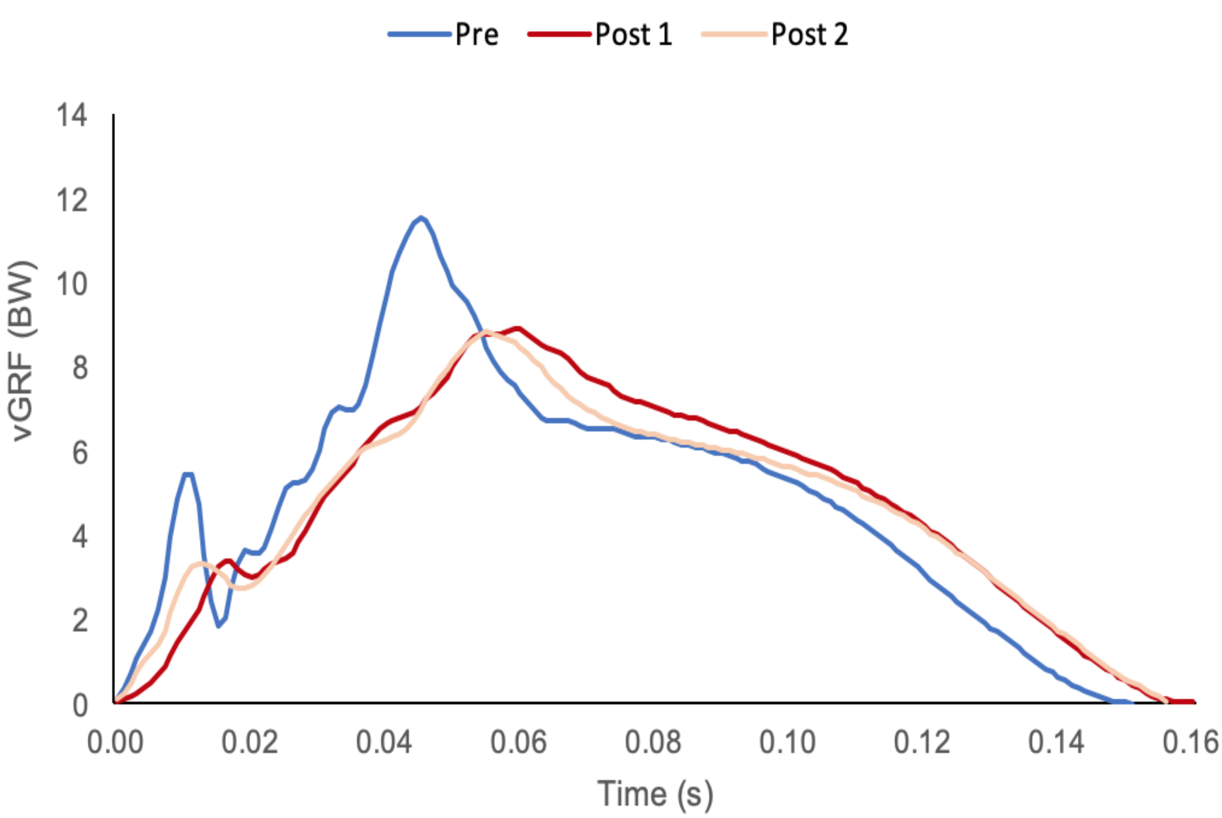

Fig. 2: Drop Jump vGRF Curves

Table 3: Drop Jump results

		RSI (FT:CT)			Flight Height (m)			Contact Time (s)			Stiffness (N.kg^{-1}.m^{-1})		
Pre		3.64	±	0.05	0.38	±	0.01	0.152	±	0.002	973.4	±	125.5
Post 1		3.70	±	0.06	0.42	±	0.02	0.158	±	0.003	728.4	±	43.0
Post 2		3.86	±	0.03	0.43	±	0.01	0.154	±	0.004	702.2	±	0.8
Pre vs.	mean diff		0.07			*0.04*			*0.006*			*-245.0*	
Post 1	95% CI	-0.03	to	0.13	0.03	to	0.07	0.002	to	0.008	-382.5	to	-139.1
	d		1.18			2.92			2.62			-2.61	
Pre vs.	mean diff		*0.22*			*0.05*			0.001			*-271.3*	
Post 2	95% CI	0.17	to	0.27	0.04	to	0.07	-0.002	to	0.004	-408.6	to	-189.0
	d		5.36			4.88			0.43			-3.06	
Post 1 vs.	mean diff		*0.16*			0.01			*-0.005*			-26.3	
Post 2	95% CI	0.09	to	0.22	-0.02	to	0.02	-0.009	to	-0.001	-52.3	to	22.8
	d		3.20			0.61			-1.44			-0.86	

Note: *Underlined and italic text* indicates a clear difference between means (95% CI does not overlap zero)

Discussion

A bimodal vGRF curve was observed both pre- and post-intervention during landings (Fig. 1). Following the intervention, peak vGRF1 (d = -1.20 (large) and -4.54 (extremely large) for post-1 and post-2, respectively) and peak vGRF2 (d =-2.60 (very large) and -2.80 (very large) at post-1 and post-2, respectively) were reduced upon landing. In addition, the time to first (TTPF1; d = 2.15 (very large) and 1.40 (large) at post-1 and post 2, respectively) and second (TTPF2; d = 2.62 (very large) and 1.42 (large) at post-1 and post 2, respectively) were elongated (Table 2). This "softer" landing may have resulted from increased muscle contribution to energy dissipation, with reduced plantar flexor and increased knee and hip negative work previously shown to facilitate this strategy (9). Softer landings involve lower segment accelerations and are extended over a longer duration which would require enhanced control from the muscles acting on these segments (15). Improved coordination could have been facilitated by improvement in muscle activation strategies unique to the eccentric phase e.g. recruitment order, discharge rate, neuromuscular inhibition (12,16,17). A bimodal vGRF curve was also observed in the drop jump, although the impact peak was much less pronounced post-intervention. Visual inspection of the curves reveal the same patterns observed in the landings, a delayed and lower peak force. This is manifested in significantly lower vertical stiffness post-intervention (d = -2.61 (very large) and -3.06 (very large) at post-1 and post-2, respectively), a likely negative adaptation for the tasks requiring high spring function such as tumbling and upright running. It is possible that the mechanisms which underpinned a greater capacity for damping in the landing, compromised spring function in the drop jump. Shifts in torque-angle relationship have been reported in this time frame (18). This could shift the angle of peak torque towards greater dorsiflexion leading to a longer GCT and reduced vertical stiffness. It is also possible that if alterations in joint contribution reported in DeVita & Skelly (9) and Zhang et al. (19) underpinned the "softer" landing strategy, that these contributions also carried over to the drop jump. However, these potential mechanisms are speculative in the absence of joint kinetic data.

While muscles have a degree of multifunctionality, their specialisation properties (e.g. architecture, neural activation) are influenced by how multifunctional the muscle has been during habitual loading (20). The architecture of a muscle like the soleus makes it ideal for strut/spring function in many dynamic tasks, loading it with a unidimensional programme biased towards damping function may be counterproductive for reactive tasks.

Practical applications

- Eccentric overload for the leg extensors may be an effective method of improving force attenuation during landings.
- Using the loading variables adopted in this study (e.g. full ROM, 3s lowering phase) may compromise leg stiffness.

Limitations

A significant limitation of this study is the absence of joint moment and work data which limits the interpretations to centre of mass analysis and not joint-level energy dissipation. Another limitation is that the centre of mass velocity upon ground contact was estimated from the height of the platform, not the actual drop height of the gymnast, which was unknown and may have varied between trials.

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