MAXIMIZING THE USE OF ELASTIC ENERGY IN A STRETCH SHORTEN CYCLE MOVEMENT

WILSON, G.J.; ELLIOTT, B.C.
Department of Human Movement and Recreation Studies
University of Western Australia
Australia

ABSTRACT

Twelve experienced male weight lifters performed a rebound bench press lift and a non-rebound bench press lift. Cinematographic and force data were obtained pertaining to the use of elastic strain energy and the eccentric load encountered during the rebound bench press lift. The stiffness of each subject's series elastic component (SEC) was also determined, using an oscillation technique performed in a position specific to the bench press movements. It was established that the variability between subjects in the use of elastic energy was largely accounted for by the stiffness of the SEC and the eccentric load. The utilization of elastic strain energy in the rebound bench press lift was maximized when a lifter possessed a SEC which, when under maximal tension, was highly compliant (ie a stiffness value less than 12000 $N\ m^{-1}$) and experienced an eccentric load of 20 to 35 Ns of impulse, additional to bar weight, during the final 150 ms of the eccentric phase of the lift.

INTRODUCTION

The performance of an eccentric muscular action followed immediately by a concentric action is a common feature of human movement. Indeed this stretch-shorten cycle (SSC) movement pattern is apparent in running, jumping, throwing, hitting and lifting activities. The rationale behind the use of the SSC is that it augments the concentric phase of movement, resulting in an increase in both work and power (Asmussen and Bonde-Petersen, 1974a; Cavagna et al., 1968) and enhanced movement efficiency (Asmussen and Bonde-Petersen, 1974b; Thys et al., 1972) when compared to similar movements performed without prior stretch. Such observations are commonly explained as being a consequence of the utilization of elastic strain energy (Alexander and Bennet-Clark, 1977).

The mechanics underlying the use of elastic strain energy in SSC activities is a simple process, analogous to stretching an elastic band and releasing it. During a resisted counter-movement the compliant regions of the musculo-tendinous unit, the SEC, are extended and consequently store elastic strain energy. On movement reversal the extended regions recoil to their original form and in so doing a portion of the stored strain energy is recovered to produce potential and/or kinetic energy that may augment the subsequent concentric action.

Two independent variables which are logically related to the utilization of elastic energy in SSC movements are: i) The stiffness of the SEC, and ii) The eccentric load. The purpose of this study was to examine to what extent these variables accounted for the variability between subjects in the use of elastic energy in SSC movements,and to determine what values of SEC stiffness and eccentric load allow for the optimal use of elastic strain energy in SSC movements. The movement paradigm used to examine these questions was the bench press lift. The bench press is a popular SSC exercise which lends itself to the storage and release of strain energy (Elliott et al., 1989). The lift is performed whilst lying face up on a bench. A bar is lowered to the chest and subsequently raised again to arms length by forces primarily exerted about the elbow and shoulder joints.

METHODS

SAMPLE

Twelve experienced male bench pressers of varying ability served as subjects in this study. Subjects' age, height, weight, years of training, and perceived maximum bench presses are outlined in Table 1. All subjects were in current training at the time of testing and signed an informed consent document prior to their participation in the study.

TABLE 1
Subjects Characteristics

		Mean	Standard deviation
Age (yrs)		25.0	3.2
Height (m)		1.80	0.07
Bodymass (kg)		95.0	19.1
Years of training		5.3	1.9
Perceived maximum			
a) *RBP	(kg)	143.1	28.0
	(N)	1403.8	277.1
b)**PCBP	(kg)	125.0	25.1
	(N)	1226.2	254.2

* RBP = Rebound bench press
**PCBP = Purely concentric bench press

The experiment involved subjects participating in two testing sessions which were separated by approximately seven days. The first testing occasion involved the determination of each subject's SEC stiffness using an oscillation technique performed in a position specific to the SSC portion of the bench press lift. The second testing session required subjects to perform two bench press lifts. These involved a SSC rebound bench press (RBP) and a purely concentric bench press (PCBP), where the movement was initiated from the chest, without prior stretch. This session provided data pertaining to the utilization of elastic energy in the SSC movement and the eccentric load experienced by each subject.

EXPERIMENTAL TASKS
A) OSCILLATION TECHNIQUE

One in-vivo method of determining the viscoelasticity of human musculature is to gently perturb a loaded musculo-tendinous unit and record the free response of the system (Shorten, 1987). The resulting damped oscillation (Figure 1) can be modelled by a second order linear equation and the stiffness (k) of the system can by determined by the following equation:

$$k = 4mf^2\pi^2 + c^2/4m$$

where m = mass of the system
The damped natural frequency (f) was quantified as the inverse of the period between successive force peaks (1/T Fig.1). The damping coefficient (c) was determined by plotting the natural log of peak forces against time and obtaining the slope of the line.

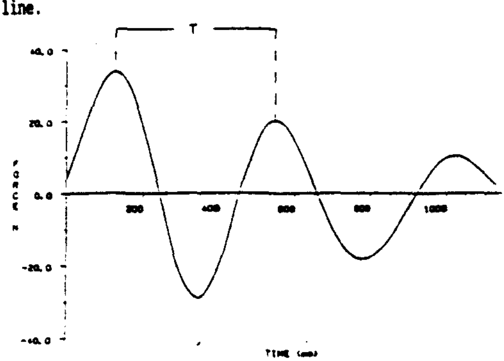

Figure 1: Damped oscillation

The oscillations were recorded from subjects while they maintained a quasi-static muscular action in a position specific to the bench press movement. To commence the procedure a standard olympic bar was lowered as if to perform a RBP, however the movement was terminated approximately 3 cm above the chest. As this position was maintained an external force of approximately 100 N was briefly (150-200 ms) applied to the middle of the bar with a downward push of the experimenter's hands.

Subjects were instructed to maintain a constant level of muscular activity and not respond to the perturbation during the oscillation of the bar. Such an occurrence was monitored by EMG electrodes placed over the pectoralis, deltoids, triceps brachii and biceps brachii muscle groups and displayed on a monitor screen of an IBM-PC compatible computer. When subjects deliberately forced the oscillations, discrete cyclic bursts of EMG activity were observed and the trial was repeated.

Fifteen oscillations comprising three trials at five progressively heavier loads were recorded for each subject. The loads were calculated as a percentage of the subject's perceived maximum RBP and represented 15%, 30%, 45%, 60% and 70% of the subject's perceived maximum. Loads above 70% were not used as they could not be reliably maintained in a stable position for the duration of the oscillation technique, as the bar tended to contact the chest following the perturbation.

B) THE BENCH PRESS

To ensure that subjects adopted a performance maximizing movement strategy a maximal load was required. Thus both bench press movements were performed at 95% of a subject's perceived maximum for each movement condition (Table 1). Prior to lifting each subject performed their standard warm-up, which included several sets of progressively increasing loads. Each subject was given as much recovery time between lifts as desired.

EXPERIMENTAL PROCEDURES

Both the bench press and oscillation movements were performed on a bench that was rigidly mounted to a force platform (Kistler 9281B) by four bolts. The vertical and horizontal components of force from these movements were recorded on disc. The bench press lifts were filmed at 100 fps by a 16 mm Photosonics high speed camera attached to a rigid tripod and fitted with a lens of 25 mm focal length. The camera was set with a shutter angle of 45 degrees giving an exposure time of 1/800 s. The camera was position perpendicular to the sagittal plane of motion of the subject and bar.

ANALYSIS AND TREATMENT OF DATA

The performance difference between the PCBP and RBP lifts was, for the purposes of this study, assumed to be dominantly caused through the utilization of elastic strain energy. The use of such energy was quantified as follows:

Elastic energy use (%) = (RBP Impulse - PCBP Impulse) /RBP Impulse * 100% where impulse was calculated over the first 0.37s of the concentric phase of each lift. This time period was determined after examination of force time and power-time curves of the PCBP and RBP lifts revealed that for all subjects the augmentation to performance derived from prior stretch was no longer evident 0.37 s into concentric motion. Such an observation is consistent with previous research (Chapman and Caldwell, 1985).

Throughout the final portions of the eccentric phase of the RBP lift subjects experienced relatively large forces. During this final approximate 150 ms of bar descent subjects were apparently storing elastic energy in their SEC to be released during the initial concentric motion. The eccentric load encountered by each subject during this period was quantified by integrating the force produced, above bar weight, with respect to time over this 150 ms epoch.

A second-order dual pass Butterworth digital filter was used to smooth the position-time data at a cut-off frequency of 5 Hz. Velocity data were subsequently derived via the process of simple finite difference calculus. The film data provided positional information which was used to delimit the RBP movement into its descent and ascent phases. The velocity data, used in conjunction with force data, allowed for the calculation of the instantaneous power exerted on the bar. By integrating the power-time curve with respect to time the work produced during each lift was determined.

RESULTS AND DISCUSSION

A) SEC STIFFNESS

To experimentally determine what value of maximal SEC stiffness (ie the value of SEC stiffness achieved during maximal loading of the musculature) optimized the utilization of elastic strain energy in the SEC stiffness was correlated against the use of elastic energy. A highly significant ($p < 0.01$) correlation coefficient of -0.718 was obtained (Figure 2). This implies that the SEC stiffness value alone accounts for approximately 52% of the variance in the use of elastic energy. Further it strongly indicates that the optimal stiffness of the SEC is towards the compliant end of the elasticity continuum. In fact during the initial portion of concentric motion of the RBP lift the five most compliant subjects (average maximal SEC stiffness of 13621.6 N m^{-1} ± 1214.9) released an additional mean of 48.7 J of elastic strain energy due to prior stretch, whereas the five stiffest subjects (average maximal SEC stiffness of 22274.9 N m^{-1} ± 3103.4) only released an additional mean of 12.8 J of elastic strain energy derived from prior stretch. These findings confirm previous postulations of Cavagna (1977) and Shorten (1987) that a compliant SEC would maximize the utilization of elastic strain energy in SSC movements.

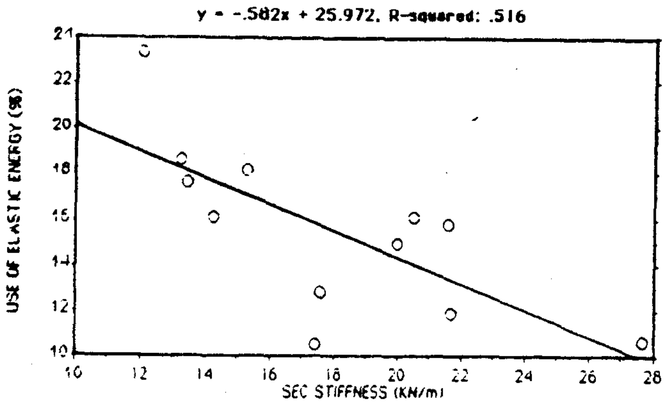

Figure 2: Correlation between SEC stiffness and the use of elastic energy

B) ECCENTRIC LOAD

The eccentric load experienced should logically be related to strain energy storage, and thus associated with the utilization of elastic energy. The best 'least squares' fit to the use of elastic energy (y) versus eccentric load (x) data was the quadratic relationship:

$$y = f(x) = 6.9295 + 0.8989x - 0.01576x^2$$

This equation provided a significant fit to the experimental data ($p < 0.05$) with a coefficient of quadratic correlation of 0.724. The relationship is depicted in Figure 3. The implication from this association is that the eccentric load experienced during the final 150 ms of a RBP lift accounts for approximately 52% of the variance in the utilization of elastic strain energy in the SSC movement. A similar relationship between eccentric load and the use of elastic energy has been reported by a number of authors in experiments involving drop jumps from various heights (Asmussen and Bonde-Petersen, 1974a; Komi and Bosco, 1978).

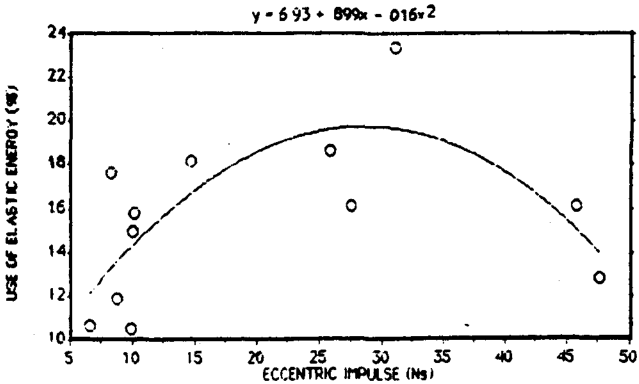

Figure 3: Quadratic regression between eccentric load and use of elastic energy

CONCLUSIONS AND IMPLICATIONS FOR PERFORMANCE

The utilization of elastic strain energy in a SSC movement would appear to be determined to a large extent by the SEC stiffness of the musculature performing the movement and the eccentric load encountered. To maximize the utilization of elastic strain energy in the RBP lift the maximal stiffness of the SEC should be towards the compliant end of the elasticity continuum (greatest elastic energy utilization achieved with the most compliant SEC ie 12 015 N m^{-1}, Figure 2) and an eccentric load of between 20 to 35 Ns of impulse, above bar weight, encountered during the final 150 ms of the descent phase (Figure 3).

The eccentric load would appear to be a performance variable that is easily modifiable as it is dependent entirely on the bar descent strategy adopted by the lifter. Thus given the appropriate feedback a performance maximizing descent strategy could be obtained. Enhancing the compliance of the SEC is a possibility that has yet to be explored and research is currently in progress to examine if flexibility training will achieve this end.

ACKNOWLEDGEMENTS

The authors would like to thank Assoc. Prof. A. Wood for his assistance throughout this research project.

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