MUSCULAR PRE-TENSION AND JUMPING: IMPLICATIONS FOR DIVE STARTS

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Isometric pre-tension has been shown to increase average torque in the leg extension movement. The effect of different levels of isometric pre-tension (PT) on vertical jumps has not been investigated. Twenty male University students completed a jumping task using PT levels of 0, **40,** 50, 60, 70 and 80% of a maximal voluntary contraction. The results were compared with those of a jump with a counter movement (CMJ). The CMJ had a significantly lower peak force than all other jumps. The rate of force development decreased with increased levels of PT. CMJ height was significantly larger than all PT jumps, with no difference in jump height between the PT levels. There was no change in reaction time with PT but time from a starting signal to take off was significantly less. This has implications in decreasing swimming dive start times.

KEY **WORDS:** pre-tension, jumping, peak force, jump height, reaction time.

INTRODUCTION: Muscular pre-stretch and its effects on work output has been widely researched (van Ingen Schenau et al., 1997). The advantage of using a counter movement in a jump and the possibility of using the stretch shortening cycle (SSC) is currently a topic of debate. Van Ingen Schenau et al. (1997) stated that enhancement occurs because pre-stretch allows muscles to develop a high level of active state and force before starting to shorten. If this is the case, the use of an isometric pre-stretch of a muscle could enhance performance. Muscular pre-tension offers potential advantages for swimming starts where reaction to a start signal mitigates against counter movements. The use of an isometric pre-load has been tested in regards to a controlled leg extension movement with equipment such as the KinCom and Cybex isokinetic dynamometers. Previous studies show that the use of pre-tension increases torque production in the initial range of motion (ROM) of a leg extension exercise (Jensen et al., 1991; Tis et al., 1993,). As a result, the average torque is increased by the use of pre-tension. This was due to the initial level of muscle tension at the beginning of the movement, allowing the muscle to work closer to its maximum earlier in the movement. However, the rate of force development (RFD) decreased with an increase in the level of pre-tension (Jensen et al., 1991; Tis et al., 1993; Viitasalo, 1983). Viitasalo (1983) showed that there was a small but significant decrease in the peak torque produced during leg extension when a pre-tension load of 20, 30 and 40 % of a maximal voluntary contraction was applied. Walshe et al. (1998) investigated the effects of pre-tension on the jump using an isometric squat device at one level of pre-tension (undisclosed) and with the pre-tension held for 0.2 s. It was concluded that the increased active muscle state at the commencement of concentric movement in pre-force conditions elicited greater positive work than a concentric only movement. Clarke (1968b) determined that there was a significantly greater maximum force produced when there was no preliminary muscle tension. Jensen et al. (1991) and Tis et al. (1993) determined that the use of pre-tension did not affect the level of peak torque produced.

Clarke (1968a) showed that, for simple arm movements, reaction time was shown to decrease when pre-tension was applied. This was attributed to an increased active state of the muscle and to a taking up of slack by the non-contractile components of the muscle and the cross bridge attachments in the muscle. Lee et al. (1992) showed a non significant decrease in reaction time with the use of low levels of pre-tension.

The introduction of swimming blocks with handles, to be used in Sydney 2000, could offer a productive area for performance gain. Pearson et al. (1998) indicated that the use of the handle start decreased time on the blocks and allowed a further forward placement of the centre of gravity. The current study was part of a series of investigations into the effects of pre-tension and joint angles on jumping and swimming dive starts. The aim was to determine whether the use of isometric pre-tension affected vertical jumping performance.

Comparisons were made between a jump utilising a counter movement and one using a concentric movement only.

METHOD: Twenty male physical education students were recruited as subjects. All were injury free, aged between 17 and 30 years, and experienced in jumping or lower limb resistance training. Data collection took place in the University of Ballarat Aquatic Research Centre. A Kistler force plate was used to obtain force data via an AP30 analog to digital board (Pearce, 1996). Custom designed software was used to collect (sampled at 500Hz) and analyse force recordings. Handles were attached to the force plate mounting platform and were separate from the force plate. This enabled the subjects to grip the handles with the hands and apply pre-tension. Adjustable handles allowed for subjects of different height.
It was anticipated that subjects would require a learning period to develop the desired pre-tension force levels. A training session was provided to familiarise the subjects with the skill of pre-tensioning against the handles. Training involved the use of feedback in a number of forms. Visual feedback was provided via a computer monitor of the force levels being produced. Verbal feedback was provided by the author and an auditory signal sounded to indicate attainment of the correct levels of force production. Subjects also practised jumping without the use of a counter movement.
Prior to the start of a testing session, height and body mass were recorded. Subjects then had a 10 minute warm-up involving sub maximal aerobic exercise (running), static stretching and jumping practice. Handle heights were adjusted so that the knees were at 110" of flexion. All jumps were performed from this knee angle.
During testing, subjects performed a maximal static vertical exertion whilst in the designated starting position to determine individual pre-tension levels used in the testing protocol. The subject grasped the handles mounted either side of the force plate and pushed vertically with the legs as hard as possible in a position similar to the performance of a dead lift. As a warm up, three unrecorded sub-maximal efforts; approximating 50%, 70% and 80% of maximum as determined by the subject, were performed prior to the maximal effort. After these practice trials were completed, subjects performed three maximal voluntary contractions (MVC). A rest period of between one and two minutes was given between trials. The highest recorded maximum was designated as the MVC.
Subjects performed three types of jumps in the test session; a counter movement jump (CMJ) allowing a dip and unrestrained movement, a vertical jump without a counter movement or dip (0% pre-tension) and pre-tension jumps (PTJ). The CMJ was started in a relaxed position with the legs straight. The depth of the counter movement was not constrained. Pre-tension levels of 40, 50, 60, 70 and 80% of the previously determined MVC were used. The lowest level of pre-tension was 40% of MVC as body weight for most subjects was more than 30% of their MVC. To obtain the levels of pre-tension the subjects were instructed to exert force with their legs downwards onto the force platform against their grip on the handles and observe a line, representing in real time the force being applied on a computer monitor positioned in their line of sight. Using the visual feedback provided by the monitor, the subject aimed to develop the desired amount of pre-tension. An error window of 2.5% above and below the desired level was allowed. Zero pre-tension was defined as the subject in the starting position with their hands by the handles but with no tension being applied upwards, even though lower limbs were under bodyweight tension. When the subject maintained the correct level of pre-tension for 0.6 s, an automatic auditory signal of 0.2 s duration was given to jump. Subjects were instructed to jump vertically as quickly and as explosively as possible, concentrating on reacting to the start signal. Each level of pre-tension was tested until the subject performed a trial in which no counter movement was observed prior to the jump, as determined by observation of the force trace. If the level of force dropped below the lower limit of the error window the trial was repeated
Two trials were recorded for each pre-tension level. Rest periods of a minimum of one minute were given between trials and two minutes between different pre-tension levels to help eliminate the effects of fatigue. Ordering of the pre-tension levels between subjects was

randomised. The CMJ was performed last on all occasions in order to prevent problems when commencing or returning to the PTJs.
Peak force, maximal RFD, flight time (used to calculate jump height), reaction time (time from the starting signal to the first perceptible movement on the force trace), time to peak force, time from peak force until feet left the force plate and total jump time were recorded.
Analysis Methods: Results were analysed using the SPSS computer statistical package. An analysis of variance with a Tukey's-b post hoc analysis was conducted to determine significant differences ($p \leq 0.05$) between the differing pre-tension levels and the dependent variables e.g. maximum rate of force development.

RESULTS: Means for each jump type compared with the CMJ are shown in Table 1.

Table 1 Mean Measures for Each PT Jump in Comparison with the CMJ.

Jump type	Reaction time (s)	First move to max (s)	Max to feet leave (s)	First move to takeoff (s)	Total jump time (s)	Peak force (N)	Max RFD (N/s)	Calculated jump height (m)
CMJ	0.157	0.672	0.153	0.826	0.983	1847	12525	0.392
PT 0%	0.142	0.141*	0.116*	0.257*	0.398*	2141**	19289**	0.258*
PT 40%	0.151	0.134*	0.115*	0.249*	0.400*	2151**	17840**	0.255*
PT 50%	0.136	0.125*	0.121*	0.246*	0.382*	2210**	16120	0.256*
PT 60%	0.136	0.119*	0.147	0.267*	0.403*	2207**	13700	0.262*
PT 70%	0.142	0.113*	0.144	0.257*	0.399*	2210**	10221	0.253*
PT 80%	0.173	0.100*	0.153	0.253*	0.426*	2150**	6394*	0.258*

(* signif. less than CMJ, $p<0.05$, ** signif. greater than CMJ, $p<0.05$)

Peak force was significantly less for the CMJ than for all the PTJs (0–40% pre-tension $p<0.001$; 80% pre-tension $p=0.004$). The rate of force development indicated by the maximum gradient of the force trace was significantly greater for the 0 and 40% PTJs than CMJ ($p<0.001$). The maximum gradient at 80% pre-tension was significantly less than CMJ.
Total jump time was significantly faster for all criteria when compared with the CMJ ($p<0.001$). Reaction time was not significantly different for any of the test criteria ($p=0.099$).
Estimated jump height was significantly greater for the CMJ than all PTJs ($p<0.001$).

DISCUSSION: The peak force obtained in the PTJs was significantly higher than the CMJ. Jensen et al. (1991), Tis et al. (1993) and Viitasalo (1983) showed a decreased level of peak torque as pre-tension increased but in this study there was no difference in the peak forces between the pre-tension levels. The instructions were to perform a jump as explosively as possible and eliminate any dip. The CMJ was performed with the instruction to obtain maximum height. This indicates that the instructions were followed and that the movements were explosive and forceful for the PTJs; and longer and more controlled in the CMJ. It had been expected that the CMJ would produce similar peak forces to the PTJs. The increased velocity of muscular contraction in the CMJ could have limited the force that was applied.
The total jump time for the CMJ was significantly longer (0.983 s) compared with the other jumps (all approx. 0.4 s). This is to be expected as the unweighting period of the jump adds substantially to the total time. Thus the PTJs allowed the jumper to get off the ground in less time than the CMJ. Hence, combined with the higher peak force levels for the PTJs meant that the jump is effected rapidly with a high level of force production. Limiting time at the start of a race is important and, if using muscular pre-tension can decrease this time while not decreasing performance, then this could be advantageous. The arm swing start in swimming is restricted to relay change overs because of the time it takes to perform. The currently favoured grab start still utilises some amount of dip or unweighting prior to push off.

The emerging presence of handles on starting blocks opens the possibility for a starting technique that eliminates any counter movement.

The rate of force development for the CMJ was less than for all other jumps, other than the 80% PTJ. Thus, the force produced in the CMJ is applied over a longer period of time. The increased jump time of the CMJ comes from an increased time to reach peak force. The time taken from peak force to the feet leaving the ground is significantly faster for the 0%, 40% and 50% PTJs. The decreased rate of force development with measured pre-tension levels can be explained by the fact that, as the level of pre-tension increases, the initial force level is higher. Hence, the difference between the initiating pre-tension force and the peak force is decreased, resulting in a smaller gradient.

While the peak force was greater and the total jump time was less for the PTJs, they produced a significantly lower jump height than the CMJ. Thus, the CMJ was the most effective jump for height when the time to perform the jump was not a critical factor. When the counter movement is eliminated, the level of pre-tension does not appear to influence jump height.

Although Clarke (1968b) found the use of pre-tension significantly decreased reaction time, this study agreed with Lee et al. (1992) who found only a non-significant trend for lower levels of pre-tension to decrease reaction time. This indicates that the active state of the muscle prior to jumping appears to have no significant effect on the rate at which the body reacts to an auditory stimulus.

CONCLUSION: The effect of pre-tension on jumping performance was to increase the peak force that was applied in the jump when compared with the CMJ. The total jump time for all PTJs was faster than the CMJ. The advantage resulted from a decrease in time to reach the maximal force. While the PTJs were not as high as the CMJ, the results still have implications in the design of starting techniques (such as swimming) where rapid reaction to a stimulus is required. Investigating the best level of pre-tension and body position for swimming starts could offer a productive area for performance gains.

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