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The effects of a plyometric training program on the latency time of the quadriceps femoris and gastrocnemius short-latency responses

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Aim. **The purpose of this study was to determine if a plyometric training program can affect the latency time of the quadriceps femoris and gastrocnemius short-latency responses (SLRs) of the stretch reflex.**

Methods. **Sixteen healthy subjects (12 female and 4 male) were randomly assigned to either a control or a plyometric training group. Maximum vertical jump height (VJ) and SLRs of both quadriceps femoris and gastrocnemius were measured before and after a four week plyometric training program.**

Results. **Plyometric training significantly increased VJ (mean±SEM) by 2.38±0.45 cm ($P<0.05$) and non-significantly decreased the latency time of the quadriceps femoris SLR (mean±SEM) 0.363±0.404 ms ($P>0.05$) and gastrocnemius SLR (mean±SEM) 0.392±0.257 ms ($P>0.05$). VJ results support the effectiveness of plyometric training for increasing VJ height.**

Conclusion. **The non-significant changes in the latency time of the quadriceps femoris and gastrocnemius SLRs seen in the training group suggest that performance improvements following a four-week plyometric training program are not mediated by changes in the latency time of the short-latency stretch reflex.**

KEY WORDS: Electromyography - Muscle, skeletal - Reflex, stretch.

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When used correctly, plyometric training has consistently demonstrated the ability to improve athletic performance [1, 2] and the production of muscle power.[3-5] During the performance of plyometric exercise, an individual's ability to produce muscular force is enhanced by means of two possible mechanisms.[6] Elastic energy is stored during an eccentric muscle action and released during a subsequent concentric muscle action, thereby increasing the total force production by naturally returning the muscle to its unstretched configuration.[7-9] A secondary mechanism is the potentiation of the concentric muscle action, as well as the control of muscle stiffness by the stretch reflex.[10-15]

Resistance training research has demonstrated that neural changes are a significant factor in the development of muscular strength following resistance training programs.[16] Early changes in muscular strength may be largely accounted for by neural adaptations; as the resistance training program progresses, hypertrophy gradually increases its contribution to increasing muscular strength.[16] Further, these neural changes may be due to increased motoneuron excitability.[17] These alterations in the "excitability" of the neural system following resistance training are important as they show that the neural system can, and does respond to resistance training. These alterations also illustrate

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TABLE I.—*Selected subject characteristics.*

Characteristic	Plyometric (N.=8)		Control (N.=8)	
	Mean ± SD	Range	Mean ± SD	Range
Age (years)	25.38 ± 2.875	20-30	25.00 ± 3.117	21-30
Height (cm)	175.50 ± 10.99	158.75-191.14	172.48 ± 8.05	161.29-186.06
Weight (kg)	70.09 ± 11.80	56.25-90.72	70.88 ± 20.97	52.62-105.23

that the neural system may adapt to different forms of training. Because the stretch reflex is involved during plyometric exercise,[10-14] it seems likely that stretch reflex adaptations may explain some of the increases in muscle power production that occur following plyometric training.

There are essentially two phases to the stretch reflex, the short- and long-latency responses. The short-latency response (SLR) of the stretch reflex is mediated by the monosynaptic reflex arc while the long-latency response (LLR) primarily involves multiple interneuronal synapses within the spinal cord. Research indicates that the LLR is involved during plyometric exercise. Kilani *et al.*[14] found that anesthetizing gamma motoneurons (a component of the LLR) significantly reduced vertical jump height, indicating the contribution of the LLR to the stretch shortening cycle. Further, the LLR has shown a decreased sensitivity following a single bout of exercise involving the stretch-shortening cycle.[18] Since LLR affect vertical jump height performance and it fatigues during stretch-shortening cycle exercise, it is apparent that it is an essential component in potentiating concentric muscle actions during plyometric exercise. Even though it is clear that the LLR plays an important role during plyometric exercise, little work has been done to determine the contribution of the SLR to plyometric exercise.

The SLR component of the stretch reflex does exhibit an adaptive plasticity to motor learning training.[19, 20] Perturbation training to upper extremity muscles significantly alters the SLR by increasing both amplitude and length of response. The adaptations to these rapid stretches, however, involved changes in amplitude of the SLR, rather than the time from stimulation to muscle activity.[19, 20]

Because agility and high-velocity training facilitate the muscle's reflexive response to a rapid stretch,[18, 21-23] it seems logical that plyometric exercise may have a similar effect. To our knowledge, no research has examined the adaptation of the stretch reflex's SLR to plyometric training. Therefore, the primary purpose of this study was to determine if plyometric exercise training can shorten the latency time of the SLR of the quadriceps femoris and the gastrocnemius stretch reflexes.

Materials and methods

Subjects

Sixteen college students (12 female, 4 male) volunteered to participate in this study. Subjects were without current or previous dominant lower extremity knee or ankle injuries that required treatment by medical professionals. Exclusion criteria included a history of injury to the ligaments or menisci of the knee, patellofemoral joint injury, and chronic ankle sprains or Achilles tendon injury. Further, all subjects were free of other known or apparent neurologic, orthopaedic, or neuromuscular dysfunction. Based on recognized standards,[6, 24, 25] subjects were participants in a resistance training program during the previous 12 months. To eliminate the possible effects of previous plyometric training on the SLRs, plyometric training during the 12 months preceding the study excluded potential subjects. Subject characteristics are provided in Table I. After approval from the University's Institutional Review Board, all subjects provided written informed consent and completed a PAR-Q [26] and Medical History questionnaire describing current activity level and medical history prior to inclusion in the study.

Subjects were randomly assigned to either the control or plyometric group using a stratified randomization technique.[27, 28] Because it may be a factor in SLR determination, all subjects were stratified according to gender, with six females and two males in each group. Subjects were assigned to their respective groups using a table of random numbers and sampling without replacement.

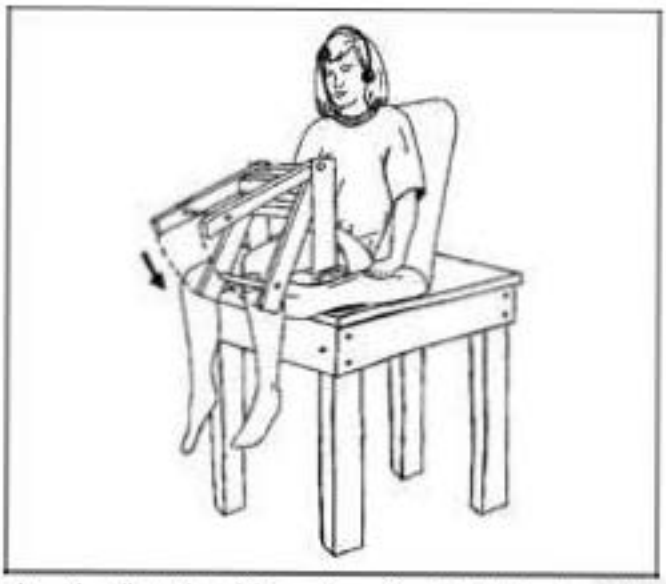

Figure 1.—Illustration of the quadriceps femoris stretch reflex testing setup.

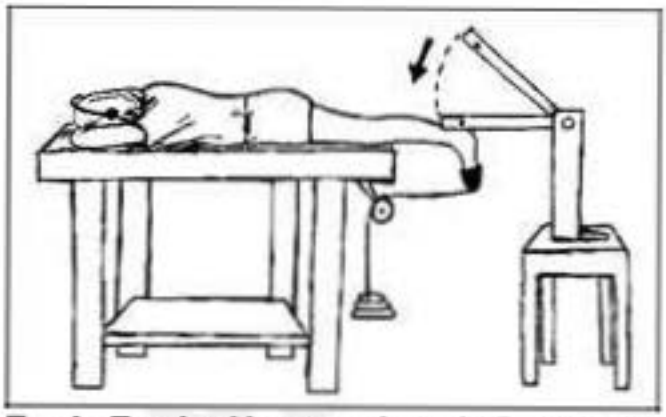

Figure 2.—Illustration of the gastrocnemius stretch reflex testing setup.

Experimental design

All subjects underwent four standardized tests in which the latency times of subjects' dominant quadriceps femoris SLR (QSLR) and gastrocnemius SLR (GSLR) were measured, as well as the maximal vertical jump height. Two pre-tests were administered on different days prior to starting the four-week plyometric exercise program to allow test-retest analysis. Upon completion of the four-week period, all subjects were post-tested twice using the same procedures. Subjects in the plyometric group were tested one week after completion of the training program and were retested one week after the initial post-test to determine the stability of the latencies. Control group subjects were post-tested five weeks after the second pre-test and were retested one week after the initial post-test to determine the stability of the latencies, as well. Pre- and post-testing were conducted under the supervision of the primary investigator.

Stretch reflex latency testing

All stretch reflexes were elicited by a pendulum-type tendon tapping device as previously described by Karst and Willett[20] (Figures 1, 2). The pendulum's frame was constructed of wood and the tapping bar was made of metal. The pendulum arm was raised to a constant height for each subject by using a protractor affixed to the side of the pendulum frame. A small piece of flexible brass foil taped to the skin overlying the patellar or Achilles tendon (for the QSLR and GSLR, respectively) served as a contact switch to begin data collection at the instant when the metal bar contacted the brass foil overlying the tendon.

For the purpose of this study, the latency time of the SLR was defined as the time in milliseconds (ms) from tendon stimulus to the first deflection from baseline of the raw EMG signal recorded from the muscle of interest. EMG signals were recorded by using bipolar, silver/silver chloride surface EMG electrodes–8 mm diameter, 12 mm interelectrode distance (Therapeutics Unlimited, Iowa City, IA) with on-site preamplifiers (gain=35±10%). Analog signals from the EMG pre-amplifiers were high-pass filtered (20 Hz) to reduce mechanical artifacts and amplified (overall gain=10 k) using optically-isolated solid state amplifiers. Unrectified EMG signals were sampled at a rate of 5 000 Hz using a 16-bit analog-to-digital converter (BIOPAC Systems, Inc., Santa Barbara, CA, USA), processed, and stored on magnetic media. A sampling window of 50 ms was used during measurement of the QSLR and a 60 ms window was used during measurement of the GSLR.

During the initial pre-test, the leg chosen to kick a stationary ball determined each subject's lower extremity dominance.[30] For each electrode site, subjects had the electrode contact area on the dominant lower extremity prepared by cleansing the skin with alcohol and shaving, if necessary. Using double-sided adhesive tape, two EMG surface electrodes were applied longitudinally over the muscle bellies of the

tested muscles; a reference electrode was placed over the anterior surface of the ipsilateral forearm.

Electrode placement was marked using palpable anatomical landmarks and recorded.[31] Measurements of the electrode placement were used to make templates for placement of the electrodes on both post-tests. To determine the QSLR, surface EMG electrodes were aligned along the longitudinal axis of the muscle fibers by orienting the electrodes oblique to the shaft of the femur at angles of 50 and 15 degrees for the vastus medialis and vastus lateralis, respectively.[27, 32] During testing of the QSLR, the subjects sat with bilateral hip and knee joints in approximately 90° of flexion (Figure 1). For the GSLR tests, surface EMG electrodes were placed over the medial and lateral heads of gastrocnemius.[31] During testing of the GSLR, the subjects were prone with the tested hip in neutral and knee joint extended. The talocrual joint of the tested limb was held in neutral by a strap placed on the plantar surface of the foot and attached to a resistance via a rope and pulley (Figure 2). The resistance used to maintain talocrual neutral differed between subjects and was primarily dependent on the flexibility of a given subject's Achilles tendon. The required resistance for each subject was recorded during the initial pre-test and used during subsequent testing sessions.

During all SLR tests, subjects closed their eyes to eliminate visual awareness and listened to standardized music to eliminate auditory awareness of the tendon stimulus. SLRs for each site were measured 10 times each; the mean latency of the 10 trials for each site (20 in total) was used for data analysis. These procedures were replicated for the second pre-test and both post-tests.

Vertical jump testing

The maximum vertical jump height for each subject was measured during the second pre-test and during both post-tests using a Vertec (Sports Imports, Columbus, OH). VJs were recorded to the nearest 0.5 inch and converted to centimeters (cm) for data analysis. The maximal reach height of each subject's dominant upper extremity (the upper extremity with which the subject reached during the VJ) was measured and each subject performed three countermovement VJs. VJ height was calculated by subtracting each subject's maximal upper extremity reach height from the maximal height jumped. The highest VJ of the three trials was used for data analysis.

TABLE II.—*Plyometric training program.*

Week one	
Session 1: Plyometric Training (80 contacts)	
2 × 10*	2-foot ankle hop
2 × 10	Standing jump-and-reach
2 × 20	Single leg push-off (40.6 cm)
1 × 10	Front box jump (40.6 cm)
1 × 10	Tuck jump with knees up
Session 2: Plyometric Training (90 contacts)	
2 × 10	2-foot ankle hop
2 × 10	Standing jump-and-reach
1 × 20	Single leg push-off (40.6 cm)
2 × 10	Jump to box (40.6 cm)
1 × 10	Tuck jump with knees up
1 × 10	Jump from box (40.6 cm)
Week two	
Session 3: Plyometric Training (120 contacts)	
2 × 10	2-foot side-to-side ankle hops
2 × 10	Standing jump-and-reach
2 × 20	Alt single leg push-off (40.6 cm)
2 × 10	Front box jump (40.6 cm)
3 × 10	Tuck jump with knees up
1 × 10	Depth jump (40.6 cm)
Session 4: Plyometric Training (100 contacts)	
2 × 10	2-foot side-to-side over barrier
2 × 10	Standing jump and reach
1 × 20	Alt single leg push-off (40.6 cm)
2 × 10	Jump to box (55.9 cm)
1 × 10	Tuck jump with knees up
2 × 10	Depth jump (40.6 cm)
Week three	
Session 5: Plyometric Training (130 contacts)	
2 × 10	1-foot ankle hop over barrier
3 × 10	Standing jump-and-reach
2 × 10	Tuck jump with knees up
3 × 10	Front box jump (40.6 cm)
2 × 10	Depth jump (50.9 cm)
1 × 10	Squat depth jump (40.6 cm)
Session 6: Plyometric Training (140 contacts)	
2 × 10	Standing jump-and-reach
2 × 20	Single leg push-off (40.6 cm)
2 × 10	Jump to box (71.1 cm)
3 × 10	Depth jump (50.9 cm)
2 × 10	Squat depth jump (40.6 cm)
2 × 10	Tuck jump with knees up
1 × 10	Depth jump to second box (40.6 cm)
Week four	
Session 7: Plyometric Training (150 contacts)	
2 × 10	2-foot side-to-side over barrier
2 × 10	Standing jump-and-reach
2 × 20	Single leg push-off (40.6 cm)
2 × 10	Depth jump to second box (40.6 cm)
3 × 10	Depth jump (71.1 cm)
2 × 10	Squat depth jump (50.9 cm)
Session 8: Plyometric Training (130 contacts)	
3 × 10	1-foot ankle hop
2 × 10	Standing jump and reach
2 × 10	Front box jump (50.9 cm)
2 × 10	Tuck jump with knees up
2 × 10	Depth jump (71.1 cm)
2 × 10	Depth jump to second box (40.6 cm)

*Indicates two sets of 10 repetitions.

Plyometric training

Following both pre-tests, the control group continued their previous program of resistance and aerobic training for four weeks. The plyometric group continued their respective exercise programs (which included both resistance and aerobic training) and participated for four weeks in a twice per week plyometric exercise program designed to increase each subject's vertical jump (Table II).[24, 25] The control and plyometric groups were instructed not to alter their exercise training programs during the four-week period although increases in weight were allowed. All subjects completed an exercise/injury log to monitor activities during the study. The plyometric training program was performed under the supervision of the primary investigator. Following a warm-up of jumping rope, subjects performed each exercise in the order shown in Table II. To be included in data analysis, any missed training sessions could be made up provided the make-up session occurred during the same week as the missed session.

Statistical analysis

For purposes of this study, the onset of reflex EMG activity was defined as the first deflection from baseline electrical activity. The time of onset was determined by the primary investigator after visual inspection of the EMG data on a high-resolution monitor. An additional investigator was also used to replicate the first deflection, especially in case of excessive noise or artifacts in the EMG signal. A mouse-controlled vertical cursor was placed at the first deflection of the EMG signal, and the elapsed time from the tendon tap was calculated to define the SLR (Figure 3).

To eliminate potential bias in determining EMG onset times, each subject was assigned an identification number and the primary investigator was blinded to both the identity and group assignment of each subject during the determination of the SLR. The primary investigator was later provided with the identity of each subject and each subject's group for data analysis purposes.

SLR DATA

The pre-test latency time of QSLR was determined from the mean SLRs of Pre-test I and Pre-test II for both vastus medialis and vastus lateralis (*i.e.*, mean of vastus medialis Pre-test I, vastus medialis Pre-test II, vastus lateralis Pre-test I, and vastus lateralis Pre-test II). The post-test latency time of SLR was calculated using the same method. Similarly, the pre- and post-test latency times of GSLRs were determined as the mean SLRs of both pre- (or post-) tests for both the medial and lateral GSLRs. A mixed two-factor within-subjects ANOVA [group x (test session x subjects)] was used to analyze mean SLRs for the pre- and post-tests within and between the control and plyometric groups.[33, 34] *Post hoc* analyses of significant *F* ratios were performed using Tukey's Honestly Significant Difference (HSD). Pearson product-moment correlation coefficients were calculated to verify the relationship between subject height and latency time of SLR.

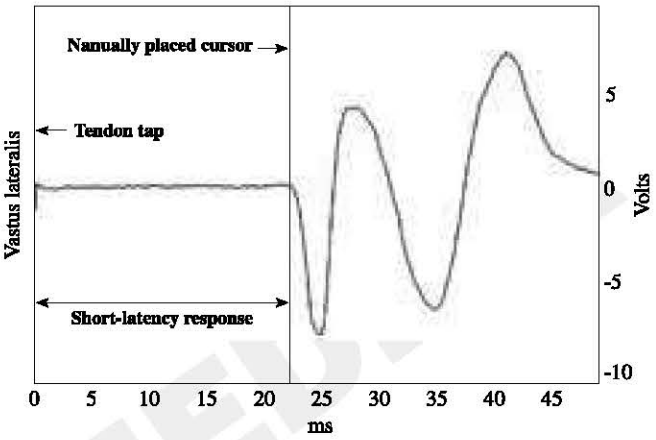

Figure 3.—Illustration of the latency time determination from the raw EMG signal.

VERTICAL JUMP DATA

A mixed two-factor within-subjects ANOVA [group x (test session x subjects)] was used to analyze mean VJs for the pre- and post-tests within and between the control and plyometric groups.[27, 35] *Post hoc* analyses of significant F ratios were performed using Tukey's HSD. Although two VJ post-tests were performed, only data from the pre-test and the first post-test were used for statistical analysis.

TEST-RETEST RELIABILITY

Test-retest reliability coefficients for the SLR conditions were determined by calculating an intraclass correlation coefficient (ICC) for each condition. Based on the design of this study and the type of reli-

TABLE III.—*Average vertical jump (VJ) and latency time of the short-latency response (SLR) pre- and post-test results for control and plyometric groups (± SEM).*

	Vertical jump (cm)		QSLR (ms)		GSLR (ms)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Control	41.83 ± 9.86	41.04 ± 8.86	23.88 ± 2.80	24.15 ± 2.31	35.09 ± 3.02	35.08 ± 3.11
Plyometric	42.31 ± 9.36	44.69 ± 10.02	25.74 ± 2.18	25.38 ± 2.08	38.09 ± 3.63	37.70 ± 3.35

QSLR: quadriceps femoris SLR; GSLR: gastrocnemius SLR.

TABLE IV.—*Average amplitude values of the short-latency response (SLR) pre- and post-test results for control and plyometric groups (± SEM).*

Group	QSLR (volts)		GSLR (volts)	
	Pre-test	Post-test	Pre-test	Post-test
Control	7.74 ± 3.61	7.56 ± 3.47	6.56 ± 4.54	7.21 ± 5.21
Plyometric	6.53 ± 2.68	6.31 ± 3.40	3.92 ± 2.63	4.06 ± 2.34

QSLR: quadriceps femoris SLR; GSLR: gastrocnemius SLR.

ability required, the single measurement form of ICC Model was used–ICC (3,1).[36] Test-retest reliability was calculated for Pre-test I and Pre-test II at each site and for Post-test I and Post-test II at each site. The ICC (3,1) for test-retest reliability ranged from 0.90 to 0.99.

INTRATESTER RELIABILITY

ICC (3,1) was also used to examine the intratester reliability of the primary investigator for visually identifying the EMG onsets.[36] EMG tracings were randomly selected from each test condition and SLRs were determined; within one week, the same EMG tracings were re-evaluated and compared to the first analysis using the ICC. The ICC (3,1) for intratester reliability of identifying EMG onsets was 0.99.

The *a priori* level of significance for all statistical analyses was set at P≤.05. SigmaStat Version 2.0 (Jandel Scientific, San Rafael, CA, USA) was used to perform all statistical analyses.

Results

All 16 subjects completed both pre-tests and both post-tests. There were no significant musculoskeletal injuries as determined by the exercise/injury logs completed by the subjects. Attendance for all testing and plyometric training sessions was 100%. In three cases, excessive noise or artifacts in the EMG signal made SLR determination impossible.

Vertical jump

The plyometric group's mean (±SEM) VJ increase of 2.38±0.45 cm following four weeks of plyometric training was significant ($F_{1,14}$=9.524, P<0.05) (Table III). The control group's mean (±SEM) VJ decrease of 0.79±0.93 cm during the same four week period was not significant (P>0.05) (Table III). The plyometric group's 2.38 cm vertical jump increase was significantly greater than the control group's 0.79 cm vertical jump decrease (P<0.05).

Stretch reflex latency

QUADRICEPS FEMORIS SLR

The latency time of QSLRs for both groups ranged from 20.00 ms to 28.74 ms and were strongly correlated with subject height (r=0.82; P<0.05). The plyometric group's mean (±SEM) latency time of QSLR decrease of 0.363±0.404 ms following four weeks of plyometric training was not significant ($F_{1,14}$=3.321, P>0.05) (Table III). The control group's mean (±SEM) latency time of QSLR increase of 0.274±0.319 ms during the same four week period was not significant (P>0.05) (Table III).

GASTROCNEMIUS SLR

The latency time of GSLRs for both groups ranged from 31.03 ms to 43.83 ms and were strongly correlated with subject height (r=0.84; P<0.05). The plyometric group's mean (±SEM) latency time of GSLR decrease of 0.392±0.257 ms following four weeks of plyometric training was not significant ($F_{1,14}$=1.823, P>0.05) (Table III). The control group's mean (±SEM) latency time of GSLR decrease of 0.008±0.123 ms during the same four week period was not significant (P>0.05) (Table III).

Discussion

The data regarding correlation of subject height to SLR were included to support the validity of the methods for determining the latency time of the SLR. Several studies have shown that height is a major factor in determining the SLR of muscles.[29, 33, 37, 38] The strong correlations between subject height and both the latency time of the QSLR (r=0.82) and the GSLR (r=0.84) found in this study confirm that relationship. Further, the means and ranges of the latency time values reported here are comparable to similar studies,[18, 29, 39] providing further evidence for the validity of the methods used during this investigation.

The principal objective of this study was to determine if the latency time of the SLR is shortened following four weeks of plyometric training. While the VJ increased significantly, the results indicate that neither the latency time of the QSLR nor the GSLR decreased significantly following four weeks of plyometric training. Because there has been no previous research conducted that examine the adaptation of the SLR to plyometric exercise, direct comparisons with other studies are difficult.

Previous studies indicate balance and agility-type training can alter reaction to an external stimulus.[30, 40] Following three months of balance and stability training, Ihara *et al.*[40] found that hamstring "reaction times" decreased significantly. While the defined "reaction time" involved mechanisms other than the SLR, the results do indicate that balance training can result in quicker mechanical responses to external stimuli. Similarly, Wojtys *et al.*[30] determined that healthy subjects performing six weeks of agility training significantly reduced the "spinal reflex times" of both vastus medialis and vastus lateralis in response to anterior translation of the tibia. Although the present study did not identify significant changes in the latency time of the SLR of the quadriceps femoris and gastrocnemius muscles following four weeks of plyometric training, previous studies indicate that reflex and reaction adaptations to training can occur.[30, 40] Koceja and Kamen [41] found that total reflex time (*i.e.*, both the stretch reflex latency and electromechanical delay) following patellar tendon tap was shorter in sprint trained subjects than their endurance trained counterparts.[41] Further, stretch reflex latencies are shorter when comparing "power" trained subjects to "endurance" trained subjects.[21] Plyometric training, like sprint training, is a specific form of power training; therefore it is possible that the stretch reflex latency may also respond favorably following training. Because different reflexes were measured, however, it is uncertain if or how much the latency time of SLRs may have adapted to the aforementioned training programs. That changes did occur reinforces the notion that a reflexive component other than the latency time of SLR may adapt to plyometric training.

The SLR can be altered with training. In their landmark work, Wolpaw *et al.*[19] found that the amplitude of the SLR may be conditioned with training. Monkeys were rewarded if they responded with either greater or lesser SLR amplitude, depending on the group assignment. Changes were apparent in as little as one week and responses remained after prolonged periods without perturbation training. Similar adaptations have been achieved in more recent investigations.[19, 20] Meyer-Lohmann *et al.*[42] also found adaptations of the SLR following perturbation training. In their research, the SLR gradually increased in duration and amplitude while the LLR decreased to insignificant amounts following chronic perturbation training. These findings indicate that while the latency times of the SLRs in the present study were not significantly altered, training can affect the function of the SLR. There are several possibilities why the latency time of the SLR was unchanged during the present study and they are listed below.

It is possible that the SLR may not significantly contribute to plyometric exercise. The quick movements of plyometric exercise involve the stretch shortening cycle (SSC).[23] The SSC is divided into three phases, eccentric – preloading of agonist muscle groups – transition – delay between eccentric loading and concentric response – and concentric –

release of mechanical energy stored during the eccentric phase. The eccentric phase of the SSC takes approximately 85 ms and the transition phase takes approximately 23 ms,[11] more than 110 ms before the concentric phase begins. This suggests that the LLR may be more involved in the reflex potentiation of muscle force and power when compared to the latency time of SLR (ranging from 20.00 ms to 43.83 ms in this study). That is, plyometric exercise may last too long to substantially rely upon the SLR of the stretch reflex for potentiation of skeletal muscle activity. The key to this determination is the instant the stretch reflex is initiated during the SSC. The stretch reflex is initiated as soon as the muscle spindle detects a rapid change in length.[34, 43] Therefore, it is initiated at the beginning of the eccentric phase (*i.e.*, after the initial stretching of the agonist muscle groups, primarily the quadriceps and gastrocnemius in this study). Because the results of this study indicate that the latency time of SLRs of the quadriceps femoris and gastrocnemius stretch reflexes do not decrease significantly following plyometric training, it may be the LLR that is altered by plyometric training.

In addition to the latency time of SLRs measured here, the overall reflex response includes the time between the initiation of muscle fiber action potentials and the time when significant muscle force production occurs (*i.e.*, electromechanical delay). Electromechanical delay depends on additional factors such as the time required for excitation-contraction coupling and the rate of force production, while a shorter latency time of SLR may provide a more rapid activation of the muscle that may not equate to a quicker movement response. Therefore, the electromechanical delay may be a more significant factor than the SLR when discussing the ability of reflex responses to potentiate muscle activity.[44]

Another possible reason for the lack of change in the latency time of the SLR during the present study is that non-neural changes may occur following plyometric training. The adaptations may increase the muscular power production that occurs following participation in a plyometric training program. Hypertrophy does occur following participation in a resistance training program.[16, 17] The increased cross-sectional area observed after resistance training may occur following plyometric training as well. However, research indicates that neural adaptations precede hypertrophic changes following resistance training.[16, 17] Although changes in cross-sectional area were not assessed, the fact that a four-week training period was employed in this study suggests that hypertrophy did not account for the increased VJ height seen in the plyometric group subjects. Rather, it is more likely that neuromuscular adaptations other than the latency time of the SLR (*e.g.*, changes in LLR or electromechanical delay) are responsible for the increased vertical jump height seen during this study.

Furthermore, while this study examined the adaptation of the SLR, the plyometric training program was designed to maximize the subjects' ability to produce muscular power (as measured by the VJ test). Results presented here indicate that the plyometric program was successful and are in agreement with previous studies involving plyometric training programs.[1, 3, 5]

An additional possible reason for the lack of change in the latency time of the SLR during the present study is that the latency time of the SLR may not represent the sensitivity of the stretch reflex arc and its functional role in stretch-shortening cycle type of muscle action. It has been shown in several experiments that it is the size of the peak-to-peak amplitude which corresponds to the amount of motor units recruited and, therefore it has a strong contribution to the stiffness control of the muscle during the eccentric phase of the SSC movement.[18, 45] Thus, via stiffness control it can have an important role in utilization of the elastic energy during the following concentric phase. Therefore, even in the present experiment peak-to-peak amplitude of the SLR could have had a significant role in the performance enhancement. However, peak-to-peak amplitude of the SLR was not measured in the present study. It is the intention of the authors to perform such measures in future studies.

Conclusions

The results of this study suggest that there are possible adaptations following participation in a plyometric exercise training program. The potential for plyometric training to increase performance in tasks such as the vertical jump was supported, and the results suggest that adaptations other than the latency time of the stretch reflex are responsible for the observed increases in performance. Further investigation of changes in long-latency reflexes, electromechanical

delay, and muscle force production characteristics could delineate the specific mechanisms responsible for performance improvements and aid in efforts to determine optimal plyometric program design.

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