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Analysis of Muscle Activation during Piston Resistance Training and Free-Weight Training

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Abstract

Purpose: This study compares the amount of muscle activation in a piston resistance machine to that of free weight resistance training. Methods: Thirty recreational athletes who participated in regular resistance training were recruited to perform five repetitions of squats and toe raises using free weights and a piston resistance machine at 70% of their one-repetition maximum. Muscle activation was recorded by surface electromyography electrodes at the vastus lateralis, vastus medialis, lateral gastrocnemius, and medial gastrocnemius. Results: For the squat exercise, there was no significant difference ($p > .05$) in the vastus medialis between free weight mean muscle activation (0.55 ± 0.58 mV) and piston resistance muscle activation (0.71 ± 0.75 mV) or the vastus lateralis ($p > .05$) during the free weight condition (0.49 ± 0.43 mV) and piston resistance condition (0.50 ± 0.44 mV). For the toe raise, there was no significant difference recorded in mean muscle activation ($p > .05$) for the lateral gastrocnemius between free weights (1.31 ± 1.59 mV) and piston resistance (1.20 ± 0.92 mV), or in the medial gastrocnemius ($p > .05$) between free weights (1.59 ± 1.40 mV) and piston resistance (1.60 ± 1.53). A high correlation was found in the vastus lateralis ($r = 0.925$, $p < 0.001$) and the vastus medialis ($r = 0.809$, $p < 0.001$) between resistance conditions during a squat. A low correlation was found in the lateral and medial gastrocnemius between free weight and piston resistance conditions during a toe raise at $p > 0.05$ with R values of 0.215 and 0.348, respectively. Conclusion: No statistically significant differences were found in muscle activation of any muscle group between either conditions. Muscle activation in free weights is similar to the muscle activation in piston resistance training, especially in the quadriceps group. Further studies are needed to test upper body muscle groups for an overall comparison of muscle activation between Nitroforce and free weights.

Keywords: Resistance, piston, training

1. Introduction

Resistance training is essential of overall health benefits including strength maintenance, bone mineral density maintenance, and body composition.[6-9,17,18,22,25,27]. It can enhance one's quality of life by improving performance during daily activities, especially those which are affected by aging such as walking and standing from a seated position. To reap health benefits, more resistance is added to a training routine to induce more muscle activation. As muscles are introduced to more resistance, muscle fibers and adapt in size and type.[3] Muscle hypertrophy occurs with increased resistance, resulting in greater fiber size and strength. As training progresses, the nervous system's muscle fiber recruitment increases in efficiency, adapting muscle contraction[3,13,23,32].Continuing to perform resistance training exercises will encourage more efficient muscle adaptations and improved overall health.

There are multiple ways to resistance train, each with different loading methods. Free weight resistance training uses isotonic contractions where the same tension is applied as the muscle shortens and lengthens during a range of motion. Momentum is a disadvantage in free weight resistance training, as it could reduce muscular loading and make the exercise less challenging [19].This type of resistance training also requires a wide range of equipment in order to progress.

Cam-based equipment (e.g. Nautilus equipment) is inconvenient as well. They are mostly found in public gym settings because they are heavy, expensive, and specialized to one muscle group. However, they do alter loading throughout a range of motion by using an elliptical pulley rather than a circular one. This design eliminates momentum and inertia- both of which are factors of weight stack and free-weight resistance training that decrease muscle loading. Decreased muscle loading results in less muscle activation, and thus lower-quality exercise. The varying radiuses of the pulley provides more resistance when joint torque is high, challenging the muscle to work harder at that position than it would if momentum was a factor during the range of motion [19].

Piston-driven resistance machines are pneumatic systems which use gas pressure to vary the resistance during a range of motion, similar to the goal of a cam-based machine. Not only are pneumatic systems challenging, but they eliminate weights, making them light and practical. One machine that implements pneumatic system characteristics into a home gym is the NitroForce Titan 1000 (Nitroforce Industries, Medina, OH), which uses nitrogen as its compressed gas. It can be easily adjusted to train multiple muscle groups with a wide range of resistance settings. Pneumatic devices offer a unique design that requires consistent muscle activation throughout the full repetition. During a concentric contraction using free weights, the mass being moved will gain momentum, resulting in less muscle recruitment required to complete the contraction. A pneumatic resistance machine will challenge the muscle consistently throughout the contraction, resulting consistent muscle recruitment until the contraction is complete[11,19]. A study on air piston-driven resistance machines has proven its efficacy toward notable strength gains following a four week protocol because of its design that requires consistent muscle recruitment and activation[26].

No previous study has observed the muscle activation in the NitroForce to compare it to that of free weights. It is unknown if the NitroForce's pneumatic system is truly advantageous for resistance training. The purpose of this study is to measure and compare muscle activation during squats and toe raises using the NitroForce to that of free weights.

2. Methods

Twenty males and ten females were recruited for this study (21 ± 1.9 years, 172.3 ± 6.8 cm, 71.1 ± 8.0 kg). Participants had to be recreationally trained and familiar with resistance exercise. Exclusionary criterion included college athletes, individuals over 35 years old, and sedentary individuals. All participants completed university-approved informed consent and had an opportunity to ask questions prior to study participation. Participants self-reported their medical history, musculoskeletal history, and one repetition maximum for each exercise. With the self-report of one rep maximums, an identical volume of weight (approximately 70% one rep maximum) was lifted for both conditions.

Each session began with the application of the Deisys Trigno Wireless EMG System (Boston, MA) (sEMG). The sEMG electrodes were placed over the vastus lateralis, vastus medialis, lateral gastrocnemius, and medial gastrocnemius. During the training session, participants completed one set of five repetitions of squats and toe presses at 70% of their one repetition maximum using free weights and the Nitroforce Titan 1000 in randomized order. Their muscle activation during each set was assessed at 1928 frames/second. The exercises were monitored to reduce chance of injury and to adjust technique, which helped ensure accurate recordings of muscle activation.[33] Participants were provided with five minutes of rest between sets.

A paired samples two-tailed t-test was run to show the relationship between the free weight and Nitroforce conditions of a squat and toe raise in the four main muscles of the study. Significance was set at $p < 0.05$. Pearson correlations were also used to assess agreement in muscle activation between the two exercise modalities. Correlations included comparison between the Nitroforce and free weights in muscle activation of the vasuts medialis and vastus lateralis for the squat, and the lateral gastrocnemius and medial gastrocnemius for the toe raise.

3. Results

The mean muscle activation quantities are reported in Table 1. The statistical analyses indicated no significant difference between free weights and the Nitroforce squat mean muscle activation in vastus lateralis or vastus medialis at $p > 0.05$. There was no significant difference recorded between the free weight and Nitroforce mean muscle activation for the toe raise in the lateral or medial gastrocnemius at $p > 0.05$.

Table 1: Mean Muscle Activation during Squat and Toe Raise Conditions

	Free (mV)	Nitroforce (mV)	Significance
Squat – Vastus medialis	0.55 ± 0.58	0.71 ± 0.75	0.078
Squat – Vastus lateralis	0.49 ± 0.43	0.50 ± 0.44	0.733
Toe Raise – Lateral gastrocnemius	1.31 ± 1.59	1.20 ± 0.92	0.791
Toe Raise – Medial gastrocnemius	1.59 ± 1.40	1.60 ± 1.53	0.883

Table 1: This table displays the mean ± standard deviation for muscle activation in vastus medialis and vastus lateralis during a free weight and Nitroforce squat, and activation of the lateral gastrocnemius and medial gastrocnemius during the toe raise. There is no significant difference found between resistance equipment conditions.

There was a strong correlation between the Nitroforce and the free weights for both the vastus lateralis and vastus medialis during the squat as shown in Figure 1. The vastus lateralis and vastus medialis had high R values at 0.925 ($p < .001$) and 0.809 ($p < .001$), respectively, which indicated similar muscle activation activity in both the Nitroforce and free weights.

Figure 2 shows the correlations of the lateral gastrocnemius and medial gastrocnemius for the free weights and Nitroforce mean muscle activation during the toe raise. The lateral and medial gastrocnemius showed low correlation between Nitroforce and free weight conditions with R values of 0.215 ($p = 0.281$) and 0.348 ($p = 0.075$), respectively, indicating different muscle activation. The unusually high data points represent spikes in recorded muscle activation from the gastrocnemius and accompanying muscles, such as the soleus.

Figure 1: Squat Quadriceps Correlation

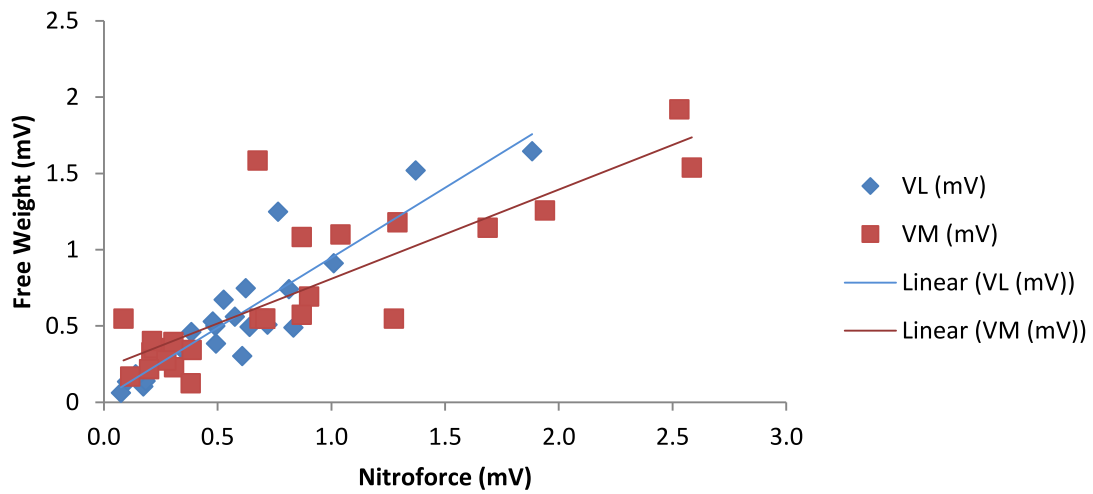

Figure 1: Squat Quadriceps Muscle Activation Correlation. Between Nitroforce and free weight squats, both the vastus lateralis (VL) and the vastus medialis (VM) had high R values at 0.925 and 0.809 respectively, indicating strong correlation between mean muscle activation for each muscle during both lifts at $p< 0.001$.

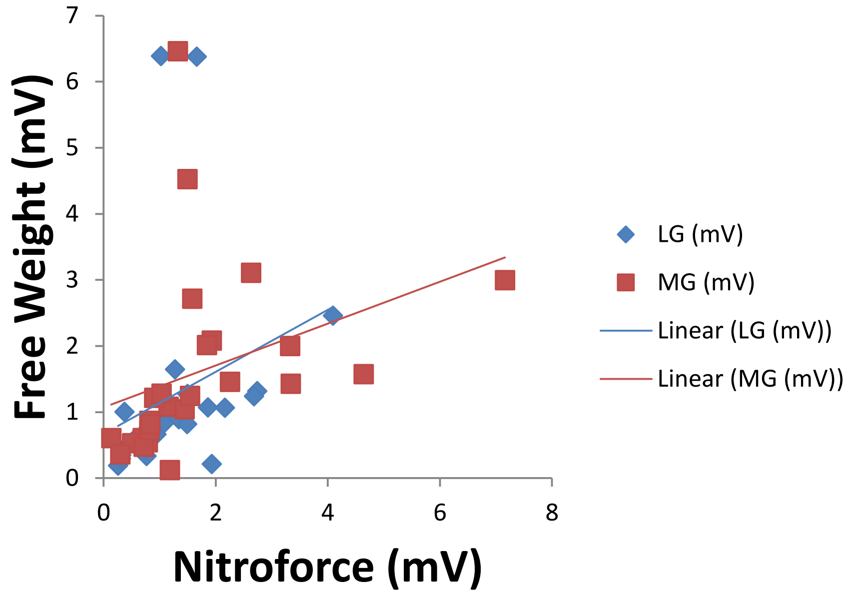

Figure 2: Toe Raise Gastrocnemius Muscle Activation Correlation. Between Nitroforce and free weight toe raises, both the Lateral Gastrocnemius (LG) and Medial Gastrocnemius (MG) had low R values at 0.215 and 0.348 respectively, indicating low correlation between mean muscle activation for each muscle during both lifts at $p > 0.05$.

4. Discussion

The results revealed that muscle activation during free weight training and the piston resistance training using the Nitroforce Titan 1000 were not statistically different in any of the tested muscle groups. There was a strong correlation found in the vastus medialis and vastus lateralis between the Nitroforce and free weight conditions at $p < 0.001$ However, no strong correlations were found when testing the gastrocnemius.

When selecting muscles to record activation, it was important to choose muscles that were easy to gather readings using the EMG equipment available. Since surface EMGs were used, selecting large, superficial muscles would result in the best readings possible. It was also important to note the types of exercises being performed by the participants, as the main muscles performing the exercises had the most activity to record. The two quadriceps muscles observed, the vastus medialis and vastus lateralis, were extremely active during a squat. The two calf muscles observed, the medial and lateral gastrocnemius, were extremely active during a toe raise.

Specifically for the squat, the Nitroforce and free weights produced similar mean muscle activation in the quadriceps. With free weights, the top of the repetition becomes easier as momentum builds, requiring less muscle recruitment. Since the Nitroforce's pneumatic design eliminated momentum, more muscle activation was expected at the top of the repetition than that of free weights. The force change throughout the concentric component of the squat demands greater motor unit recruitment, which would coincide with more EMG activity[31]. This did not hold true for the gastrocnemius muscle activation between Nitroforce and free weight conditions. This inconsistency could be a result of the Nitroforce's inconvenient structural design compared to that of free weights. Participants had to alter their stance to complete their task, forcing their foot placement further forward than that of a typical free weight stance or forcing them to flex at the knee in order to fit beneath the bar. Adjusting to the new stance caused some participants to struggle, which influenced muscle activation in the soleus and accompanying muscles. Because some participants were tall, they had to flex their knees slightly in order to fit underneath the bar and perform toe raises. Flexing slightly at the knee allows greater activation of the soleus, which contributed to overall muscle activation and explains abnormally high recordings. This skewed the possibility of a correlation in the gastrocnemius between conditions, displaying low correlations for the lateral and medial gastrocnemius. The soleus activation using the piston resistance machine is supported by the lower EMG values recorded in the lateral gastrocnemius during the toe raise using the Nitroforce than free weights.

Altered foot placement was a major limitation to the study as it resulted in less muscle activation in muscles that could have activated more using correct form. For example, a taller participant who had to fit beneath the bar by placing his feet further out from under his body encourages more hamstring use than quadriceps use during a squat, decreasing the amount of quadriceps activation. During a toe raise, the knees had to flex in order to fit beneath the bar, encouraging more soleus activation. Although altered foot stance decreased the amount of activation that could have been observed, it was allowed in moderation in order for the participants to complete the exercise fully and comfortably. The Nitroforce's design made form difficult to enforce and altered foot stance had to be forgiven.

Further studies should be performed to observe the mean muscle activation differences in other muscle groups. Since there was no statistical difference between Nitroforce and free weights for two main lower body muscle groups, there could be differences in main upper body muscle groups. It would be presumptuous to assume that, based on this study's results, all muscle groups would have similar muscle activation between Nitroforce and free weight conditions. When studying the Nitroforce, upper body exercises could be more comfortable to perform than lower body exercises, resulting appropriate muscle activation and different results. The design could favor certain exercises, so it is important to study different regions of the body and their ranges of motion.

When further studies are performed, there should be more precautions. Monitoring and enforcing foot placement during toe raises and squats has proven to be effective in gathering accurate EMG data in other studies[35]. Enforcing technique during upper body exercises would help gather more accurate data in future studies. Most participants knew their one-repetition maximum, but others had to estimate which could have altered the amount of muscle activation relative to other participants at their 70% one-repetition maximum. To ensure that every participant is lifting 70% of their one-repetition maximum, it may be useful to test their one-repetition maximum prior to their data collection.

This study has shown enough evidence that the Nitroforce Titan 1000 home-gym can provide similar muscle activation during a workout as free weights for squats and toe raises. The results demonstrate that using either method of resistance training will demand similar effort from the muscles used during a squat and toe raise. Using either method will result in muscle mass maintenance, bone density maintenance, and possibly hypertrophy with proper progression.

In addition, it would be fair infer that the Nitroforce can be used in space to receive similar muscle activation as one would on Earth with free weights. A study conducted by Schneider et al. compared muscle activation while performing squats and toe raises using free weights and a similar resistance machine in a space simulator [33].Their results mirrored ours in that their two conditions were not statistically different in muscle activation. Studying the other aspects of the Nitroforce could further support its use in space to maintain bone density, muscle mass, and overall health in astronauts.

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6. References

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