Original Article

Electromyographic and kinetic comparison of a flexible and steel barbell

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ABSTRACT

Purpose: This research design compares mean peak integrated electromyography (I-EMG) and mean peak ground reaction forces (GRFs) between a standard steel Olympic barbell (SB) and flexible barbell (FB) during the squat (SQ) exercise for human subjects, as well as GRFs for a similar machine-driven lift. Methods: A lifting machine set atop a force plate and lifted either a SB or FB with a total loaded weight of 47.6 kg at a rate of 52 repetitions per minute for a minimum of 12 repetitions. Next, ten NCAA Division I football players familiarized with both bars were randomly assigned the SB and FB loaded at 30% one repetition maximum (1RM) and performed 7-10 repetitions at the same rate as the machine. I-EMG data was collected from surface electrodes placed on the legs and trunk according to the SENIAM protocol where appropriate. Results: Paired t-tests between the SB and FB revealed significant increases ($p<0.05$) in GRFs for the FB during the machine-driven lift and the SQ exercise. I-EMG was significantly higher for the FB when compared to the SB for the vastus lateralis (VL), rectus abdominis (RA), rectus femoris (RF) and external oblique (EO). Results show increases in some leg and trunk muscle activity and increases in GRFs when using a FB loaded at 30% 1RM for the SQ exercise when compared to a SB. Conclusions: A FB, when used under certain conditions, may illicit increased muscle activity for the SQ exercise for some leg and trunk muscle groups compared to a SB. **Key words:** POWER, SQUAT, GROUND REACTION FORCES, MUSCLE ACTIVITY, STABILIZING

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INTRODUCTION

Previous research suggests that training for improvements in strength versus increases in explosive power requires different training loads, with heavy resistance developing strength and lighter resistance lifted at a faster velocity developing power (Brandon, Howatson, Strachan, & Hunter, 2015; Walker, Peltonen, Avela, & Häkkinen, 2011). To determine which training regime elicits the greatest gain in strength and power, previous studies have focused on traditional lifts such as the bench press and back squat using electromyographic (EMG) and ground reaction force (GRF) analysis (Ebben & Jensen, 2002; Newton, Kraemer, Häkkinen, Humphries, & Murphy, 1996). Previous studies have also measured the impacts of using resistance bands and chains in conjunction with standard Olympic steel barbells (Ebben & Jensen, 2002), impacts of using kettlebell swings (McGill & Marshall, 2012) and plyometric exercises (Ellenbecker, Sueyoshi, & Bailie, 2014). Most of these studies are designed to measure relative muscle activation, which could evaluate the effectiveness of these non-traditional resistance training modalities.

The flexible barbell (FB) is a relatively new training apparatus that is being used by a number of strength and conditioning programs in college sports. The manufacturer (Tsunami Bar, LLC) purports the FB allows for maximal speed and power development since, at specific joint-angles, the bar provides maximal resistance due to the momentum change generated by the lifter as he or she tries to reverse the direction of the bar. Theoretically, this so-called "reversal force" requires the recruitment of higher threshold motor units (Zatsiorsky & Kraemer, 2006) to counteract the momentum of the bar as it moves both downward and upward. In addition, structures within the flexible barbell cause an oscillation, which the manufacturer claims, activates more stabilizer muscles than a standard steel bar (Abernethy & Brown, February 2014). The purpose of this study is to test the effectiveness of the FB compared to a SB in generating greater muscle activation and GRFs during the SQ exercise as well as GRFs during a similar controlled machine-driven lift.

MATERIALS AND METHODS

Experimental Approach to the Problem

This randomized control research design reports data from a combination of a machine-driven experiment and a human subject experiment conducted within the same year in which a FB is compared to a SB, which is considered the control for both experiments. The first experiment incorporated a lifting machine set atop a force plate to measure ground reaction forces (GRFs) in response to lifting both a SB or FB (Tsunami Bar®, West Columbia, SC), both loaded with plates for a total weight of 47.6 kg. Each bar was lifted at a frequency of 52 repetitions per minute and a linear travel distance from the bottom to top position of 30.5 cm. The human subject experiment was also designed to compare the SB and FB for the SQ exercise by measuring muscle activity with EMG and GRFs. The total weight of the loaded bar for the human subjects was set to 30% of their one repetition maximum (1RM) (Kraemer & Ratamess, 2004) for each respective lift and was also lifted at a rate of 52 repetitions per minute. Procedures are described in detail below for both the machine and human subject protocols.

Participants

Ten NCAA Division I male freshman football players (age = 19.5 ± 1.4 yrs., body mass = 89.4 ± 17.1 kg, height = 182.0 ± 7.4 cm) who had been familiarized with both the SB and FB volunteered to participate in the study. All subjects read and signed a written informed consent form that had been previously approved by the University Human Subjects Review Board.

Measures

Electromyography and Ground Reaction Forces

In all trials the EMG surface electrodes were connected to a wireless transmitter and continuously streamed through to an analog to digital converter (BIOPAC systems, Inc. Goleta, CA) connected to a Windows-based PC. Using methods described by Winter (Winter, 2009), all EMG data was collected at 1000 Hz with a 10-500 Hz band pass 2nd order Butterworth filter. If the subject could not perform the 1RM, a forced repetition procedure was used where a spotter would provide the minimal assistance to allow the subject to complete the lift. After a minimum of 3 minutes rest (Martorelli et al., 2015), 30% of the subject's 1RM was loaded onto either the FB or SB, and they performed seven to ten repetitions in time with the metronome. Once they completed that set and a minimum of 3 minutes rest (Martorelli et al., 2015) was once again provided, the subject performed a set of seven to ten repetitions on whichever barbell or lift they had not previously used.

Vertical GRFs recorded through the force plate (AMTI LG6-4-200, Advanced Mechanical Technology, Inc., Watertown, MA) were collected at a sampling rate of 2,000 Hz (4000 gain, Butterworth filter). For the machine experiment, the entire machine was placed on the force plate and zeroed to minimize GRF variability. For both experimental protocols, force plate data was zeroed and then collected for the entire duration of the trial. Human subjects stood with one foot on a force plate for the purposes of a later follow-up analysis of inverse dynamics in the lower extremity. Each subject was instructed to lift in time with a metronome set at 104 beats per minute to establish a lifting rate of 52 repetitions per minute.

Procedures

Machine-Driven Experiment

The lifting machine (Palmetto Machine, Columbia, SC) was driven by a 1491 W, 180.64 rad/s constant speed electric motor (World Wide Electric Corporation, Model T2-18-56CB) capable of lifting the weight at 0.527 m/sec in successive up and down repetitions. Based on pilot motion analysis data, the machine was designed with a travel distance of 30.5 cm from the bottom to the top of the lift at a cadence of 52 repetitions per min with the bar secured to the machine in metal clamps 43.2 cm apart to allow for similar handgrip position seen with human subjects. Once the bar was loaded, the machine started in the top position and remained on for a duration long enough to record data for a minimum of 12 repetitions.

Human Experiment: Back Squat

A familiarization trial was held for each subject in order for them to become proficient at moving both the FB and SB (loaded with 30% of their 1RM) in time with a metronome set at 52 repetitions per minute.

Once the subject was comfortable with lifting the barbells at the required pace, they were allowed a 5 minutes rest period during which time EMG surface electrodes were placed on six major muscles consisting of the rectus femoris (RF), biceps femoris (BF), rectus abdominis (RA), erector spinae (ES), external oblique (EO), vastus lateralis (VL). The SENIAM protocol (Hermens et al., 1999) was followed for the muscle groups (BF, ES, VL). For muscle groups not listed under the SENIAM protocol (RA, RF, EO), two electrodes were placed in line with the muscle fibers at a distance of 2 cm apart on the belly of each muscle while ground electrodes were placed on a bony surface such as the patella, Iliac crest, manubrium, and clavicle. The different experimental conditions were randomly assigned based on bar type (FB or SB). A 1RM for the SQ was also determined to normalize the EMG data and establish the 30% of 1RM resistance tested (Kraemer & Ratamess, 2004).

For the SQ exercise, the bar was placed across the shoulders below the seventh cervical vertebral spine. On the second beat of the metronome corresponding to the top position, the subject was instructed to oppose the upward momentum of the bar, pulling it down into the original starting position.

Analysis

Data Reduction and Statistics

The EMG data for the FB and SB sets were normalized based on the 1RM SQ voltage so that values for each contraction were represented as %MVC. The EMG signal was full-wave rectified and the peak was taken from the integration of each muscle contraction. The mean peak integrated EMG (I-EMG) was taken by excluding the first and last repetition and then taking the mean from the four highest peaks of the integrated muscle contractions. Comparisons were made between the SB and FB for the GRFs in the machine and human subject studies and the I-EMG for the human subject squat study using paired sampled t-tests. The data were analyzed using SPSS statistical software with significance reported in the tables below.

RESULTS

Machine and human subject GRF and I-EMG data are reported in tables 1 and 2. GRFs were significantly greater ($p<0.05$) for the FB (704.8 ± 113.1 N) compared to the SB (334.8 ± 13.3 N) for the machine experiment. In the human subject trials, GRFs were significantly greater during the squat exercise (mean SB = 1119.95 ± 203.26 N, mean FB = 1194.8 ± 209.37 N). I-EMG activity was also significantly higher during the squat exercise using the FB for the VL, RA, RF, EO, while the BF and EF showed no differences.

Table 1. Mean peak ground reaction forces (N, mean ± *SD*) for a standard steel bar and flexible bar moved by a motor driven machine at 52 repetitions per minute.

Machine peak vertical ground reaction forces		
Steel Bar	**Flexible Bar**	**Significance**
334.8±13.3	704.8±113.1	p = 0.007

Table 2. Comparison between the steel bar and flexible bar for mean peak ground reaction forces (GRFs) and mean peak integrated electromyographic (I-EMG) response during the squat exercise.

Squat Exercise			
I-EMG	**Steel Bar**	**Flexible Bar**	**Significance**
VL	66.52 ± 16.12	75.69 ± 18.55	p = 0.03
BF	51.79 ± 33.55	58.40 ± 44.58	p = 0.468
RA	115.09 ± 53.91	189.58 ± 114.55	p = 0.03
ES	65.42 ± 29.71	70.77 ± 29.17	p = 0.07
RF	59.92 ± 17.62	69.77 ± 17.32	p = 0.013
EO	68.98 ± 29.50	114.62 ± 52.98	p = 0.0004
GRFs	1120 ± 203.3	1195 ± 209.4	p = 0.001

I-EMG: %MVC of squat 1RM, mean ± *SD* for the Vastus Lateralis (VL), Biceps Femoris (BF), Rectus Abdominus (RA), Erector Spinae (ES), Rectus Femoris (RF)
GRFs: N, mean±*SD*

DISCUSSION

The results of this study demonstrated that the squat exercise produced greater mean peak GRFs when using the FB when compared to the SB. Variable resistance training (VRT) techniques with devices such as bands and chains have shown mixed results on GRF, power, and muscle activity and seem to be specific to the protocol used (Ebben & Jensen, 2002; Walker et al., 2011; Wallace, Winchester, & McGuigan, 2006). Our study demonstrated that a machine-driven lift resulted in an increase in mean peak GRFs for the FB compared to a SB using the same weight, repetitions per minute, and travel distance of the bar. Increases in muscle activity and GRFs with the FB could be attributed to variations in loading due to the bending bar (Wallace et al., 2006). This may not be the case for other FB configurations of differing properties, weight placement of the bar or different lifting frequencies and would be subjects for future studies.

The SQ exercise had greater motor unit activity for some muscle groups using this configuration of the FB compared to the SB. These results have not been previously reported in the literature. Anderson and Behm (Anderson & Behm, 2005) found increased trunk muscle activity increases with unstable squat movements. Assuming that the flexibility of the FB adds instability to the squat compared to SB, our results would also support these results. Different protocols of different percentages of 1RM and lifting frequencies may elicit different results.

PRACTICAL APPLICATIONS AND CONCLUSIONS

Based on the findings in these research studies, the FB would be recommended for increasing stabilizer core muscle group activation such as the RA, RF, EO for the squat as well as the knee extensors such as the VL for the squat exercise. Because of the flexible nature of the bar, this additional muscle activity may be due to the additional instability introduced by oscillations perpendicular to the lifting motion proposed by the manufacturer. The squat data also suggests that increase in GRF for the FB may contribute to the increased muscle activity when compared to a SB. The current study is not designed to isolate this variable. Familiarization is suggested to prepare athletes for this inherent instability and to limit any safety concerns.

Future protocols could compare the potential changes in strength or power over various training periods using the FB compared to SB. There may be adaptations that would limit the increases in muscle activity as subjects become more accustomed to the motion of the FB. Further research would also need to explore variations in experimental protocols including additional lifts, various lifting rates, and percentages of maximum loading to see if the same trends hold true.

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