2000

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HAMSTRING ELECTROMYOGRAPHIC RESPONSE OF THE BACK SQUAT AT DIFFERENT KNEE ANGLES DURING CONCENTRIC AND ECCENTRIC PHASES

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This study examined mean I-EMG for the hamstring group, during eccentric vs. concentric phases of the back squat at knee angles of 160-150°, 140-130°, 120-110° and 100-90°. A 2X4 Repeated Measures ANOVA of the I-EMG hamstring activity revealed a significant interaction of contraction phase by angle ($p<.05$), but not for main effects of contraction phase or angle ($p>.05$). Closer analysis of each contraction phase via a One-way (angle) Repeated Measures ANOVA showed hamstring I-EMG during the eccentric contraction at 120-110° and 100-90° to be greater than 160-150° ($p<.05$), but not different from 140-130° ($p>.05$). In addition, there was no difference between 160-150° and 140-130° during the eccentric phase ($p>.05$). Furthermore, there were no differences found between mean I-EMG activity for any of the angles during concentric knee extension ($p>.05$).

KEY WORDS: EMG, squat, weight lifting, women

INTRODUCTION: The back squat is an essential exercise for the physical development of athletes since it offers a excellent training stimulus for the development of strength and power of the hip and leg musculature (Chandler et al., 1992). Squats may be performed to a variety of depths. One recommendation for squat depth includes performing squats until the upper thigh is parallel or slightly lower than parallel (Chandler et al., 1992). There are no known disadvantages to squatting to parallel or slightly below and Chandler et al. (1992) provide evidence that full squats do not compromise knee structure and stability.

During the squat, the primary movers are the quadriceps and gluteals, whereas the hamstrings function as a synergist (Wathen, 1994). Training the agonist (i.e. quadriceps) without concomitant training of the antagonist can result in undesirable antagonist (i.e. hamstrings) muscle imbalance and may increase the likelihood of injury (Wathen, 1994). Unfortunately, agonist-antagonist strength ratios do not exist for isotonic exercises. However, desirable agonist-antagonist strength ratios for isokinetic movements have been suggested. For example, recommendations for quadriceps/hamstring ratios are 3:2 and the further this muscle balance ratio is from 1:1, the greater the cause for concern about muscle imbalance and possible injury (Wathen, 1994).

During squats, the co-contraction hypothesis suggests the hamstrings provide a stabilizing force at the knee by producing a posteriorly-directed force on the tibia in opposition to the anterior tibial force generated by the quadriceps (Isear et al., 1997). Isear et al. (1997) assessed hamstring co-activation during unloaded squats determining that there is minimal hamstring activity compared to quadriceps activity during unloaded squats. They also noted that the role of the hamstrings seems to be more significant with loaded squats.

Escamilla et al. (1998) compared hamstring activity of squats, leg press, and knee extension exercises. Results reveal that the squat generated twice as much hamstring activity as the leg press and knee extension. Thus squats seem superior to other lower body exercises that include knee extension. However, the same may not be true regarding the value of squats as a hamstring training stimulus.

Wright et al. (1999) evaluated hamstring integrated and peak EMG of subjects performing the leg curl, stiff leg dead lift, and back squat. Their findings indicated that the performance of the back squat resulted in approximately half of the motor unit activity compared to the leg curl and stiff leg dead lift. Results suggest that exercises thought to specifically train the hamstrings are superior to squats as a hamstring training stimulus.

The hamstrings are frequently thought of as knee flexors and synergistic co-contractors during knee extension. However, since the long head of the biceps femoris, semitendinosus, and semimembranosus all cross the hip joint and originate at the ischial tuberosity, they also serve as hip extensors (Tortura, 1989). Theoretically, the depth of the squat may play a role in hamstring activation as a concentric hip extensor, in addition to its role as a co-contracting stabilizer.

Pre-stretching a muscle before concentric contraction can enhance the potential force production of that muscle (Hunter et al., 1992). In fact, pre-stretching two joint muscles such as the long head of the biceps femoris, semitendinosus, and semimembranosus increases the muscles' ability to generate force at the other joint (Hunter et al., 1992). Conceivably, pre-stretching the hamstring (via greater knee flexion as a result of squat depth) develops greater hamstring force (Hunter et al., 1992). Therefore the purpose of this study was to assess hamstring motor unit activation at varying degrees of squat depth.

METHODS: Four female, NCAA Division I athletes (two volleyball and two basketball players) volunteered to serve as subjects for the study. All subjects used squatting exercises in their regular weight-training regimen. Subjects completed a Physical Activity Readiness-Questionnaire and signed an informed consent form prior to participation in the study. Approval for the use of Human Subjects was obtained from the institution prior to initiation of the study. Subjects had performed no strength training in the 48 hours prior to data collection.

Warm-up activity and exercise specific warm-up activity, including one set of 5 repetitions at 50% of the subject's 1RM, and one set of 3 repetitions at 80% of the subject's 1 RM, were performed five minutes prior to the exercises.

Electromyographic data were recorded at 500 Hz by surface electrodes placed on the biceps femoris. This muscle was selected to be representative of the hamstring as noted by Isear et al. (1997). The surface electrodes were connected to an amplifier and streamed continuously through an analog to digital converter (Biopac Systems, Inc. Goleta, CA) to an IBM-compatible notebook computer and diskette. Electromyographic data were filtered with a 10Hz high pass filter (Winter, 1990) and saved with the use of computer software (AcqKnowledge 3.2, Biopac Systems, Inc. Goleta, CA). Saved EMG data were full wave rectified and integrated.

To determine knee angle during the exercise, the subjects were videotaped at 60 Hz from the left side to provide a sagittal view of the exercise. Reflective markers were placed on the subject's lateral malleolus, lateral epicondyle of the tibia, greater trochanter of the femur, and on the end of the barbell. To synchronize the videotape with the EMG data a light was illuminated in the view of the camera with a signal from the light gathered by the Biopac System (Goleta, CA). Kinematic analyses were performed at 30 Hz via the Peak Motus system (Englewood, CO). Angles of interest were determined as the closest point in time when the knee angle attained the initial part of the range (for example 160° was the start of the eccentric160-150° range) to the closest point in time when the final point in the range was reached. EMG data were analyzed for each time frame based on the times corresponding to the desired range of knee angles.

Following the warm-up, the subjects were allowed at least five minutes rest, during which time their skin was prepped for surface electrode placement. Skin preparation for surface electrodes included shaving any hair, removing dead skin from the surface with a roughing pad, and cleansing the surface with alcohol and testing for a resistance of < 1000 ohms. Three surface electrodes were used with placement according to Cram, Kasman, and Holtz (1998). The first electrode was placed in the center of the thigh midway between the gluteal fold and the back of the knee; the second electrode was placed 1cm distal to, and in the same longitudinal axis, as the first electrode; the ground electrode was placed on the lateral condyle of the femur. Following placement of the surface electrodes and connection of the electrodes to the computer, the subject participated in the three randomly ordered exercises. Five minutes rest was provided between each condition. Data was collected for five repetitions with the third repetition analyzed for EMG and kinematics.

Mean integrated EMG data for the hamstring were analyzed using a two-factor analysis of variance (movement X angle) with repeated measures and an alpha level of $p=.05$. The repeated measures were eccentric vs. concentric movement and 160-150° vs. 140-130° vs. 120-110° vs. 100-90°.

RESULTS: A 2X4 (contraction phase X angle) Repeated Measures ANOVA of the mean EMG hamstring activity revealed no significant main effects for angle ($p=.21$) or contraction phase ($p=.36$). There was however, a significant interaction of contraction phase by angle ($p=.018$) indicating that the type of contraction resulted in differences at different angles (Table 1). Indeed, as the subjects moved eccentrically toward greater flexion the mean EMG of the hamstrings appeared to increase; as the subjects moved in extension concentrically the mean EMG of the hamstrings appeared to increase (Figure 1). Closer analysis of each contraction phase via a One-way (angle) repeated measures ANOVA showed a mean EMG hamstring activity during eccentric contraction at 160-150° to be less than 120-110° and 100-90°, but not different from 140-130°. There was no difference found between mean EMG hamstring activity for any of the angles during concentric knee extension.

Table 1 Mean EMG (Mean / SD) Hamstring Activity at Four Angle Ranges (°) during a Squatting Movement in Two Directions

	160-150 °	*140-130°*	*120-110°*	*100-90°*
Eccentric	.302/.143	.658/.175	.941/.381	.919/.326
Concentric	.910/.169	.929/.230	.845/.404	.671/.387

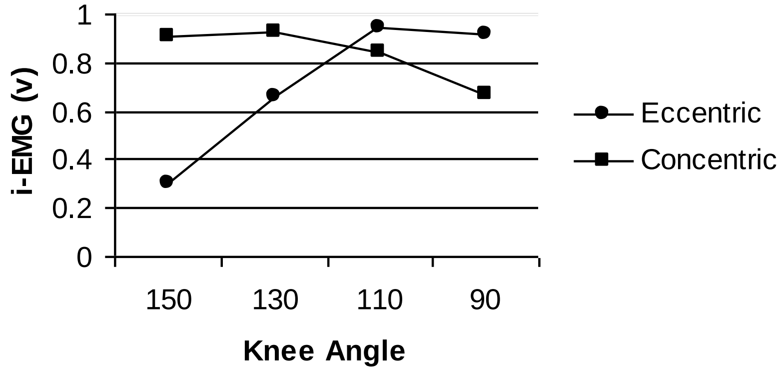

Figure 1 - Mean EMG Hamstring activity during a squatting movement in two directions. Knee angles listed are for maximal flexion of each range. (see text for explanation of ranges)

DISCUSSION: Results of the current study revealed that hamstring motor unit activity, as measured by surface EMG, did not change as a function of depth during the concentric portion of the back squat. These results suggest that despite changes in knee and hip joint angle, their effect on hamstring length did not alter the hamstring EMG during the ascent phase of the back squat. This is in contrast to findings of Isear et al. (1997) who showed that the hamstrings were more active at the beginning of the ascent (concentric) phase after holding in a squat position. Furthermore, because both knee and hip angle change during both (concentric and eccentric) phases of the exercise (Wright et al., 1999) it would also be difficult to determine the amount of pre-stretch placed on the hamstring. Indeed the length, and thus the force, of biarticulate muscles such as the hamstring can be optimized, because they are effected by both joint angles (Hamill and Knutzen, 1995). Finally, it was not possible to determine if the EMG activity during the concentric phase is a result of the hamstring

functioning as a co-contractor and stabilizer or if the hamstring plays a role as an agonist assisting hip extension as noted by Isear and co-workers (1997).
During the eccentric portion of the back squat hamstring activity did change as a function of squat depth. Hamstring activity was greatest at 120 degrees or less of knee flexion. This may be due to a stabilizing effect at the knee during the eccentric stopping action taking place at the end of the descent phase (Wright et al., 1999). Results suggest that during the back squat, the eccentric role of the hamstring is greater that the concentric and that the eccentric activity increases as a function of squat depth to a degree. These finding are somewhat consistent with the findings of Escamilla et al. (1998) who report the squat resulted in greater hamstring EMG than exercises such as the leg press and knee extension due to their role as a co-contracting stabilizer.

CONCLUSION: Some observers suggest that performing the back squat to parallel or deeper is necessary to optimally activate the hamstrings. However, results from the current study suggest that during the concentric portion of the back squat, squat depth from a knee angle of 90° or greater (parallel and up to extension) is not a determinant of hamstring activity as assessed by EMG. During the eccentric phase, squat depth did effect hamstring activity, but only in the initial stages, as at 120° and beyond (slightly above parallel and continuing down to parallel) there were no differences in muscle activity. Therefore, because muscle activity was not altered by squat depth, back squat depth should be dictated by factors such as the need for biomechanical specificity rather than to increase muscle activity. This recommendation is supported by the findings of Wright et al. (1999) who reported that exercises such as the stiff leg dead lift and leg curl offer a significantly greater hamstring training stimulus than the back squat.

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Acknowledgements
Sponsored in part by a Northern Michigan University Faculty Research Grant.