MASTER THESIS

Course code: MKI210

Candidate name: Tom Roar Knutli

Differences between sticking region in high-bar and low-bar, barbell back squat

Forskjeller mellom "sticking region" i knebøy med høy- og lav stangplassering

Date: 15.05.18

Total number of pages: 19

NORD University

www.nord.no

Index

Abstract

Aim of the research:

The aim of the study was to investigate if there are any differences between the sticking region in low bar and the high bar two-legged free weight squat in muscle activity or joint angles between the two techniques, or across different regions in the squat. Another point of interest was to see if there were any gender differences.

Design: Quantitative research design.

Subjects: 16 resistance trained subjects, ten males and six females (age 26±11 years, body mass 89±34 kg, body height 183±20 cm) with 6±4 years of resistance training experience performed a 5RM in high bar squat and low bar squat.

Background: The author has been competing in powerlifting since the spring of 2016 and has during that time seen that most of the powerlifters in no-equipped powerlifting prefers to use a low bar squat over the high bar squat.

Results: The last repetition in both techniques was analysed for a sticking region. In every subject a sticking region was observed. In every subject the muscle activity in rectus femoris and vastus lateralis decreased in contrast to gluteus maximus and biceps femoris that increased muscle activity around the sticking region. No significant results were found in vastus medialis, gluteus medius, erector spinae, gastrocnemius or semitendinosus. No significant differences were found in measurements of the joint angle in the ankle, knee or hip. There was not found any significant differences between gender in muscle activity or joint angles.

Conclusion: In present study there is no significant differences between the sticking region in the low bar and the high bar two-legged free weight squat.

Preface

This master thesis is written at Nord University, department of Sports Sciences and Physical Education.

The joy of delivering this product is huge, and I am happy that I can come out of the bubble I have been in the last year. I want to thank my girlfriend, family and work for their understanding and patience with me since I've been away a lot, even when I have been home I haven't been there mentally. Without their help, this thesis never had been delivered. A special thanks to my girlfriend for motivating me to finish this year, and for proofreading my paper. I also would like to thank my supervisor Roland van den Tillaar for guidance through this year, and for haven't giving up on me. To the sixteen subjects that participated in the study, thank you very much for giving me this opportunity.

Tom Roar Knutli

Mai 2018

Introduction

Barbell back squat is an exercise that is used in general strength training, powerlifting contests, and as a part of a rehabilitation program for the lower extremity (Sandler, 2005) (Kompf & Orandjelovic, 2016). Barbell back squat is performed by bending the knees and lower the body until the top surface of the legs at the hip joint is lower than the top of the knees. The lifter must recover at will to a upright position with the knees locked (International Powerlifting Federation, 2015), All variants of the squat involve a synergistic knee and hip flexion till desired depth, and knee and hip extension in the ascent till start position (Schoenfeld, 2010) (Kompf & Orandjelovic, 2016).

Squat is one of the most used resistance exercises, because its biomechanical and neuromuscular similarities to many every day and athletic tasks. In powerlifting and weightlifting it is super specific. There are some significant biomechanical differences in the squat based on execution style, such as bar placement (Russel & Phillips, 2013) and stance width (Escamilla, Fleisig, Lowry, Barrentine & Andrews, 2001) (Kompf & Orandjelovic, 2016).

There are two main techniques of barbell back squat. They're called "high bar back squat" and "low bar back squat". The difference in the placement of the bar, high bar places the bar slightly above the acromion height and low bar places it slightly below (Escamilla, 2001). Low-back barbell squat is mostly used in powerlifting contests, with a few exceptions that uses high-bar back squat. A low-bar back squat will be the best alternative when the main goal is to lift as heavy as possible (O'Shea, 1985). One of the main reasons is shorter moment arms, and better work conditions for the hamstrings-, gluteus-, and adductor muscles (Glassbrook, Brown, Helms, Duncan & Storey, 2017).

In 1996 a study was published that compared peak force outputs over of the knee and hip joints, and EMG on vastus lateralis, rectus femoris and biceps femoris during the high bar and low bar back squat. It was tested in paralell and deep squats. Six powerlifters (low bar) and eight weightlifters (highbar) participated in the study. The powerlifters produced a higher peak force in the hip joint than the weightlifters did high bar, while the weightlifters produced a higher force in the knee joint than the powerlifters. In EMG there was different results (Wretenberg, Feng, & Arborelius, 1996).

The sticking region

During many resistance exercises, there is a region where the velocity on the weights is lower than the rest of the range of motion. This is referred to as the sticking region. Sticking region is defined as the region from the highest velocity to the lowest velocity after which it increases again (Madsen N, 1984).

There is not very much research on this region during the squat, but the sticking region has been observed in several studies (McLaughlin, Dillmann & Lardner, 1977) (Escamilla, et al., 2001) (Hales, Johnson & Johnson, 2009) (Van Den Tillaar, Andersen, & Saeterbakken, 2014). It is suggested that a probable reason that sticking region occurs is the combination of increased activity in m. biceps femoris and decrease of activity in m. rectus femoris during the region. (Van Den Tillaar, et al., 2014)

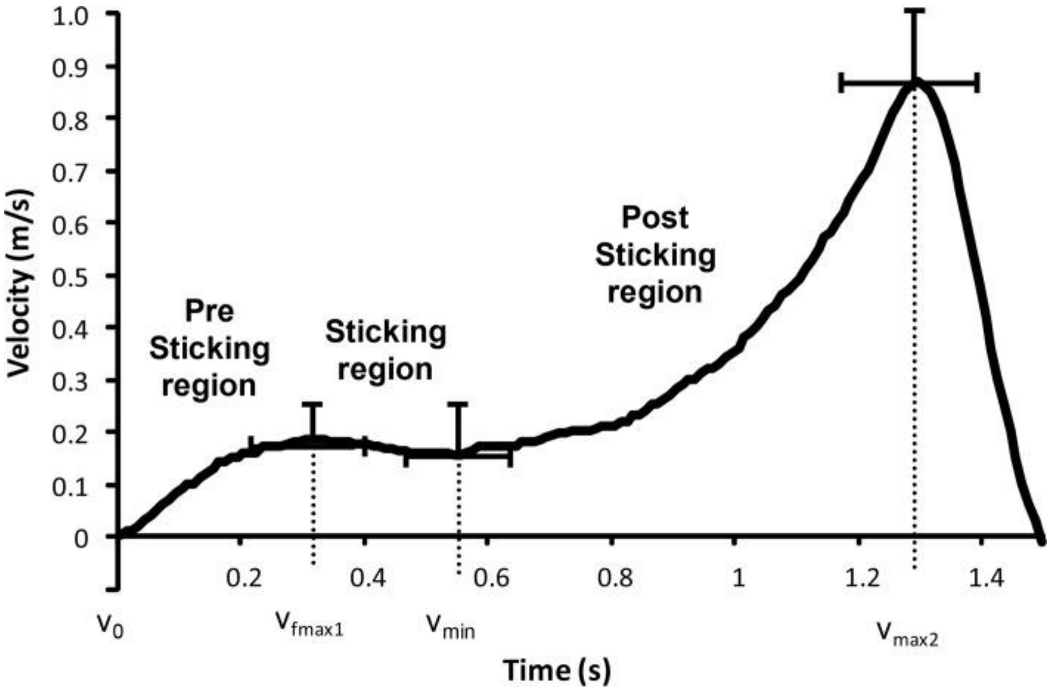

Figure 1 (Van Den Tillaar, et al., 2014)

This is how a typical near maximum attempt in the barbell back squat looks like. Pre-sticking, sticking and post sticking region and the following events: Lowest barbell position(v_0), first maximum barbell velocity(v_{max1}), first located lowest barbell velocity(v_{min}) and second maximal barbell peak velocity(v_{max2}) (Van Den Tillaar, et al., 2014).

In the squat the muscle activity pre- and post-sticking region has been researched to find out which muscles that help the lifter to pass the sticking region. Van Den Tillaar, et al. did not find any significant results that could say which muscle that helps the lifter through the sticking region (Van Den Tillaar, et al., 2014).

Sticking region does appear in the barbell back squat in most athletes (Van Den Tillaar, et al., 2014). 10 of 15 subjects in this study had a sticking region in their 6RM squat test. The reason that five subjects didn’t have a sticking region is not known, maybe that they didn’t squat heavy enough (Newton, et al., 1997, ss. 333-342). Another probable reason is that the subjects didn’t go deep enough in the squat.

To the best of my knowledge there has not been done studies on the difference between the sticking region in high-bar and low-bar back squat. Investigating the kinematics and muscle activation presumed the sticking region of both squat techniques would provide information about possible explanations on the occurrence of the sticking region. Furthermore, it can give information about which muscles that can help the lifter through the sticking region and explain the reason why most raw powerlifters prefer to use low-bar technique when squatting maximal weights.

Hypothesis

The aim of the study was to investigate if there are any differences between the sticking region in low bar and the high bar two-legged free weight squat in muscle activity or joint angles between the two techniques, or across different regions in the squat (Figure 1). Another point of interest was to see if there were any gender differences.

The hypothesis is that changes in biomechanics between the two squat techniques, will shorten the sticking region in both length and duration during the low-bar technique compared with the high-bar technique. It will be a smoother transition from the use of rectus femoris to the use of gluteus maximus and biceps femoris. There will not be any differences between gender.

H_0: There is no difference in occurrence, duration and muscle activity involved during the sticking region, or across different regions in low-bar and high-bar back squat.

H_1: Sticking region will have shorter duration, it will occur later during the lift (joint angles), and there will be more muscle activity in the hamstrings and gluteus muscles during the low bar squat compared with the high-bar squat.

Material and methods

Design

The study was designed to look at the differences in muscle activity in the thigh and seat muscles during the high-bar and the low-bar back squat, by use of EMG- electrodes. In present study a linear encoder was used to investigate the barbell kinematics together with 3D kinematics for joint angles.

Test subjects

The study sample consisted of 12 medium- to well-trained powerlifters, 1 football player, and three “mma” (mixed martial arts) athletes. It was ten males and six females, (age 26±11 years, body mass 89±34 kg, body height 183±20 cm) with 72±48 months of resistance training experience. Every subject in the study were familiar with both squat techniques. Inclusion criteria was being able to lift 1.5 times their own body mass in 1RM squat with a good technique. The subjects had no injuries that could reduce their maximum performance. None of the subjects did follow any resistance training of the legs 24 hours before testing. All subjects were informed both verbally and by writing of the possible risks of the test and provided a written consent before they were included in the study.

Procedures

In present study a 5RM test was used to investigate kinematics and muscle patterns during the sticking region in the high-bar and the low-bar squat. 5RM was used because it is a typical training load used to increase maximal strength, and because the subjects are used to five repetitions in both techniques.

One familiarization test was conducted two weeks before the experimental test. In the familiarization test the 5RM load was anticipated by the subjects. 90% of their estimated 5RM was used during the familiarization test. The subjects used their preferred stance width. A minimum requirement of depth was that the hip joint had to be lower that the knee joint. The depth was measured and marked with a horizontal rubber band. In the experimental test, the subjects started at 95% of estimated 5RM, and added 2.50-7.50kg until their real 5RM were obtained. Then they shifted to the other technique and did the same. They had 1-3 attempts and 4-5 minutes pause between each. The subjects performed a specific warm up protocol before testing, consisting of five sets with different load based on their thought 5RM. They did eight repetitions with barbell, six repetitions at 35%, five repetitions at 55%, 3 repetitions at 70% and two repetitions at 90% of thought 5RM in squatting.

Testing was performed in an eleiko weightlifting rack, with an eleiko weightlifting barbell (50mm width, 28 mm diameter). The subjects bended the knees until the hamstring touched the rubber band and returned to starting position. Verbal sign was given by the test leader before the first rep could be performed.

Measurements

A linear encoder (Ergotest Innovation -02) was connected to the barbell to measure the lifting time and the vertical displacement was measured from the lowest point of the barbell. Barbell displacement and velocity was identified at the following positions in the upward movement of the squat: lowest position of the barbell (V_0), first maximal barbell velocity (V_{max1}), first located lowest barbell velocity (V_{min}) and second maximal barbell peak velocity (V_{max2}).

EMG (electromyography) is a technique for evaluating and recording electrical activity in the muscles. Muscle activity was measured on gluteus maximus, gluteus medius, vastus lateralis, vastus medialis, semitendinosus, rectus femoris, biceps femoris, soleus and gastrocnemius. Before placing the electrodes, the skin was shaved and dried off, and a small amount of conducting gel was applied on each electrode (EMG Triode Electrodes T3402M, Thought Technology, USA) before placing it on the muscles. The electrodes were placed along the presumed direction of the underlying muscle fibre according to the recommendations (Hermens, Frederiks, Disselhorst-Klug, & Rau, 2000). The EMG signals were sampled at a rate of 1000hz and synchronized with the kinematic data. The EMG and 3D Kinematics were synchronized by a signal. The software program Muscle lab v10.67 (Ergotest, Porsgrunn, Norway) was used to analyse the stored EMG and linear encoder data.

To be able to compare muscle activity during the sticky region in the squat, three regions were assigned. First region was named pre-sticking, from the lowest barbell point (V_0) to first maximal barbell velocity (V_{max1}). Second region was called sticking, from the first maximal barbell velocity(v_{max1}) to the lowest located barbell velocity(V_{min}). Post sticking was the last region, from the lowest located barbell velocity (V_{min}) to the second maximal barbell velocity (V_{max2}). Root mean square (RMS) EMG of each region in each subject who experienced a sticking region, was used in further analysis.

Three- dimensional positions were measured using a 3D motion capture system (Qualysis, Gothenburg, Sweden). Eight cameras tracked the positions of the reflective markers that were placed on following anatomical places on both sides: wrist, elbow, lateral tip of acromion, sternum, superior iliac crest, trochanter major, knee, ankle, heel and toe. On the knees, elbows, wrists and ankles, there were placed two reflective markers, lateral and medial.

A 3D model was constructed on each person in both techniques from these reflective markers in Visual 3D (C-motion, USA). The software was used to find ankle angle, knee angle and hip angle in all subjects that experienced a sticking region. Angles were measured in the lowest barbell position(V_0), first maximum barbell velocity(V_{max1}), first located lowest barbell velocity(V_{min}) and second maximal barbell peak velocity(V_{max2}).

Statistics

Paired t-tests for repeated measures were conducted to identify differences in muscle activity and joint angles between sticking region in the low bar squat and high bar squat. Independent sample t-test was used to compare differences between gender in muscle activity and joint angles. A two-way ANOVA was used with Holm-Bonferroni post hoc tests to access differences in muscle activity for the different regions and between low-bar and high-bar for each muscle. Statistical analyses were done with Excel – 2016 (Microsoft office). Statistical significance was set at $P \leq 0.05$. All results are being presented as means ± standard deviations.

Results

General

The weight that was successfully lifted by the subjects at 5RM was 118±62kg. All subjects lifted their assumed 5RM, and 10 of them achieved 2.5-10kg more than their assumed 5RM. All subjects experienced the sticking region in both squat techniques.

Displacement

Figure 2 shows the velocity in the squat with a sticking region from V_{max1} to V_{min}. After V_{min} the velocity increases again, and the second peak velocity was clearly higher after V_{min}. The sticking region in high-bar squat lasted for 0.19 ± 0.8 s, and the sticking region in the low bar squat lasted for 0.16 ± 0.08. The sticking region in low-bar squat started at 0.25 m ± 0.09 from the deepest point of the barbell, while high-bar squat started at 0.27 m ± 0.09. There was no significant difference between the sticking region between the high bar and the low bar barbell back squat.

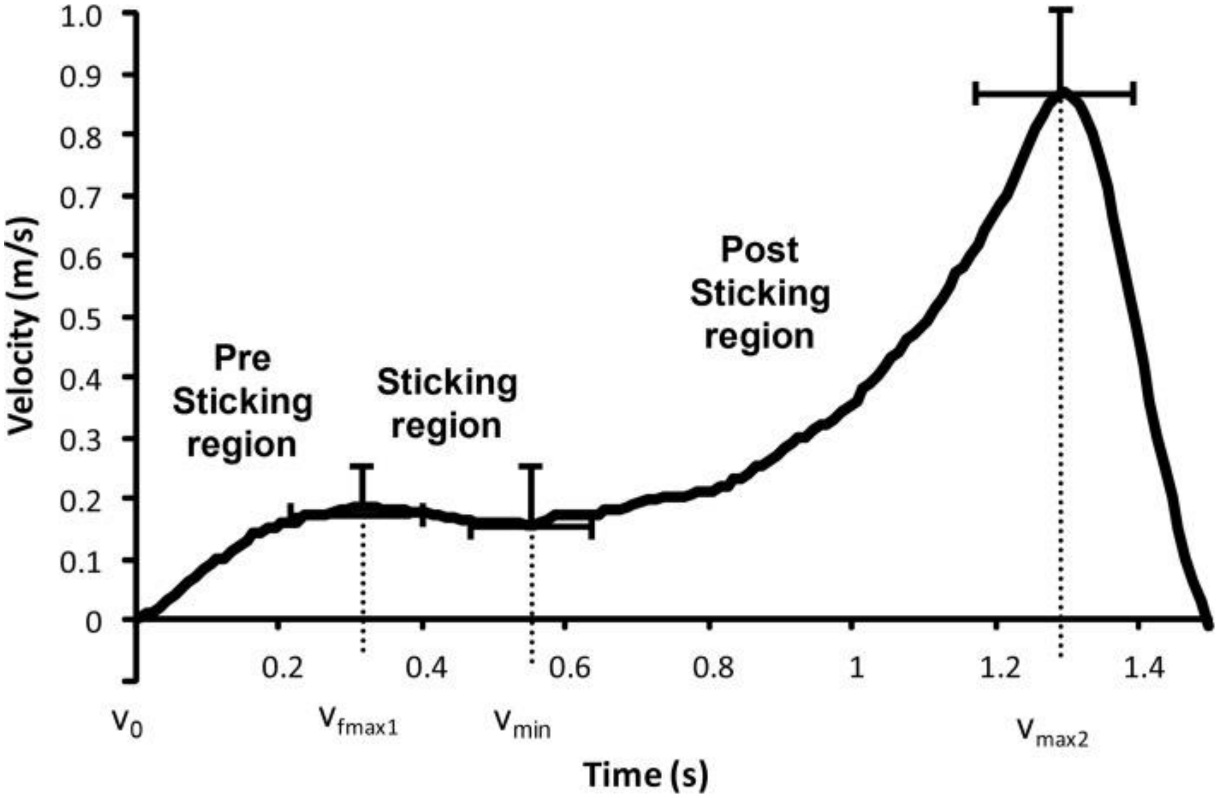

Figure 2

A typical barbell velocity during a squat with a sticking region (Van Den Tillaar, et al., 2014).

Joint angles

A two-tailed t-test was performed to compare the joint angles between the high bar and the low bar free weight squat at the different events. There were no significant differences in joint angles between the high bar and the low bar free weight squat. T-test result for the hip angle (P=0,098) and knee angle (P=0,099) at v_{max2} shows a trend that the hip joint angle is higher than in the low bar than the high bar squat. Which tells us that the test subjects reached V_{max2} earlier when squatting low bar. Further a independent sample t-test was performed to see if there was any differences between gender. There were not found any significant differences between gender.

Table 1

Mean variables with their standard deviation at lowest barbell point, first maximal barbell velocity, minimal barbell velocity and second maximal barbell velocity during the high bar and the low bar squat.

	Variable	**v_0**	**v_{max1}**	**v_{min}**	**v_{max2}**
High bar squat	Barbell Velocity(m/s)	0	0.171±0.069	0.163±0.086	0.746±0.183
	Barbell Height (m)	0	0.085±0.042	0.188±0.121	0.307±0.084
	Ankle joint angle (°)	65±7	71±6	80±5	86±7
	Knee joint angle(°)	45±4	97±7	104±6	125±7
	Hip joint angle(°)	55±5	55±7	70±5	100±8
Low bar Squat	Barbell Velocity(m/s)	0	0.177±0.072	0.169±0.076	0.773±0.178
	Barbell Height (m)	0	0.085±0.042	0.186±0.101	0.297±0.076
	Ankle joint angle (°)	64±8	71±6	82±5	83±6
	Knee joint angle(°)	55±4	98±7	102±5	118±6
	Hip joint angle(°)	43±4	55±7	66±5	92±7

EMG

A two-tailed t-test was performed to compare the muscle activity between the high bar and the low bar free weight squat. There were no significant differences between the high bar and the low bar free weight squat in either of the regions assigned. Some trends for biceps femoris (P=0,058) and gluteus maximus (P=0,084) was found in the sticking region. Independent sample t-test was performed to see if there were any differences between gender. There were no significant differences between gender.

Further a two-way ANOVA was performed on the different muscles for every subject. The results indicated significant effects for the biceps femoris (F=3.151; P=0.049; figure 3), gluteus maximus (F=6,446; P=0.0025, figure 3), vastus lateralis (F=4,6 P=0,0129; figure 4), rectus femoris (F=4.099; P=0.1978; figure 4), soleus (F=5.222; P=0.007, figure 4), and erector spinae down (F=3.9; P=0.024) during the three regions. Post hoc comparison revealed that for the soleus, gluteus maximus, vastus lateralis and rectus femoris the activity significantly increased from pre-sticking to post sticking region. The activity for gluteus maximus significantly increased from pre-sticking to sticking region. The activity in vastus lateralis significantly increased from sticking region to post sticking region. No significant effect was found for the lower erector spinae. The other muscles did not change their muscle activity during the three regions in the squat.

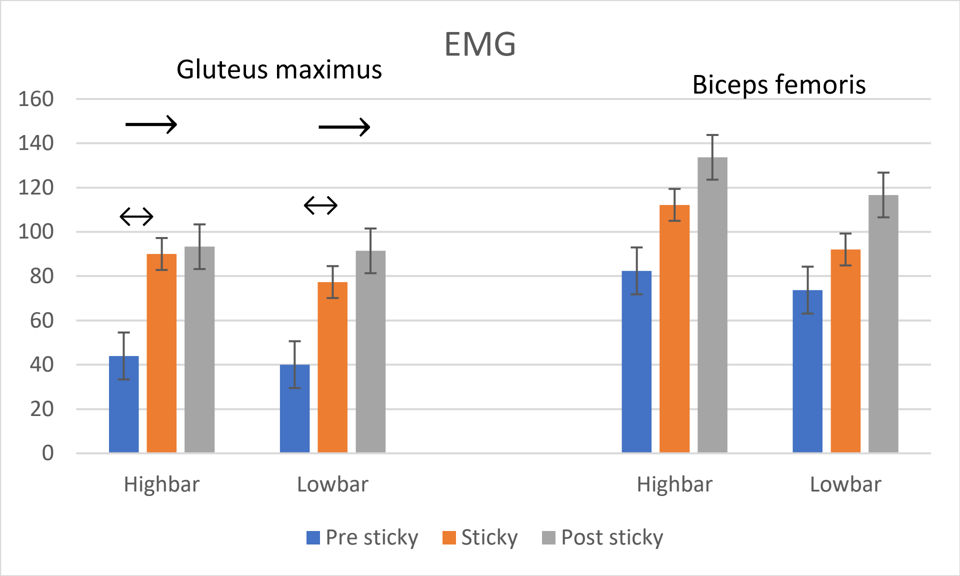

Figure 3

Mean (± SD) root mean square (RMS) EMG activity of pre-sticking, sticking, and post sticking region in gluteus maximus and biceps femoris.

↔ indicates a significant difference in muscle activity between the pre-sticking region and sticking region.

⟶ indicates a significant difference in muscle activity from pre-sticking region to post sticking region.

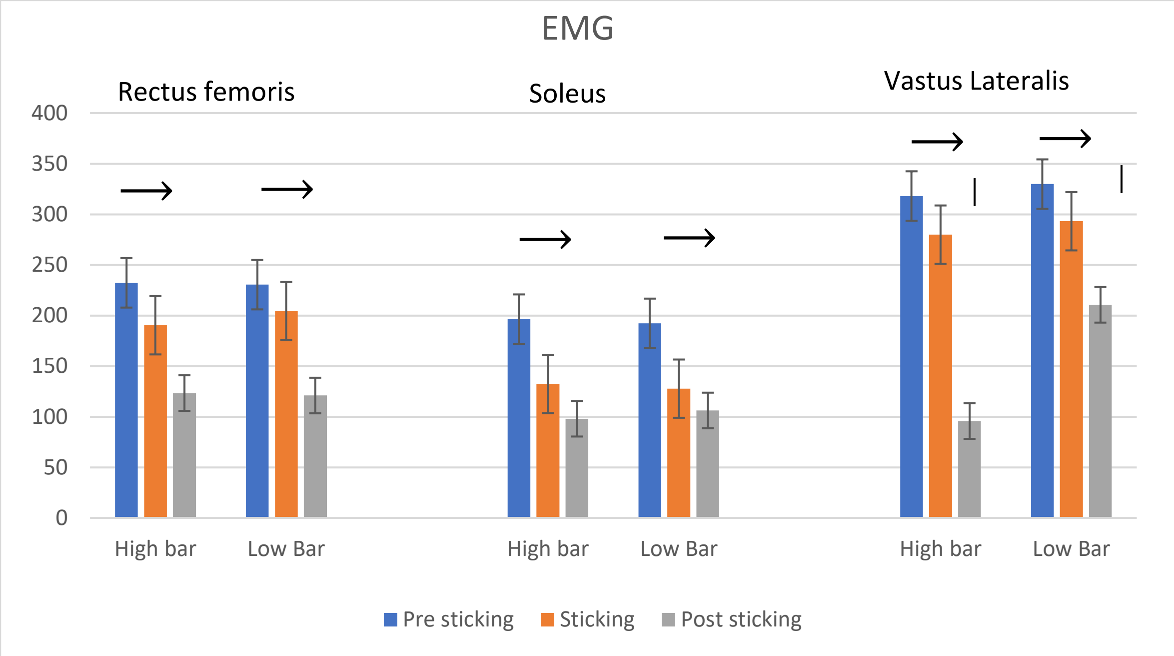

Figure 4

Mean (± SD) root mean square (RMS) EMG activity of pre-sticking, sticking, and post sticking region in biceps femoris and gluteus maximus.

⟶ indicates a significant difference in muscle activity from pre-sticking region to post sticking region.

| indicates a significant difference in muscle activity with all other regions.

Discussion

The aim of the study was to investigate if there are any differences between the sticking region in low bar and the high bar two-legged free weight squat in muscle activity or joint angles between the two techniques, or across different regions in the squat. Another point of interest was to see if there were any gender differences.

Every subject had a sticking region in both squat techniques, which indicate that every subject had a load above 85% of their 5RM (Van Den Tillaar, et al., 2014), this is also the fact in bench press (Newton, et al., 1997). However, there were no significant differences found in muscle activation and kinematics between the sticking regions in low-bar and high-bar squat. T-test result for biceps femoris (P=0,058) and gluteus maximus (P=0,084) shows a trend, and with a few more test subjects it could been a significant result for bigger muscular activity in these two muscles during low bar back squat in the sticking region.

3D vision was used to calculate the joint angle of the ankle, the knee and the hip. This calculation shows that from pre-sticking- to sticking region the main movement is extension of the knee, while from sticking region hip extension is the main movement. The analyses did not show any significant differences in joint angles between the low-bar and the high-bar squat. In present study there is a trend that the knee- and hip angle is bigger in v_{max2} which could indicate that the test subjects reaches v_{max2} earlier in the low bar squat. This was not a significant result when analysing the speed of the barbell. The results could probably be affected about the requirement of depth for both squat techniques. Almost every subject said that the requirement of depth ruined they're normal low-bar squat technique, because they had to have much more dorsal flexed ankle to hit the required depth. This could have changed the whole biomechanics of the low-bar squat and removed the difference between these two squats. A minor change in technique for the subjects could be enough to make the results different. In present study the depth requirement could have been pushed a bit too far.

To the best of my knowledge this is the second study on sticking regions in the barbell back squat, but the first that differentiate between low-bar and high bar squat. The other study measured EMG on vastus lateralis, vastus medialis, rectus femoris, biceps femoris and soleus. There is some difference between our results. Both studies found a significant change in biceps femoris. Van den Tillaar et al. (2014) found that study the biceps femoris significantly changed from pre- to sticking region (Van Den Tillar, et al., 2014), while in present study there was not a significant result between any on these regions. Further comparison shows that Van Den Tillaar, et al. found other results regarding rectus femoris. They found significant results between all regions, while in present study just found significant results between pre- to post sticking region. In soleus the present study found significant results from pre- to post sticking region, while in the other study (Van Den Tillar, et al., 2014) found significant results from pre- to sticking region. In vastus medialis there was no significant results in either of the studies. A probable reason for the differences in muscle activity could be joint angles or the difference in technique between powerlifters and none-powerlifters.

Gluteus maximus was the only muscle that had significant change in muscle activity from pre- to sticking region. It is logical that gluteus maximus is being more active in the sticking region since it is one of the main muscle for extension of the hip. This also strengthen the idea that from pre- to sticking region the knee extends, and from sticking- to post sticking region it is the hip angle that changes the most. Gluteus maximus will have higher muscle activity from the sticking region, that will help us extend the hip through the sticking region. From the calculation of joint angles, hip extension seems to be the main movement in the sticking region.

The EMG results also show that the vastus lateralis and rectus femoris has a higher muscle activity in the bottom of the squat, which Is needed to extend the knee. Muscle activity is lower in gluteus maximus and biceps femoris in the bottom of the squat. Further vastus lateralis, rectus femoris and soleus had less muscle activity in the sticking- and post sticking region compared to the pre-sticking region, while it was the opposite for gluteus maximus and biceps femoris since the muscle activity in them increased. It is logical that the soleus muscle activity decreases since its function is plantar flexion of the ankle. The decrease in muscle activity in the rectus femoris and vastus lateralis also makes sense and build upon what's been written earlier. From pre-sticking to sticking region the main movement is knee extension, and from the sticking region the hip angle is what mainly changes.

The main function for the biceps femoris is to flex the knee, but the long head of the muscle is originated in the pelvis, so it is also included in hip extension. This results in the long head being a weaker hip extensor while the knee is flexed due to inadequacy (Van Den Tillaar et al., 2014) (Marshall, Girgis, & Zelko, 1972). The switch from extending the knee to extension of the hip could be one of the explanations of the sticking region, and the "delay" of extending the hip is due to the long head of biceps femoris is weaker when the knee is flexed.

From to the results from EMG measurement from the two techniques and across the three assigned regions (Figure 1) and calculation of joint angles does not give a straight answer to why not equipped powerlifters seems to prefer to lift with a low bar technique. In present study there is no significant differences between gender in muscle activity or joint angles.

Conclusion

To the best of my knowledge this is the second study done on sticking region in the barbell back squat, but the first that checks both the high-bar and the low-bar squat. In present study there is no difference between the sticking region in the high bar and the low bar squat either in muscle activity, joint angles, or between gender. Present study could not give a answer to why many powerlifters prefers to lift low-bar when they want to lift heaviest possible.

It is possible that the subjects were not as familiar with the two techniques as they said, or that the requirement of depth changed the technique too much as previous mentioned. Future studies should include more test subjects, both female and male to investigate for gender differences, and several lifters who are more experienced with the two techniques. From the trends found in this study, it would be interesting doing a new study on this, with more subjects. It could be interesting to see if training gluteus maximus and biceps femoris more actively to reduce the sticking region and improve the free weight squat performances.

The information from present study could help researchers, coaches and athletes to better understand the sticking region in the 5RM squat. From present study the gluteus maximus and biceps femoris are the most important muscles for surpassing the sticking region, but it is not possible to say that training these muscles would reduce the length or duration of the sticking region. More research must be done on this region before training recommendations could be formed.

References

Escamilla, R. F. (2001, Januar). Knee biomechanics of the dynamic squat exercise. *Medicine & Science in Sports & Exercise*, pp. 127-141.

Escamilla, R. F., Fleisig , G. S., Lowry, T. M., Barrentine, S. W., & Andrews, J. R. (2001, Juni). A three-dimensional biomechanical analysis of the squat during varying stance widths. *Medicine and science in sports and exercise*, pp. 984-98.

Glassbrook, D., Brown, S., Helms, E., Duncan , J., & Storey, A. (2017, Februar 08). The high-bar and low-bar back-squats: A biomechanical analysis. *Journal of strength and conditioning research*.

Hales, M., Johnson, B., & Johnson, J. (2009, December 23). Kinematic analysis of the powerlifting style squat and the conventional deadlift during competition: is there a cross-over effect between lifts? *Journal of strength and conditioning research*, pp. 2574-2580.

Hermens, H., Frederiks, B., Disselhorst-Klug, C., & Rau, G. (2000, October 10). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of electromyography and kinesiology*.

International Powerlifting Federation. (2015, 01 01). Retrieved from http://www.powerlifting-ipf.com/fileadmin/ipf/data/rules/technical-rules/norwegian/2015_NOR_IPFs_tekniske_regler.pdf

Kompf, J., & Orandjelovic, O. (2016, September). The Sticking Point in the Bench Press, the Squat, and the Deadlift: Similarities and Differences, and Their Significance for Research and Practice. *Sports medicine*, pp. 631-640. Retrieved from The Sticking Point in the Bench Press, the Squat, and the Deadlift: Similarities and Differences, and Their Significance for Research and Practice: https://www.ncbi.nlm.nih.gov/pubmed/27600146

Madsen N, M. T. (1984, August 16). Kinematic factors influencing performance and injury risk in the bench press exercise. *Med Sci Sports Exerc*, pp. 376-381.

Marshall, J., Girgis, F., & Zelko, R. (1972, October). The biceps femoris tendon and its functional significance. J Bone Joint Surg Am. 1972;54:1444–1450. [PubMed]. *The journal of bone and joint surgery*, pp. 1444–1450.

McLaughlin, T., Dillmann, C., & Lardner, T. (1977). A kinematic model of performance in the parallel squat by champion powerlifers. *Medicine in science and sports*, pp. 128-133.

Newton, J., Murphy , A. J., Humphries, B., Wilson , G., Kraemer, W., & Häkkinen, K. (1997). Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper body movements. *European journal of applied physiology and occupational physiology*, pp. 333-42.

O'Shea, P. (1985, Februar). Sports Performance Series: The parallel squat. *Strength & conditioning journal* , pp. 4-6.

Russel, P. J., & Phillips, S. J. (2013, February 08). A Preliminary Comparison of Front and Back Squat Exercises. *Research quarterly for exercise and sport - Volume 60*, pp. 201-208.

Sandler, D. (2005). Sports Power. Champaign III: Human Kinetics.

Schoenfeld, B. J. (2010, Desember 24). Squatting kinematics and kinetics and their application to exercise performance. *Journal of strength and conditioning research*, pp. 3497-506.

Van Den Tillaar, R., & Ettema, G. (2010, Mars 28). The "sticking period" in a maximum bench press. *Journal of sports science*, pp. 529-535.

Van Den Tillaar, R., & Ettema, G. (2013, Oktober 08). A comparison of muscle activity in concentric and counter movement maximum bench press. *Journal of human Kinetics*, pp. 63-71.

Van Den Tillaar, R., & Sæterbakken, A. (2012, November 26). The sticking region in three chest-press exercises with increasing degrees of freedom. *Journal of strength and conditioning research*, pp. 2962-9.

Van Den Tillaar, R., Andersen, V., & Saeterbakken, A. H. (2014, September 29). The Existence of a Sticking Region in Free Weight Squats. *Journal of human kinetics*, pp. 63-71.

Van Den Tillar, R., Andersen, V., & Saeterbakken, A. H. (2014, September 29). The existence of a sticking region in free weight squats. *Journal of human kinetics*, pp. 63-71. Retrieved from Pubmed: https://www.ncbi.nlm.nih.gov/pubmed/25414740

Wretenberg, P., Feng, Y., & Arborelius, U. (1996, Februar 28). High- and low-bar squatting techniques during weight-training. *Medicine and science in sport and exercise*, pp. 218-224.