COMPARISON OF KINEMATICS AND EMG IN THE LAST REPETITION DURING DIFFERENT MAXIMUM REPETITION SETS IN THE BILATERAL BACK SQUAT

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This study compared kinematics and electromyography (EMG) in the lower extremities during different phases of the last repetition, when performing the squat of different repetition maximums. Thirteen strength trained men performed a 1-, 3-, 6-, and 10-RM squat, in a randomized order. The main findings were that kinematics was very similar, except for a smaller inclination of the trunk at V_0 in the 1-RM compared to other repetitions, and at V_{max1} compared to 10-RM. Furthermore the 1-RM revealed significantly higher EMG amplitude in the vastus lateralis in the sticking- and post-sticking region when compared to 10-RM. It was concluded a 10-RM may fatigue the vastus lateralis, explaining the lower EMG amplitude, accompanied with a greater inclination of the trunk, which is possibly a compensatory strategy of the body to reduce knee-extensor torque.

KEYWORDS: Strength, Load, Angles, Electromyography, Specificity

INTRODUCTION: Resistance training is a common training modality for improving health in the general public (Kraemer et al., 2002), while also being used as a tool for improving sports performance among athletes (Falch et al., 2019; Rædergård et al., 2020). A common exercise utilised is the bilateral back squat, whereby adaptions from a set may be influenced by the repetition range (Schoenfeld et al., 2015). Thus, the load chosen for a set, which is negatively proportional to number of repetitions, is a decision made on the specific training goal (hypertrophy, maximal strength, strength endurance). As such, repetition range might be influencing joint- and barbell kinematics and electromyography (EMG) amplitude, which are explanatory variables and may explain transfer from a given repetition range to 1-RM strength. Of interest for the practitioner is if there are differences in kinematics and EMG amplitude of the last repetition when performing sets of different repetition maximums, and if so, during which phase of the lift? Similar EMG and kinematics in the different phases of the last repetition, when performing squats of different repetition ranges could induce similar training adaptions, allowing greater flexibility when choosing an appropriate repetition range. Such knowledge could aid in constructing more individualized training programs for improving 1-RM squat strength and possibly reducing the chance of injury, by choosing a repetition range based upon personal preference with similar technical requirements in the final repetition. As such, this study aimed to compare kinematics and EMG amplitude in the lower extremities in the last repetition, when performing the bilateral back squat of different repetition maximums (1-, 3-, 6- and 10-RM). A similar investigation was conducted by Larsen et al. (2022) in the bench press, observing similar EMG and joint kinematics, but it is unknown if the findings also apply to the squat. Based upon the study by Larsen et al. (2022), barbell velocity was expected to be higher for 10-RM compared to the other repetition ranges, with no difference in EMG amplitude and joint kinematics as a maximal voluntary contraction is required to complete the final repetition.

METHODS: Thirteen recreationally strength trained men able to back squat 1.2 x body mass (age: 23.6 ± 1.9 years, height: 181.1 ± 6.5 cm, body mass: 82.2 kg) participated in the study. Each participant performed two sessions, separated by at least 72 hours of rest: the first session was required for familiarization with the protocol and to establish the load for the different repetition ranges, while data collection was conducted on the second session. The sessions were performed in a similar manner, starting with a standardized warm-up (Gomo &

Van Den Tillaar, 2016), before performing a 1-, 3-, 6-, and 10-RM back squat in a randomized order. Appropriate depth was defined according to the international powerlifting federation, requiring the trochanter major to be vertically lower than the patella (Figure 1). A motion capture system (Qualisys, Gothenburg, Sweden) with eight cameras sampling at 500 Hz tracking reflective markers was used to determine joint kinematics of the hip-, knee-, and ankle joint defined as 0° in a standing upright position. Lean of the trunk was defined relative to the surface. EMG amplitude was placed on 9 muscles (gluteus maximus, gluteus medius, rectus femoris, vastus medialis and lateralis, biceps femoris, semitendinosus, gastrocnemius and soleus) of the participants´ lower limbs, after appropriate preparation according to the recommendations of Hermens et al. (2000), using Musclelab 6000 (Ergotest Technology AS, Langesund, Norway). Mean RMS EMG-signals during the different phases of the lift was analyzed, which was found by synchronizing EMG with a linear encoder (ET-Enc-02, Ergotest Technology AS, Langesund, Norway). Both EMG- and kinematic data were sampled from the different events (V_0: bottom position, V_{max1}: first peak velocity, V_{min}: first minimum velocity and V_{max2}: second peak velocity) and phases (pre sticking-, sticking- and post-sticking region) of the upwards lift. To compare joint kinematics and barbell velocity across different repetition ranges, a one-way analysis of variance (ANOVA) with repeated measures (events: V_0, V_{max1}, V_{min} and V_{max2}) was assessed. A four (repetition range: 1-RM, 3-RM, 6-RM and 10-RM) by three (phase: pre sticking-, sticking- and post-sticking region) with repeated measures was assessed to compare EMG amplitude for each muscle through the different repetition ranges across the different phases.

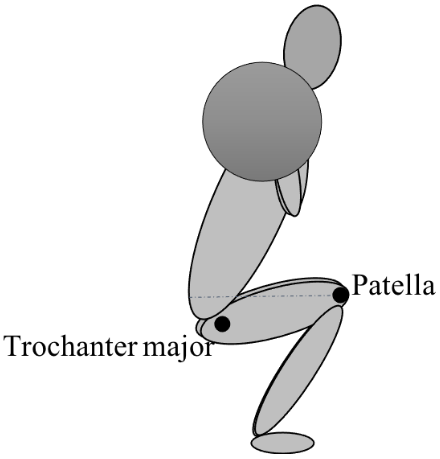

Figure 1. Depth requirements for the bilateral back squat.

RESULTS: A significant difference was observed for trunk angle at V_{max1} and V_0, and knee angle at V_{min} ($F \geq 3.34$, $p \leq 0.05$, $\eta_p^2 \geq 0.25$). Trunk angle was significantly lower at V_0 for 1-RM compared to all other loading ranges and at V_{max1} compared to 10-RM ($p \leq 0.04$). Furthermore, knee angle was significantly lower at 6-RM compared to 1-RM at V_{min} ($p = 0.01$). No significant difference was observed for hip-angle and barbell velocity when comparing the different repetition ranges ($F \leq 1.61$, $p \geq 0.21$, $\eta_p^2 \leq 0.15$) (Table 1).
No interaction effect was observed for EMG amplitude across the different loads and phases of the lift ($F \leq 2.11$, $p \leq 0.08$, $\eta_p^2 \leq 0.21$). A significant difference was observed for vastus lasteralis, soleus and gastrocnemius at the sticking region and post-sticking region and for gastrocnemius at the pre-sticking region ($F \geq 3.35$, $p \leq 0.04$, $\eta_p^2 \geq 0.32$). Significant higher EMG amplitude was observed in the vastus lateralis in the sticking region and post-sticking region when performing 1-RM, compared to the 10-RM ($p \leq 0.03$) and in the post-sticking region for the 3-RM compared to the 10-RM. EMG amplitude in the soleus was significantly higher in the 1-RM compared to the 6- and 10-RM in both the sticking- and post-sticking region ($p \leq 0.02$). EMG amplitude in the gastrocnemius was significantly higher in the 1-RM compared to 10-RM in both the pre-, sticking and post-sticking region, and when compared to 6-RM in the post-sticking region ($p \leq 0.02$). EMG amplitude was also significantly higher for the soleus in the 3-RM compared to the 10-RM in the pre- and post-sticking region (Figure 2).

Table 1. Barbell and joint kinematics of the different phases during the last repetition in sets of different repetition ranges.

V_0	1-RM	3-RM	6-RM	10-RM
Knee angle	124.4 ± 8.2	125.1 ± 8.8	124.8 ± 8.6	125.4 ± 9.7
Hip angle	-96.7 ± 12.3	97.4 ± 13.1	-95.3 ± 15.0	-96.7 ± 13.1
Ankle angle	-111.1 ± 5.7	-108.2 ± 5.8	-108.5 ± 6.7	-108.2 ± 7.7
Trunk angle	-50.5 ± 6.2*	-52.5 ± 6.1	-52.4 ± 7.0	-53.9 ± 6.9
V_{max1}	**1-RM**	**3-RM**	**6-RM**	**10-RM**
Knee angle	113.2 ± 10	112.7 ± 8.3	112.1 ± 8.3	113.5 ± 9.8
Hip angle	-90.9 ± 10.5	-90.2 ± 9.8	-88.2 ± 14.2	-90.1 ± 10.6
Ankle angle	-108.1 ± 6.5	-105.2 ± 5.8	-105.2 ± 6.8	-105.2 ± 7.7
Trunk angle	-54.2 ± 6.1	-55.9 ± 6.0	-56.0 ± 6.6	-57.0 ± 6.1†
Barbell velocity	0.28 ± 0.05	0.32 ± 0.07	0.33 ± 0.08	0.33 ± 0.08
V_{min}	**1-RM**	**3-RM**	**6-RM**	**10-RM**
Knee angle	85.9 ± 12.2	84.1 ± 11.6	79.9 ± 7.8†	82.5 ± 9.3
Hip angle	-72.4 ± 10.2	-71.5 ± 6.4	-67.2 ± 10.7	-70.0 ± 8.4
Ankle angle	-101.6 ± 6.4	-97.2 ± 6.4	-96.3 ± 6.7	-97.2 ± 7.7
Trunk angle	-56.1 ± 6.2	-58.6 ± 7.1	-58 ± 7.4	-59.0 ± 7.8
Barbell velocity	0.08 ± 0.05	0.09 ± 0.07	0.11 ± 0.05	0.12 ± 0.05
V_{max2}	**1-RM**	**3-RM**	**6-RM**	**10-RM**
Knee angle	43.2 ± 8.6	42.7 ± 6.6	43.1 ± 7.1	42.9 ± 8.7
Hip angle	-34.5 ± 14.0	-33.1 ± 16.2	-32.5 ± 15.5	-33.9 ± 13.4
Ankle angle	-92.4 ± 6.4	-90.0 ± 4.8	-90.1 ± 7.0	-89.4 ± 8.0
Trunk angle	-39.5 ± 6.4	-40.4 ± 7.4	-40.2 ± 7.6	-41.5 ± 6.8
Barbell velocity	0.55 ± 0.16	0.6 ± 0.13	0.57 ± 0.13	0.52 ± 0.14

* Indicates a significant difference compared to all other repetition ranges at a $p < 0.05$ level.
† Indicates a significant difference compared to 1-RM at a < 0.05 level.

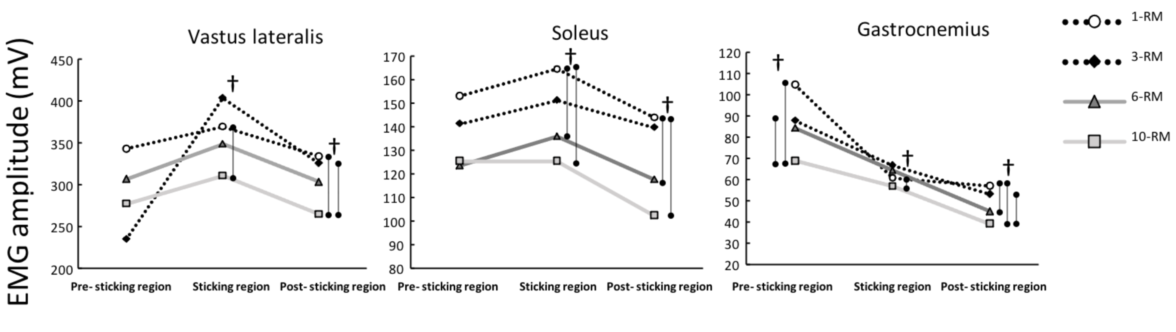

Figure 2. EMG amplitude for the vastus lateralis, soleus and gastrocnemius through the different phases of the last repetition in the squat, at different repetition maximums. † Indicates a significant difference between these two repetition ranges at a < 0.05 level.

DISCUSSION: In this study comparing kinematics and EMG amplitude at different repetition maximums, the main finding was that in comparison to the 1-RM, the 10-RM revealed greater inclination of the trunk at V_{max1} and V_0, accompanied with lower EMG amplitude for the vastus lateralis and soleus in the sticking-, and post-sticking region, and in the gastrocnemius for all phases of the lift. The lower EMG amplitude of the vastus lateralis in the 10-RM is probably a result of fatigue, limiting the motor neurons ability to fire (Tesch et al., 1983). This would explain the greater inclination of the trunk, which could be a compensatory strategy of the participant to reduce knee-extensor torque to complete the lift. Based on the principle of specificity, the observed EMG and joint kinematics during the last repetition indicates the 10-RM to share the least similarities with maximal strength expression in a 1-RM squat. The higher EMG amplitude of the plantar flexors in the 1-RM compared to the 10-RM might be a result of necessitating more stabilization at higher loads. However, the practical importance of this difference might be limited as it is not likely that fatigue accumulation or strength deficits in the plantar flexors when performing the squat becomes a limiting factor. Future studies replicating this study should include measurements with a force plate to model forces acting upon the different joints. Furthermore, the different repetitions of the set should be analysed to investigate if EMG and joint kinematics change throughout the set.

CONCLUSION: Based upon EMG and kinematic findings of the current study, the last repetition of a 10-RM squat seems different compared to the last repetition at the other repetition ranges, whereby fatigue in the knee-extensors might lead to a different movement strategy. As such, if specificity to a 1-RM is the aim, it might be wise to practise with higher loads to learn how to accelerate the bar out of the sticking region with similar kinematics and EMG amplitude. However, this conclusion is caveated by sets being performed to volitional failure.

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