Comparison of Two Techniques for Lifting Low-lying Objects on a Table
Part II: EMG and Psychological Measurement

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Abstract: The purpose of this study was to determine differences in health benefits and fatigue when using various lifting techniques. Worldwide, back pain is a common disease. In this context, muscular tension in shoulder and neck areas as well as tension-type headaches are the most common side effects. One frequent cause for this pain is connected with the wrong lifting and carrying of loads. To avoid these types of back pain numerous recommendations concerning the right lifting technique already exist. The most common recommendation is that one should use squat lifting instead of stoop lifting. By means of this technique a relief for the back should be obtained. However, these benefits have not been proven yet. For this study eight healthy subjects were evaluated. The test persons had to lift a load for ten minutes. During the lifting task the muscle activity of nine muscles was documented. At the same time, psychological data were collected in a questionnaire. Both, the physiological and psychological data revealed differences between the lifting techniques. During the stoop lifting, a higher burdening of the back muscles was measured. In addition, following the exercise, a greater and prolonged discomfort in the back muscles was documented.

1 INTRODUCTION

People who had not at least once in their lifetime low back pain are the minority. A survey of German health insurances companies showed that back pain is one of the five most frequent illnesses. Almost 80% of all people in Central Europe have reported at least once in their lifetime about back problems. Especially, the number of children involved highlights the increasing importance of prevention programs (Lezius, 2004).

Frequently, the affected persons do not only suffer from low back pain but also from muscular tensions in the spine, shoulder and neck areas. Additionally, back pain often leads to tension-type headache. Common causes of these pain patterns are incorrect or excessive pressure to the back as well as psychological factors like stress. In everyday life, heavy lifting and moving of loads are equally as responsible for an increased stress of the back as wrong postures during lifting (Kempf, 2009; Buhr, 2011).

The current recommendations for avoiding back pains consist primarily of guidelines for a correct lifting technique. The often suggested squat lifting is done by bent knees and erected back. In contrast, the stoop lifting is characterized by straight legs and a bent back. However, the advantages of squat lifting in terms of effectiveness and positive health benefits have not been sufficiently proven (Dietrich, 2009).

To proof the suspected superiority of the squat lifting technique different studies have been made. Revuelta et al. (Revuelta et al., 2000) as well as Straker and Duncan (Straker and Duncan, 2000) were able to show that using the squat lifting leads to a higher heart rate response than the stoop lifting. A different physical strain of the lifting techniques was also confirmed by analyzing the muscle activity. Besides different activity and fatigue patterns, recorded datasets also showed that a heavy pressure caused a changed in the lifting technique from squat to stoop (Troup et al., 1983; Hagen et al., 1994; Dietrich, 2009).

The aim of the current study was to show that there is a difference in effectiveness, health benefits and fatigue between both techniques. For the verification of these assumptions a loading test was conducted. Analyzing psychological data as well as physiological data should show the differences between squat and stoop lifting.

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2 EXPERIMENTAL SETUP

2.1 Subjects

Eight students were recruited through personal contact. An equal distribution of the sexes was given. The ages ranged from 18 to 27 years. The average body height of the test persons was 173.5 (*SD* 8.6) *cm*. All were healthy, without back pain symptoms and gave their written consent to participate after being informed about the experiment.

2.2 Test Procedure

On the first day of the experiment the subjects had to execute the stoop lifting. Test persons returned one week later to perform the squat technique.

Initially, the test persons were briefed about the selected lifting technique (Loose et al., 2013). A maximum voluntary contraction (MVC) test for all analyzed muscles followed. Afterwards, the subjects did a test lift with the aim to practice the correct motion sequence while it was being made sure that the test person is not restricted. The lifting task itself consisted of three different stages. Firstly, the test person had to remain still for one minute. During the second phase, the subject performed the lifting of the load for ten minutes. The requirements included both, the correct motion sequence and a lifting frequency of at least five lifts per minute. The final stage was equal to the initial phase, one minute rest. A different load weight for the sexes was given (male: 15 *kg* , female: 8.4 *kg*) (Loose et al., 2013). For the post-processing of the lifting task an immediate survey about the subjective effort and discomfort was conducted. Furthermore, a questionnaire about the same topics was filled out on each of the seven following days.

2.3 Measurement

The used Shimmer^{TM} sensors are characterized by their small form and their low power consumption. The Bluetooth technology offers real-time data streaming. The basic module consists of an on-board micro-controller, wireless communication modules, a microSD slot and an integrated three-axis accelerometer. In this study the used daughterboard was the electromyography (EMG). The EMG module records the electrical activity of a muscle with a sampling frequency of 1024 *Hz*. The sensor disposes of three connectors which allow to measure two or three channel pre-amplificated EMG-signal (Shimmer Research Support, 2012).

2.4 Sensor Placement

Muscular contraction data were collected for nine muscles. The EMG was recorded from the following trunk and extremities muscles: M. gastrocnemius medialis and lateralis, M. biceps femoris, M. vastus lateralis, M. rectus femoris, M. gluteus maximus, M. erector spinae, M. trapezius ascendes and M. biceps brachii. The muscles were chosen based on their function to carry out the defined motion sequences. Ag/AgCl surface electrodes were applied after a standard skin preparation considering the recommendations from the SENIAM project (SENIAM project, 2012).

2.5 Data Analysis

The first questionnaire was completed immediately after the lifting task. The second questionnaire was completed on a daily basis at home over a period of seven days. The content included questions regarding the effort and discomfort in general and in special parts of the body. Using an eleven-point answer scale, the test persons had to judge from 0 (no effort/discomfort) to 10 (very high effort/discomfort). The statistical evaluation was performed by using mean values to compare the two lifting techniques.

The raw EMG signal was band-pass filtered from 15 to 500 *Hz* (Merletti and Parker, 2004). Additionally, a notch filter with a blocking frequency of 50 *Hz* was applied.

For analyzing the signal in the time domain a full-wave rectification was carried out. Statistical parameters like maximal or mean amplitude were calculated over the time. They were calculated over an interval of seven seconds, which is the average length of a lifting cycle. Additionally, the parameters were calculated for ten detected liftings. Using the MVC data for the standardization of the EMG an inter-proband analysis was possible. A second standardization was made by using time normalization.

Transformation of the EMG signal from the time to the frequency domain was achieved by the Fast Fourier Transformation over signal segments of 512 *ms* (Grimshaw et al., 2006; Kaplanis et al., 2009). The Frequency-Analysis included the computation of the median frequency as well as the computation of the total power. Both parameters were used as indicators for muscle fatigue (Merletti and Parker, 2004; Lukas, 2000).

The accumulation of the power density spectrum for all frequencies is defined as the total power, figured in equation 1 (Kaplanis et al., 2009).

$$E_{totalPower} = \int_0^\infty S_{PD}(f)df \tag{1}$$

The median frequency is the frequency where the accumulated power spectrum energy is 50 % of the total power spectrum, figured in equation 2 (Chang et al., 2012; Kaplanis et al., 2009).

$$F_{medianFrequency} = \frac{1}{2}\int_0^\infty S_{PD}(f)df \tag{2}$$

3 RESULTS

3.1 Physiological Data

For the comparison of the course of the maximum amplitude of the M. rectus femoris in stoop and squat the measured values of all subjects were averaged. Figure 1 shows the changes in the maximum amplitude (normalized values) of the M. rectus femoris throughout the lifting task. A comparison of the stoop and squat values illustrates the higher strain of the M. rectus femoris in squat lifting. On average, using squat technique produces threefold greater voltage values than using stoop technique. That corresponds to the characteristic that in squat the load is lifted from the knees and not from the back.

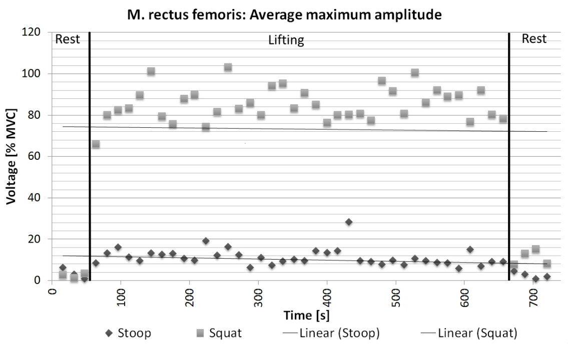

Figure 1: M. rectus femoris - Comparison of the maximum amplitude in stoop and squat.

As in the previous calculation, the maximum amplitudes of all subjects were averaged. The visualization of the averaged values (normalized values) of the M. erector spinae is shown in figure 2. Both techniques have in common that on average the values rise over time. This observation supports the assertion that load lifting leads to a fatigue in the back muscle. The figure further indicates that the stoop technique involves a higher participation of the back muscle. The consideration of figure 2 together with figure 1 points out for both techniques that the measured values reflect the strain in the suspected body areas. The relative measurements in stoop show a threefold higher effort in M. erector spinae than in M. rectus femoris. The measured values in squat technique show a strongly contrasting distribution. M. rectus femoris is producing twice as high values as M. erector spinae.

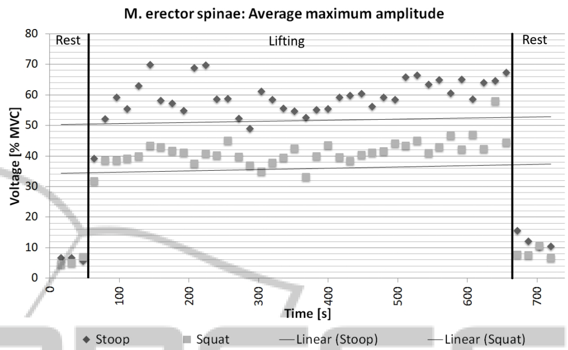

Figure 2: M. erector spinae - Comparison of the maximum amplitude in stoop and squat.

Fatigue is defined in muscle physiology as a state when a subject can no longer maintain a required force (Merletti and Parker, 2004). Hence the maintenance demands an increasing recruitment of motor units (Lukas, 2000). Figure 3 shows the course of the total power of one test person during the load lift. The difference between the absolute values for both techniques are clearly visible. Furthermore, there is a noticeable course difference. For the total power in stoop nearly static values were recorded. In contrast, the calculated total power when using squat technique shows a steady increase. Both observations indicate a higher strain in M. rectus femoris during squat lifting. Additionally, the course of the total power illustrates the fatigue of the muscle when using squat lifting.

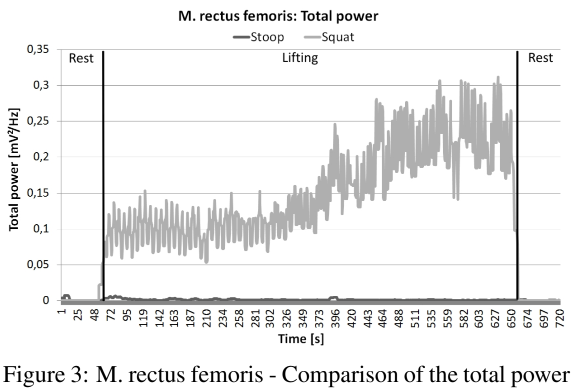

Figure 3: M. rectus femoris - Comparison of the total power in stoop and squat.

One of the most widely applied indexes for muscle fatigue is the median frequency. In the state of muscle fatigue the EMG spectrum is compressed towards lower frequencies (Merletti and Parker, 2004). The development of the median frequency of M. erector spinae for both lifting techniques is represented in figure 4. Both graphs show descending median frequencies. Hence, squat lifting is as well as stoop lifting fatiguing for the back muscles. However, a close-up look at the values shows that the decrease of the frequency in stoop lifting is higher than in squat. The allegation that stoop lifting causes a higher strain on the back is supported by figure 4. The course of the median frequency of this subject is similar to the curves of the other test persons.

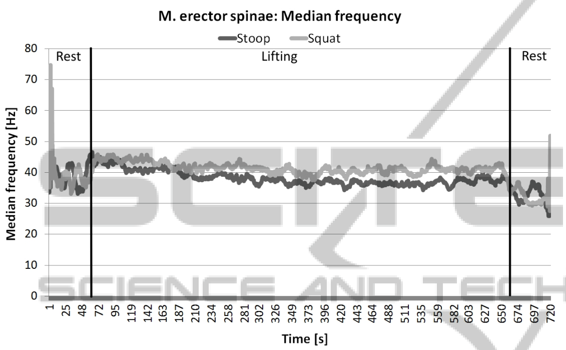

Figure 4: M. erector spinae - Comparison of the median frequency in stoop and squat.

To assess the fatigue of the M. gastrocnemius lateralis during the execution of both techniques the maximum amplitude (time normalized) of ten detected repetitions was considered. According to Werner (Werner, 2006), the fatigue of a muscle accrues as a result of strain and is recognizable by the increase of the electrical activity. On average, the test persons showed higher maximum values during the squat than the stoop technique. Figure 5 illustrates the behavior of the maximum amplitude of the M. gastrocnemius lateralis for both techniques over the ten detected repetitions. Because of the higher electrical activity during the squat technique it can be assumed that this technique led to a higher strain. However, if the behavior of the maximum values is considered over the ten repetitions, no continuous increase or decrease is visible. Referring to the first and the last detected repetition, there is an increase of the values in both techniques. Hence, a fatigue of the M. gastrocnemius lateralis could not be proven. This could be due to either none of the techniques causing a fatigue of the M. gastrocnemius lateralis or too many factors being present that influence EMG signals.

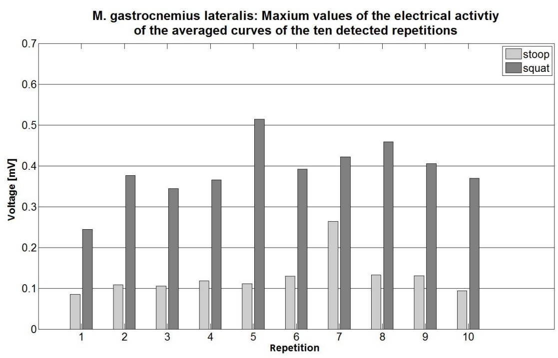

Figure 5: Maximum values of the electrical activity of the averaged curves of the ten repetitions, M. gastrocnemius lateralis.

3.2 Psychological Data

The immediately conducted survey of all test persons after the lifting task (fig. 6) revealed as part of the comparison of stoop and squat lifting that the subjective general effort in squat lifting is higher than in stoop. A detailed look at the distribution in figure 6 shows that both, the effort in quadriceps and biceps femoris in squat lifting are higher than in stoop lifting. A contrary result is shown in terms of subjective exertion in low and upper back. In both cases the perceived effort in stoop lifting is several times higher than in squat lifting. The information gathered from the test persons consultation presents the expected results in dependency to the described motion sequences of the lifting techniques.

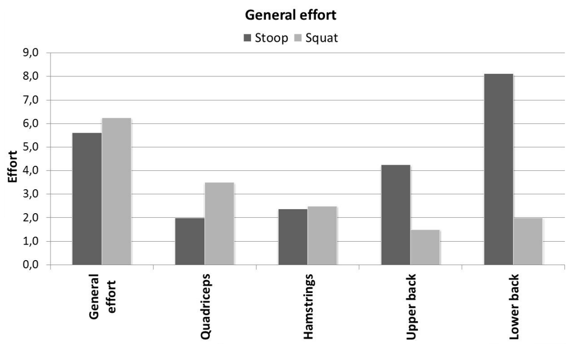

Figure 6: Comparison of the general effort in stoop and squat

In addition, the surveys sought information about the actual discomfort. In general, all test persons suffered a higher discomfort after using the squat technique. However, a more detailed analysis of this point revealed that while some body areas led to a higher discomfort when using the squat technique other body areas had a higher discomfort following the stoop technique. Firstly, the look at discomfort of the thigh in figure 7 shows that using the squat technique caused higher values, especially in the quadriceps. The discomfort is nearly seven times higher than using the stoop technique. Therefore, the use of the stoop technique can be expected to have a higher discomfort in the back. Figure 7 confirms the assumption that the subjective pain after using stoop is in the lower as well as in the upper back many times higher than after using the squat lifting.

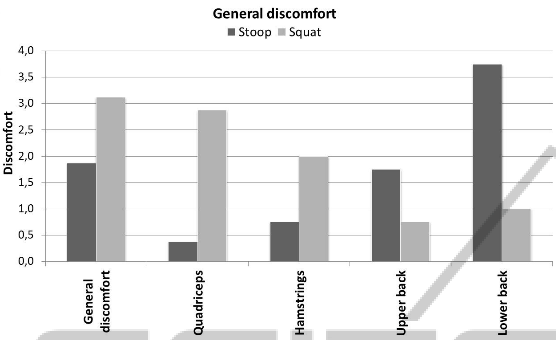

Figure 7: Comparison of the general discomfort in stoop and squat.

The assessment of general discomfort one day after the lifting tasks showed similar values to those obtained immediately after the lifting. The comparison of the course of the complaints differs (fig. 8). The discomfort on the first days after using the squat technique shows a decreasing level. In contrast, the complaints in the back after using stoop are still growing on the second day. Compared to the squat technique, the pain level in the lower back is in stoop over ten times higher.

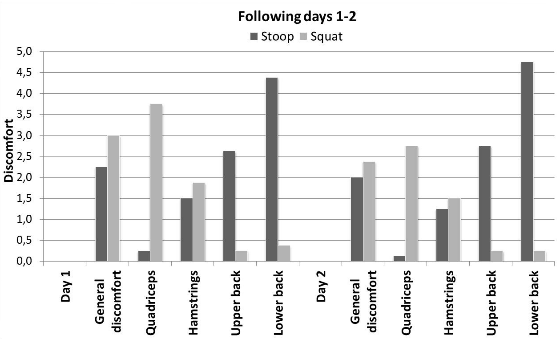

Figure 8: Following day 1 and 2 - Comparison of the general discomfort in stoop and squat.

The course of the general pain levels shows a faster regeneration after using squat technique. On the third day after the lifting task the comparison of the general pain shows for the first time lower values for the squat lifting. Already on the fourth day after using the squat technique, the test person reported scarcely any complaints. The values of the subjective pain in the back after using stoop are comparatively high.

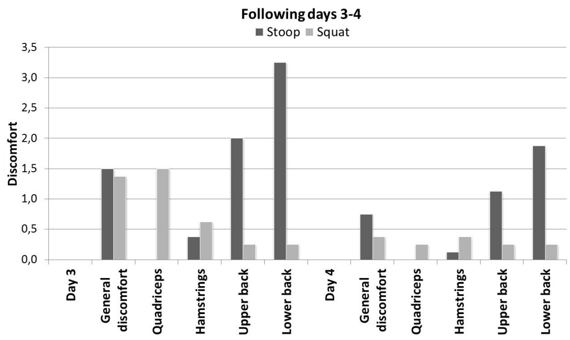

Figure 9: Following day 3 and 4 - Comparison of the general discomfort in stoop and squat.

4 DISCUSSION

The main finding in this experimental study is that the EMG patterns of stoop and squat lifting differ. On one hand, high values in muscle activity were suspected for the M. rectus femoris. On the other hand, the presumption for the squat lifting was a high performance of the M. erector spinae. Both assumptions are proven with the analyzed EMG courses. Moreover, in the frequency domain the typical properties of the lifting techniques are visible. The comparison of the course of total power of the M. rectus femoris in stoop and squat showed a great difference in the effort of the muscle. The increase of the total power in squat indicates the fatigue of the muscle. The higher voltage values as well as the fatigue point out that the effort in squat is higher than in stoop. The detailed observation of the maximum amplitudes and the fatigue of the M. erector spinae show lower differences. Although stoop technique creates higher voltage values and a steeper decrease of the median frequency of the M. erector spinae, the differences are not as powerful as the differences in squat technique. This can be caused by the definition of the motion sequence of Loose et al. (Loose et al., 2013). A lifting and lowering of weights without placing the weights on a table might be useful for a more conclusive result. Additionally, the placement of the sensors can be more effectively. As the investigation of the muscle activity of the M. gastrocnemius lateralis shows that this muscle is less important for the evaluation of the lifting techniques. Instead, the placement of additional sensors at the back can be useful.

The analysis of the subjective pain impressions recorded via the questionnaires support the statement that squat lifting is healthier than stoop lifting. Especially the course of the discomfort in the four days following the lifting shows that complaints after using stoop are more intensive and the regeneration takes longer. Furthermore, the observation of the general effort and general discomfort immediately after the lifting task confirms the thesis that squat is more fatiguing than stoop lifting.

5 CONCLUSIONS

This paper investigated the hypothesis that the squat lifting technique is more ergonomic, healthy and less exhausting on a real life example of a combined motion of lifting and putting a beer crate into a car trunk. The analysis of the physiological and psychological data indicates on the one hand that squat causes a higher effort in the upper legs and on the other hand that the effort of the back is higher in stoop. Furthermore, the investigation of the discomfort in the back shows that the intensity and duration of the complaints are higher when using stoop. In contrary, the ECG analyzed in Loose et al. (Loose et al., 2013) showed a higher physical stress when using squat. In summary, it can be concluded that no general assumption for an optimal lifting technique can be made.

Further assumptions about the lifting techniques can be reached by an individual analysis of the lifting cycles. This can be realized by an observation of the EMG patterns or by the use of the Kinect data (Loose et al., 2013).

The feature of the characterized motion sequence is that it represents an everyday situation like lifting a beer (or similarly shopping) crate into a car. However, the experimental study was not able to show a significant benefit of the squat lifting with regards to the fatigue of the M. erector spinae. Due to that reason the validity of the statement that squat lifting is healthier has to be proven in everyday situations. Another continuation of the study could focus on the behavior of the muscle activity when lifting different loads using various lifting techniques.

Further measurements (Kinect and ECG data), results, discussions and finalizing conclusions are included in Loose et al. (Loose et al., 2013).

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