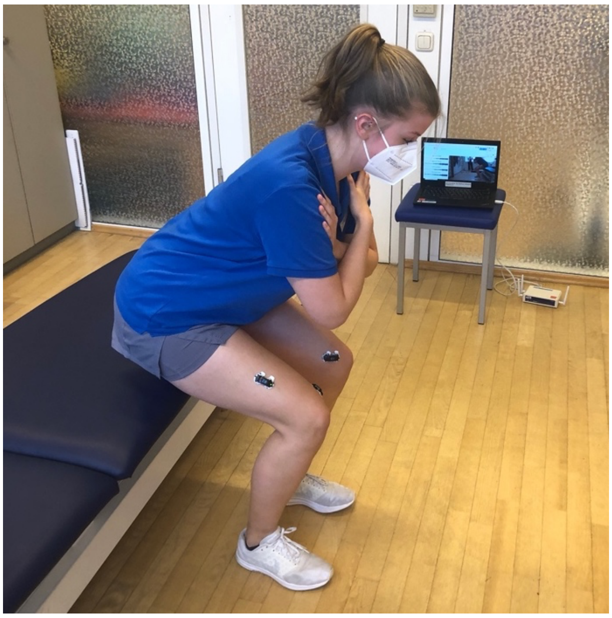
A sEMG Pilot Study:

COMPARISON OF THE QUADRICEPS MUSCLE ACTIVITY (VASTUS MEDIALIS OBLIQUUS AND VASTUS LATERALIS) DURING A SIT-TO-STAND AND A SQUAT EXERCISE IN PATIENTS RECOVERING FROM TRAUMATIC KNEE INJURIES

PRACTICAL RESEARCH



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Preface

This study was executed as a collaboration between the *Rehazentrum City BGK Hamburg* and *Hanzehogeschool*. I would like to thank the whole team of the Rehazentrum for their support, but especially Melanie Meyer and Claudia Hennecke for their supervision, Hendrik Witte for his technical expertise in the EMG technology, Matthias Vogt for the support and Nathalie Mordhorst for her help in recording the measurements.

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Abstract

Background: Traumatic knee injuries often lead to long-lasting consequences such as osteoarthritis, pain, and functional limitations. Correct knee alignment and neuromechanics seem to be essential in the prevention of future complaints. During activities involving the knee the vastus medialis obliquus and lateralis muscles play an essential role in this alignment. Little is known about which rehabilitation exercises are most effective in this regard.

Purpose The purpose of this sEMG pilot study was to investigate if the task specific sit-to-stand exercise would elicit quadriceps muscle activity (vastus lateralis and vastus medialis obliquus) to the same extent as the more commonly used squat exercise.

Methods: Using sEMG technology the electrical muscle activity of the vastus medialis obliquus (VMO) and vastus lateralis (VL) was measured in 12 participants, who were recovering from traumatic knee injuries. The measurements were conducted during a sit-to-stand exercise and a squat. The root mean square (RMS) of five repetitions was calculated for each exercise and a statistical comparison was carried out.

Results: There is a significant ($p < 0.05$) correlation between the total muscle activity elicited throughout the sit-to-stand and the squat within the same participant. Across individuals, the collected sEMG data was not normally distributed and no comparisons could be made between participants.

Discussion: Since the quadriceps muscle activity (VMO and VL) is comparable during a sit-to-stand exercise and a squat exercise, therapists may choose to incorporate either one into the rehabilitation programs of their patients. The sit-to-stand is specific for daily activities, easily carried out without supervision and well suited as an exercise for individuals with a lower fitness level. This activity should thus be incorporated as a standard during the rehabilitation process in patients suffering from lower limb injuries.

Conclusion: Both, the sit-to-stand and the squat exercise, can be compared regarding the total elicited muscle activity of the VMO and VL and are suitable exercises for individuals recovering from traumatic knee injuries. Considering the task specificity of the sit-to-stand exercise this should be the exercise of choice.

Key Words: *EMG, sit-to-stand, squat, vastus medialis obliquus, vastus lateralis*

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Introduction

After traumatic knee injuries, regaining correct knee alignment and neuromechanics is essential in the prevention of serious long-term complaints, such as osteoarthritis, pain, and functional limitations (1–3). Little is known about the effectiveness of preventive exercises such as the sit-to-stand or the squat exercise and how they activate certain muscle or movement patterns, especially after an injury. A direct comparison via surface electromyography (sEMG) of the muscle activity of the vastus medialis obliquus and the vastus lateralis could give insight into which exercise may be preferrable to use for certain patients.

Knee injuries are common and the second leading cause for absences from work (9%; US data; (4)). The main reasons for work-related knee injuries are falls and overexertion (5), with 14% of all work-related accidents happening in road traffic rather than at work (6). Recovery from traumatic knee injuries can take more than a year (7) and long-term complaints such as osteoarthritis, pain, functional limitations, and stability loss are often seen (7,8).

The risk of developing osteoarthritis (OA) after a knee joint trauma increases by 3-6 times (9-11). Lower limb OA is one of the major reasons for disability in older adults (1,9) and can result in the development of other diseases (12). A history of knee injury has also been linked to an accelerated version of knee OA (13) and previous knee injuries are even suggested to be responsible for an increase in the number of total knee replacements (14).

It is important to be aware of this increased risk for degenerative diseases and to focus on their prevention during early stages of rehabilitation. However, it is unclear which rehabilitation exercises for the knee would be most effective in doing so. Evidence suggests that these late consequences of knee traumata can be prevented by improving patellar tracking and knee joint alignment (1). It has been shown that the severity of knee malalignment has an impact on OA disease progression and the decline in physical functioning (1). A varus or valgus alignment increases OA progression on the respective joint side by 4-5-fold (1). Especially because of the common loss of joint protection and load anticipation, caused by a loss of essential mechanosensors due to the trauma (2,3), it is important to focus on re-establishing balanced knee neuromechanics during rehabilitation.

As the main knee extensor, the quadriceps muscle plays an essential role in knee joint neuromechanics and dynamic stabilization. The vastus medialis obliquus (VMO) is an important stabilizer for patellar tracking, especially when co-contracting with the vastus lateralis (VL) in a simultaneous and coordinated manner (15). It is assumed that weakness of the VMO causes a lateral patellar shift, changing the patellofemoral joint contact pressures, which could cause degeneration and joint pain (16). In order to regain healthy knee joint neuromechanics after a knee injury, it is essential to incorporate training for the co-activation of both the vastus medialis obliquus and the vastus lateralis into the strength training during rehabilitation.

The standard quadriceps strengthening exercise used in most knee rehabilitation programs is a squat, or a variation of it. In practice, therapists often visually observe patients struggling with the correct execution of a squat, especially ones of older age, or with lower fitness levels. When training unsupervised some patients adopt compensatory movement patterns that can put additional strain on the knee. Therefore, the question arose if for those patients, the sit-to-stand exercise would be better suited than the squat exercise.

For older patients or stroke patients, sit-to-stand exercises are already commonly being used as part of training programs (17,18). They are effective in increasing leg muscle strength and improving dynamic balance and offer several advantages compared to more demanding exercises. The sit-to-stand exercise is specific in training activities of daily living (ADL) and easier to perform correctly for unfit patients without supervision (18,19). Nevertheless, it seems to be effective especially in older adults, who exhibit twice as much muscle activity in the vastus lateralis during the movement compared to young adults (20).

At the point of writing, no studies could be found directly comparing the muscle activity in both exercises. Additionally, there is a general lack of EMG studies in injured patients as most existing studies focus on muscle activity in healthy adults or athletes. This pilot study aims to provide insights into the effectiveness of rehabilitation exercises and to show to some extent how the movement patterns and coordinative muscle patterns could change after an injury.

To measure the electrical activation signals in contracting muscles, which in turn represent neuromuscular activity, the golden standard is *surface electromyography* (sEMG) technology (21-24). The sEMG signal shows the combined motor unit action potentials of a muscle (25). It, therefore, represents the neuronal activation in the muscle during a contraction, rather than the overall output as strength or movement. This gives more detailed insights into the coordination of muscles and the interplay of individual muscle bellies during specific movements (26).

Furthermore, the non-invasive sEMG technology allows for analysis in movement in a non-clinical setting with minor risks for the patient. Wireless sensors can detect electrical activation signals of the underlying muscle bellies through the skin. These signals are amplified and filtered and converted into a digital signal, making the electrical signal from the muscle visible and quantifiable (26).

Purpose and Research Question

This sEMG pilot study aims to show if the more ADL specific sit-to-stand exercise is a suitable alternative to the more commonly used squat exercise in the rehabilitation training of knee trauma patients. If the less strenuous sit-to-stand exercise elicits the same extent of muscle activity levels in the VMO (vastus medialis obliquus) and the VL (vastus lateralis) it may be a suitable strengthening exercise for patients with a lower fitness level and require less supervision during training.

The research question of this **pilot study is how the total muscle activities of the vastus medialis obliquus and vastus lateralis (measured with a sEMG) compare to each other in a sit-to-stand exercise and a squat exercise in patients recovering from a traumatic knee injury.**

Methods

Ethical Clearance and Informed Consent

This pilot study gained ethical clearance and all subjects gave informed consent prior to their participation[1]. All tests were conducted in the *Rehazentrum City BG Klinikum Hamburg* between December 2020 and January 2021.

Population Selection

The population sample included 12 patients from the rehabilitation centre (four females, eight males; aged 18 – 56) at different points of their rehabilitation process following traumatic knee injuries. For this sEMG pilot study, a broad category of traumatic knee injuries was included: knee ligament ruptures, menisci tears, proximal tibia fractures, proximal fibula fractures and femur condyle fractures. Participants were selected according to their current level of functioning, resulting in a wide range in terms of time since accident (12 – 86 weeks) and length of treatment at the rehabilitation centre (1 – 19 weeks).

An overview of the inclusion and exclusion criteria can be found in **Table 1**. All test subjects had to be able to perform the single leg stance test (> 20 s) on either leg, have sufficient available active range of motion (AROM) and activation of the quadriceps muscle (measured through the loss of extension during an active straight leg raise). Participants were excluded from testing if they showed any of the following: additional lower limb injuries (i.e., hip, ankle), pain with walking, a limitation in ankle mobility (measured with the weight-bearing lunge test), or a significant extension deficit of > 10° compared to the unaffected knee.

Table 1 – Overview of Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
▪ Patients recovering from knee ligament ruptures, menisci tears, proximal tibia fracture, proximal fibula fracture, femur condyle fracture. ▪ Single Leg Stance[2] > 20 s both legs ▪ Min AROM Ext/Flex 0/5/120° ▪ Active Straight Leg Raise[2] possible with < 5° loss of knee extension	▪ Limited ankle ROM (Weight-bearing Lunge Test[2] < 5 cm) ▪ Pain with Walking > 3/10 VAS ▪ Active extension of the knee: extension deficit of > 10° compared to the unaffected leg ▪ Additional lower limb injuries (i.e., hip, ankle)

Abbreviations: AROM (active range of motion), ROM (range of motion), VAS (visual analog scale)

Measurement Protocol

A translated version of the full measurement protocol can be found in Appendix B.

The selection of participants was based on their impairment level and functional abilities at the day of testing. Since these tend to vary almost daily during the rehabilitation period, test subjects were first tested for their ability to participate in the study. Knee mobility was measured using a goniometer and further tests like the active straight leg raise, the weight-bearing lunge test and the single leg stance (test protocols in Appendix A) were carried out. Following that, participants spent five minutes on an ergometer to ensure equal levels of warming up, because this can influence the

[1] Ethical Testing Protocol and Informed Consent form in German can be found in Appendices E and F

[2] Test Protocols can be found in Appendix A

results of the sEMG measurements (27). Then the electrodes were placed according to the SENIAM guidelines (28,29).

Before each measurement a five-minute break of inactivity was ensured, to avoid muscle fatigue. All exercises were explained and demonstrated, and participants were given a chance to try them out before the actual measurements.

First, a maximum voluntary isometric contraction (MVIC) was recorded at ~ 60° of knee flexion. This was done as a closed chain movement, rather than the usual open chain exercise, because it puts less strain on the recently injured knees. Therefore, a leg press machine with a fixed footrest was chosen and muscle activity was recorded while subjects tried to extend one leg at a time at their maximum available force. Since it was later decided to perform the analysis using ratios of muscle activity, the MVIC values were not required anymore and therefore not used in the statistical analysis.

Participants were then asked to perform 20 repetitions each of 1) a sit-to-stand exercise and 2) a squat exercise. For both exercises the test subjects were instructed to keep their arms crossed in front of their chest. A physiotherapy treatment bench was used to mark the sitting or the low point of the movement. To correct for height differences, the bench was adjusted to the height of the individual's posterior knee crease. The velocity of the movement was set to match four seconds per repetition in order to improve comparability. Participants could match their movement speed to visual feedback, which was continually shown, and had a chance to practice up to four repetitions prior to testing.

During the sit-to-stand they could choose their foot position freely, while keeping them parallel to each other. The exercise instructions were purposefully kept short with the goal that the participants would perform the movement similar to how they would stand up from a chair in their daily living.

For the squat exercise the foot position was marked in a way, so that the feet were parallel and hip width apart. Participants were instructed to distribute their weight equally between both feet. The low point of the squat was set at bench height, so that the tactical feedback of touching the bench with the buttocks would mark the end point. Due to the fixed foot position knee flexion at the lowest point of the squat would be at around 90 - 100°.

Each test was carried out by one researcher, who would instruct the participant on the movements, and one research assistant, who would start and stop the recordings. Video recording were taken of the measurements, to be able to match sEMG data to set points of the exercise.

Surface Electromyography

sEMG measurements were performed using the *Cometa Wave Plus Wireless EMG System* (receiving unit) combined with *PicoEMG* (wireless EMG) and used with *Kendall ECG* surface electrodes (Ag/AgCl, Foam, Hydrogel, 30mm x 24mm). Recordings were made at a sampling rate of 2000 Hz and data was filtered between 5 and 500 Hz.

Following the SENIAM standards for electrode placement (28,29), skin was cleaned with 95% alcohol and rubbed with a cotton towel to remove excess skin cells to ensure better impedance. The electrodes were placed in the centre of the muscle belly along the direction of the muscle fibres according to the SENIAM guidelines (Appendix C). Since only four electrodes were available, two quadriceps muscle bellies were chosen for analysis: the vastus medialis obliquus (VMO) and the vastus lateralis (VL) due to their importance in patellar tracking and correct alignment of the knee joint during movement (30–31). Additionally, the correct placement of electrodes on these muscles is easier compared to the vastus intermedius and the rectus femoris (29).

Data from the sEMG was processed using the *proEMG2.0* software. With the help of video recordings, individual movement cycles were set from standing to standing and for each participant five adjacent cycles were chosen for analysis, disregarding the first three as trials. For those the root mean square (RMS) of each cycle was calculated and used for further analysis.

To be able to compare the amount of muscle activity between participants, the ratio was calculated of muscle activity on the affected side / unaffected side. It is difficult to compare EMG results of individual muscles from different test subjects or test sessions, due to the differences in muscle anatomy and electrode placement (33). Therefore, standard practice is to compare the value to a maximal voluntary isometric contraction (MVIC) (34,35) or to analyse the outcome result in relation to another muscle of the same participant from the same measurement (36). The ratio of muscle activity on the affected side compared to the same muscle on the unaffected side was chosen ($\frac{VM\ or\ VL\ Affected\ Side}{VM\ or\ VL\ Unaffected\ Side}$), as this ratio would also highlight the difference between the affected and the unaffected leg. A ratio of < 1 indicates that the affected muscle is less active than the unaffected counterpart during the contraction, while a ratio of > 1 indicates more muscle activity in the affected side.

Statistical Analysis

The mean RMS and standard deviation (SD) of five repetitions were calculated for each dependent variable (VMO left/right and VL left/right per participant) and used for statistical analysis in *IBM SPSS Statistics 27.* The alpha level of significance was set to $p < 0.05$ for all analyses. To test if the data followed a normal distribution the Shapiro-Wilkin's test was used, due to the small sample size and its higher power compared to the Kolmogorov-Smirnov test (37).

The root mean square (RMS) has been shown to be the best processing technique for EMG analysis of dynamic contractions (38). It estimates the EMG amplitude and represents the sum of electrical activity in the motor units when the muscle is contracting (38,39). Mathematically, it represents the square root of the average power of the recorded EMG signal for a fixed period of time, in this case one movement cycle (**Figure 1**). With a sampling rate of 2000 Hz/s one repetition of four seconds would give measurements for 16.000 datapoints. To minimize the influence of sensor disturbance and faulty single point measures, the average of five repetitions was chosen for analysis.

When calculating the correlation between datasets the Pearson's correlation was used because the datasets were comprised of continuous data and the Spearman correlation is more utilized for rank ordered data, which is often ordinal (40,41). The two-tailed t-test was performed, to determine if the correlation significantly explains the relationship between the sit-to-stand and the squat exercises. A p-value of less than 0.05 indicated significant differences between the outcomes of both tests.

The data was then furthermore plotted to test if the relationship holds after accounting for differences of scale in the measurements. In order to explore the limits of agreement, Bland-Altman plots were performed, in which the difference between the outcomes are plotted against the means of the outcomes. Bland-Altman plots can visualize if the outcomes lie within the agreement levels, which themselves reflect two times the standard deviation of the mean difference. Since the correlation calculation alone does not account for a possible difference in scale of the two datasets, this technique can identify a fixed statistic bias. It allows for the visual identification of outliers and can highlight the evidence of proportional bias.

Additionally, a linear regression was calculated to specifically test the hypothesis of statistical bias in the data. Here the hypotheses were: the null hypothesis was that no difference or statistical bias would be found between datasets, and the alternative hypothesis was that there would be significant differences. Both the linear regression and the involved beta coefficients should not be statistically significant ($p > 0.05$) to indicate that the agreement of the investigated datasets is not influenced by statistical bias.

Results

Population

For this sEMG pilot study the muscle activity of 12 patients undergoing knee rehabilitation was measured. The average age was 39.58 years (± 15.08) and the sample consisted of four women and eight men (**Table 2**). The nature of traumatic knee injury was varied (**Table 3**), with four participants with (fragmented) fractures, two with ligament injuries, five with injuries of the ligaments and the menisci and one individual with a meniscus injury. Three participants received conservative treatment, while the other nine underwent fixating surgery (of the fractured bone fragments, ligaments, or menisci) an average of 20.85 (± 5.71) weeks before testing. The average time since the accident was 26.86 (± 20.43) weeks.

Table 2 – Demographics of Study Participants.

	Gender	Age (years) Mean (± SD)	Affected Leg	Fixating Surgery	Time since surgery (weeks) Mean (± SD)	Time since accident (weeks) Mean (± SD)	Injured tissue per participant
n	12	12	12	12	9	12	12
	4 Female 8 Male	39.58 (± 15.08)	9 – Right 3 – Left	9 – Yes 3 – No	20.85 (± 5.71)	26.86 (± 20.43)	4 – fractures 2 – ligament 5 – ligament & meniscus 1 – meniscus

Abbreviations: SD – standard deviation

Table 3 – Categorized diagnoses of participants.

Participants n	Category of knee injury	Diagnosis
4	Fractures	Femoral condyle fracture Proximal tibia fracture, lateral meniscus rupture Proximal tibia fracture, proximal fibula fracture Proximal fibula fracture
2	Ligament	MCL rupture ACL rupture (with fracture of eminentia intercondylaris of tibia)
5	Ligaments and Meniscus	ACL rupture, partial rupture MCL, lateral meniscus rupture ACL rupture, medial meniscus rupture ACL rupture, lateral meniscus rupture ACL, PCL partial rupture, lateral meniscus rupture Medial meniscus tear, Chronic instability after ACL replacement (8 years prior)
1	Meniscus	medial meniscus tear
Comorbidities (at time of testing, per participant): Osteomalacia, Hypothyroidism, Diabetes mellitus type I Congenital strabismus, restricted vision Fracture of lumbar vertebrae L1-L3, hypertonus, anxiety disorder Lumbar contusion Elbow fracture		

Abbreviations: MCL (medial collateral ligament); ACL (anterior cruciate ligament), PCL (posterior cruciate ligament)

sEMG Results

The sEMG data output from this pilot study shows the muscle activation of the investigated muscles in volt (V) at any time point of the executed movements. **Figure 1** depicts the average muscle activity of five repetitions for the sit-to-stand exercise (A + B) and the squat exercise (C + D) for one individual. Per exercise, a similar pattern can be seen for both the vastus medialis obliquus muscle (A + C) and the vastus lateralis muscle (B + D) of higher and lower activity at certain points of the movement.

Slight differences can be seen between the curves of the VMO and the VL and between the affected and unaffected side, but the graphical analysis does not allow for a precise comparison. The calculation of the root mean square (RMS) for each cycle makes a numerical and statistical comparison of muscle activities possible. It represents the average area underneath the curve for each individual muscle in numerical form, allowing for a statistical analysis.

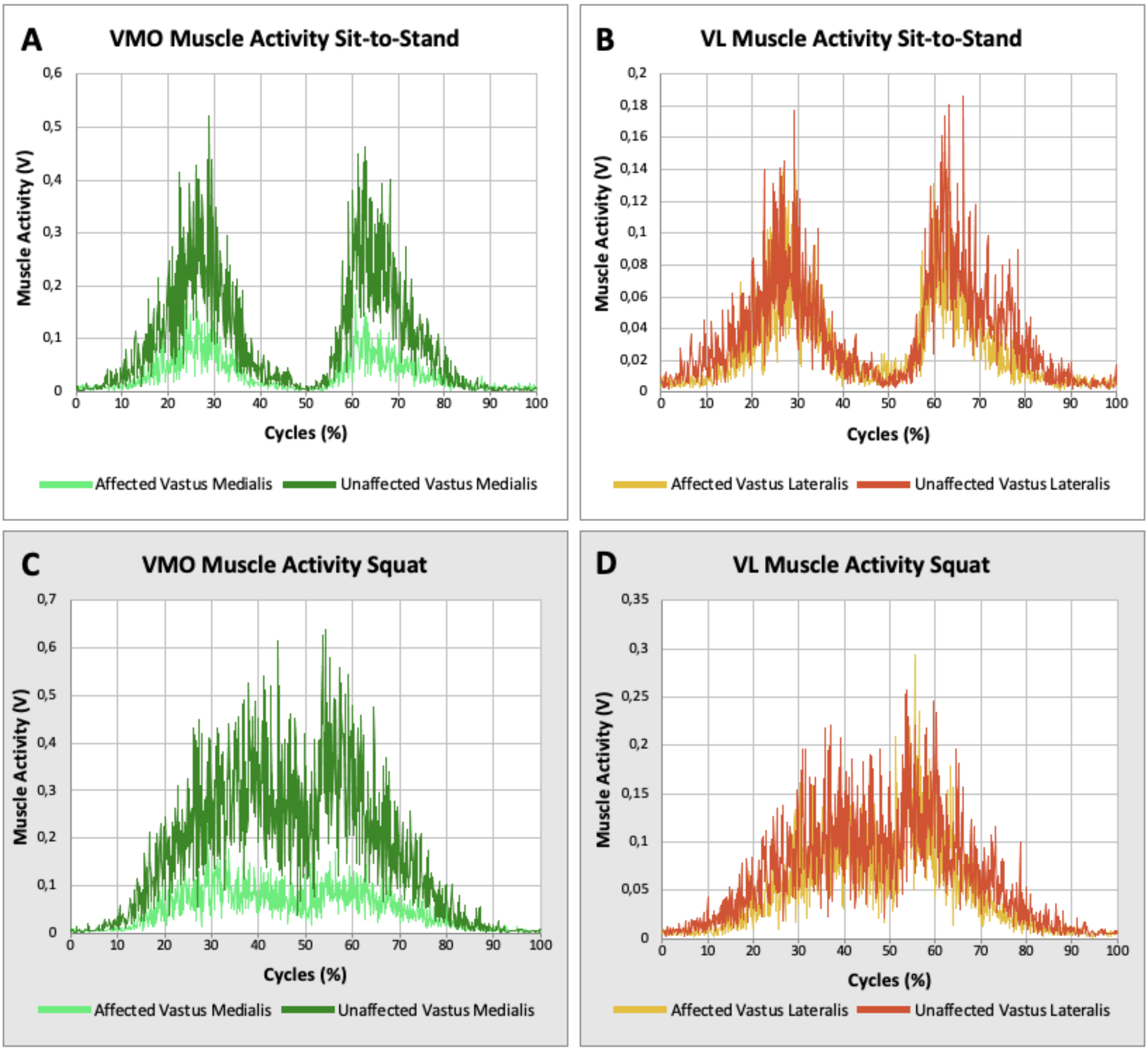

Figure 1 – Average of five movement cycles for one participant showing the muscle activity of both the vastus medialis obliquus (VMO; A + C) and the vastus lateralis (VL; B + D) on the affected and the unaffected side. One movement cycle was set as following: starting from sitting at 0% of the cycle, standing around 45-55% and sitting again around 90% of the cycle. The top row (A + B) shows muscle activity during sit-to-stand exercise and the bottom row (C + D) shows muscle activity during squat exercise.

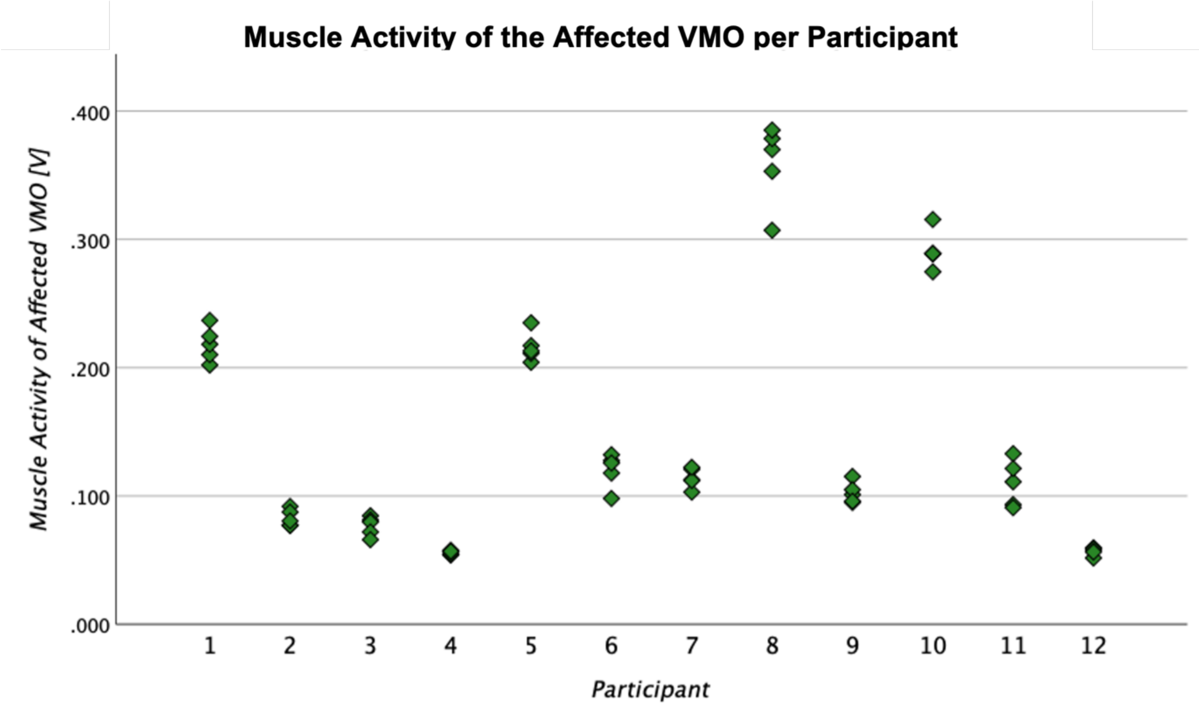

Figure 2 – Scatter plot of vastus medialis obliquus (VMO) muscle activity on the affected side per participant (five repetitions each). This graph demonstrates the high variability of data between participants.

Muscle activation differed greatly between participants making comparisons difficult. The values were not normally distributed and there was no correlation between the affected and the unaffected side amongst participants. **Figure 2** demonstrates the variability in results between participants, but also shows that the five analyzed repetitions per participant were similar to each other.

Ratios were calculated of the mean RMS per participant to show the relation of the affected and the unaffected side for each muscle. A ratio > 1 indicates that the affected muscle belly was more active than the unaffected, and a ratio < 1 means that the unaffected muscle was more active than the one on the affected side.

Comparison of Muscle Activity during Sit-to-Stand and Squat

When comparing the muscle activity ratios (affected/unaffected side) between exercises, there is a strong and significant correlation for both the VMO and the VL ($r > 0.9$; $p < 0.001$; **Table 4**). This indicates that both exercises target the respective muscles in a similar way.

Table 4 – Correlation of muscle activation ratios between exercises 1) sit-to-stand and 2) squat for vastus medialis obliquus (VMO) and vastus lateralis (VL).

	Ratio VMO (affected/unaffected)	**Ratio VL (affected/unaffected)**
Pearson's Correlation (r)	0.903**	0.918**
Significance (2-tailed)	p < 0.001	p < 0.001
**. Correlation is significant at 0.01 level (2-tailed)		

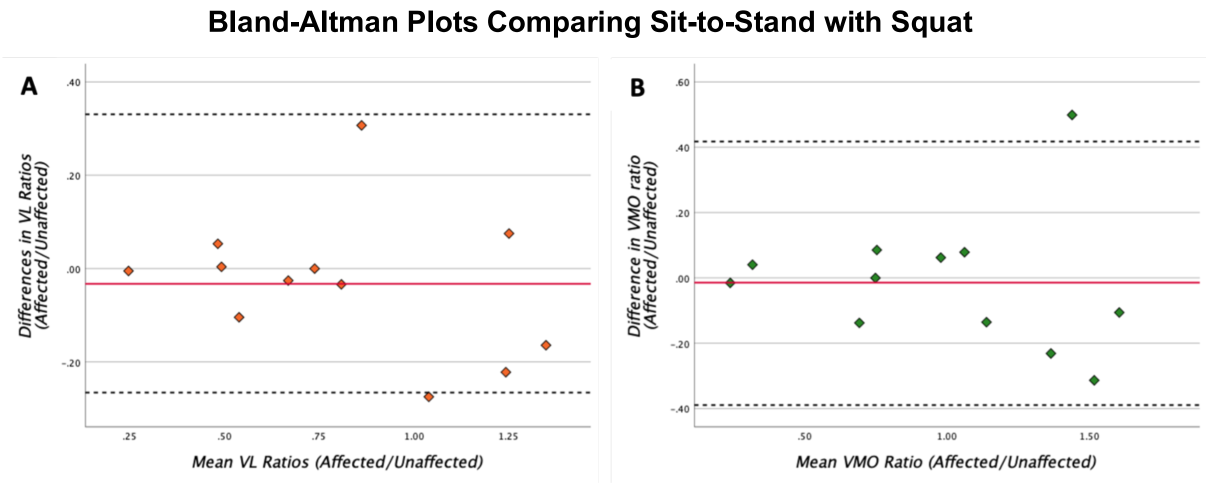

Figure 3 – Bland-Altman plot of A) the vastus medialis obliquus (VMO) ratio (affected/unaffected) and B) the vastus lateralis (VL) ratio (affected/unaffected) comparing the differences between sit-to-stand and squat – dotted line: 95% agreement levels (upper and lower), red line: mean of all values.

The Bland-Altman graphs (**Figure 3**) plot the difference in the muscle activity ratio values against the means of the ratios and can highlight the evidence of proportional bias. For both muscles (VMO and VL) most values lie within the upper and lower agreement level (dotted line), which indicates that the correlation between measurements of the two exercises is not only strong but also on the same scale. Neither the linear regression nor the beta coefficients were significant (**Table 5**) so the null hypothesis that there is statistical bias was rejected. Hence, there is no statistical bias for the correlations of muscle activity between exercises.

Table 5 – Linear regression and beta coefficients of Bland-Altman plots.

Linear Regression	Significance (2-tailed)	Beta Standard Coefficient
Mean VMO Ratio	0.755	- 0.101
Mean VL Ratio	0.326	- 0.311

Abbreviations: VMO – vastus medialis obliquus; VL – vastus lateralis

Significance was measure with the 2-tailed t-test

When comparing the muscle activity during the different exercises per participant, small differences in activation can be seen (**Figure 4**). Most participants had a slightly higher VMO muscle activation ratio in the squat compared to the sit-to-stand exercise, meaning that there was more muscle activity on the affected side. For participant one (see arrow) the sit-to-stand exercise elicited more activity in the affected vastus medialis obliquus, while the squat resulted in a more balanced activity ratio between sides. Similarly for participant one, the affected vastus lateralis was also more active during the sit-to-stand than during the squat.

The ratios differ between participants and between vastus medialis obliquus and vastus lateralis activity, not permitting further comparisons. An overview graph including both muscles and both exercises per participant can be found in Appendix D (**Figure 6**).

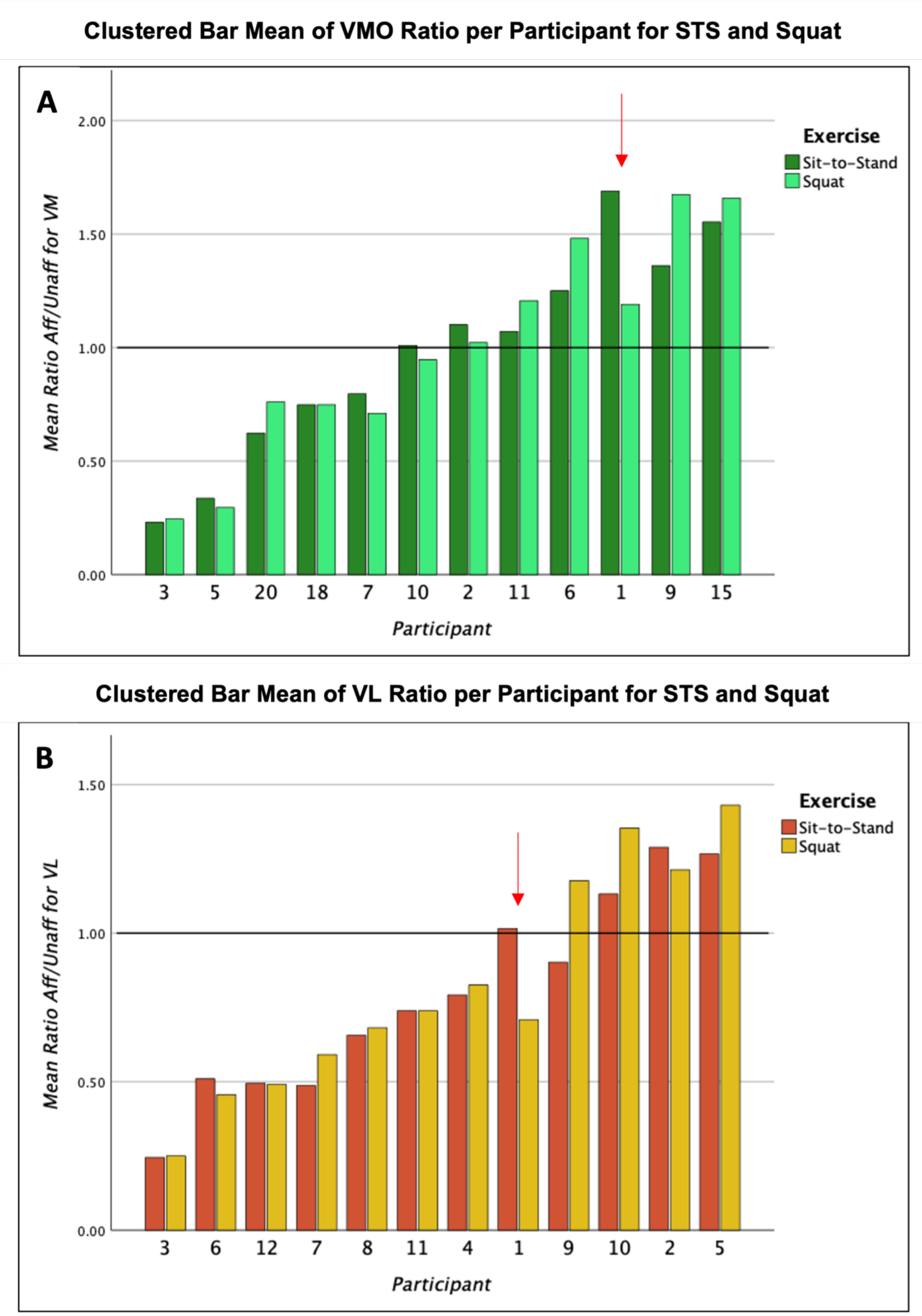

Figure 4 – Muscle activity ratios (affected/unaffected side) of A) vastus medialis obliquus (VMO) and B) vastus lateralis (VL) during Sit-to-Stand or Squat exercise. A ratio of ~1 shows equal muscle activity on both sides, a ratio of < 1 indicates less activity in the affected muscle and a ratio of > 1 indicates more activity in the affected muscle compared to the unaffected.

Discussion

The purpose of this study was to give insight into the comparability of two exercises 1) sit-to-stand and 2) squat regarding the activation of the quadriceps muscle. Surface electromyography (sEMG) data was used to analyze how much muscle activity is elicited in the vastus medialis obliquus and the vastus lateralis (VMO and VL) during an average repetition of either exercise.

The results of this sEMG pilot study show a strong significant correlation ($r > 0.9$) in overall VMO and VL muscle activity between the two exercises, suggesting that they may be equally as effective in strengthening the targeted muscles and could be used interchangeably in a rehabilitation program. This correlation holds true when checking for statistical and proportional bias. Analysis with Bland-Altman plots confirmed that the correlation is independent of the scale of data and a linear regression calculation excluded the presence of further statistical bias.

Points of Discussion

The sit-to-stand exercise is commonly integrated into muscle strengthening training programs for older people with a decreased level of fitness (17,18). The question arose if it would also be a suitable exercise for the rehabilitation of patients recovering from traumatic knee injuries, instead of the more commonly used squat exercise. Patients with a decreased level of fitness may benefit more from performing a (less strenuous) exercise like the sit-to-stand, which is specific to everyday activities and demanding enough, especially considering the muscle weakness that usually occurs after an injury (42,43).

The sit-to-stand transfer is a key component of daily living (44) and it is estimated that most adults perform the manoeuvre at least 45 times a day (17). According to the specificity of training principle, it would be beneficial to include an everyday task into the training plan to aid patients in regaining functional independence. This is the first and central goal of rehabilitation and could speed up a patient's recovery process.

The high risk of lasting complaints following a traumatic knee injury such as pain, functional limitations, and osteoarthritis (7-11) indicates the importance of a rehabilitation program focused on their prevention. Knee osteoarthritis is one of the leading causes of disability in older adults (1,9) and the main reason for knee replacement surgeries (45). There is strong circumstantial evidence that malalignment of the knee joint is connected to the disease progression and functional decline (1). The quadriceps muscle, especially the vastus medialis obliquus and its co-contraction with the vastus lateralis, are important in knee alignment and patellar tracking (15,16) and should therefore be a training focus after a knee injury.

Malalignment of the knee joint during a squat exercise will alter quadriceps activation (46), so when training a balanced interplay of the quadriceps heads the correct execution of the exercise is important. Especially for patients with a decreased level of muscle functioning it may be more effective to train with a less demanding exercise, like the sit-to-stand. Additionally, other exercises such as the monopodal squat, the forward lunge and the lateral step-up should be investigated more and also considered for a rehabilitation program, as these have been shown to elicit the most muscle activity from the vastus medialis obliquus and vastus lateralis, especially (47).

Since there was a high variability in functional level of the participants, it was not possible to analyze significant findings about possible differences in muscle activity between the participants. For example, no comparison between muscle activity on the affected and the unaffected side could be made. Between the participants the data was not normally distributed and could therefore not be statistically compared. However, datasets for repetitions within one individual were normally distributed and a correlation analysis could be performed. It can therefore be concluded that this study design is suited for analyzing correlations between various measurements within an individual but not across participants. For this, a more homogenous study sample would be necessary.

It was interesting to see, that there was a big variability in the ratios of muscle activity, when comparing one muscle on the affected versus the same muscle on the unaffected side. For some participants this ratio was low, indicating that the affected muscle showed less activity than the unaffected muscle. After a traumatic knee injury and prolonged periods of immobilization, muscle wasting is common (42,43) and less muscle activity is to be expected. Nevertheless, some individuals exhibited high ratios indicating that the muscles on their affected leg were more active than the ones on the unaffected leg. One explanation for this could be that weaker muscles need to recruit more motor units for the contraction and will therefore have more active motor units with an electrical activation signal. Since the sEMG signal represents the sum of all motor unit activation signals (25), this could result in a higher value. Another possible explanation for this is that in rehabilitation training there is often a bigger focus on the affected side than the unaffected side. Participants, who have had more training at the time of testing, could have learned to activate the muscles more on the affected side, as a result.

At the time of writing no studies could be found that directly compare the muscle activity during a sit-to-stand exercise and a squat exercise. There are several EMG studies describing the muscle activity patterns in squat variations in healthy adults or athletes (46,48-51) and some EMG studies investigating the sit-to-stand exercise, mainly in healthy adults (20,52,53). In general, there is a lack of research on muscle activity in injured adults with acute limitations. Even though it may be a challenge to assemble a sample group of patients with comparable injuries at a comparable level of functioning, it would be beneficial to have more studies focused on this. More insight in this field could give indications about the effectiveness of certain exercises for the recovery of these patients and the prevention of further complaints.

Strengths and Limitations of this Study

This study had several strengths and limitations. Major strengths of this study were the quality of the protocols and the study design. The experiment protocol was well thought through, tested before the start of the measurements, and altered accordingly to ensure a smooth flow of the measurements. Both executing researchers followed the protocol and their roles strictly and ensured that the participants knew how to execute the exercises correctly. Test results were obtained following the current golden standard guidelines for EMG studies and state-of-the-art equipment. Statistical analysis was checked by an experienced statistician, to control for possible mistakes/research bias.

The study design was well suited to answer the research question. Analysis of the sEMG data was able to compare the total muscle activity of two quadriceps muscles (vastus medialis obliquus and vastus lateralis) during the sit-to-stand exercise and the squat exercise. However, it should be pointed out that there was no blinding involved and that the main researcher conducted both the measurements and the data analysis.

The biggest limitation of this study was the high variability in selected participants. Even though the study sample was representative of the types of patients being treated at the participating rehabilitation center there was a big variation in diagnosis, illness history and general level of fitness. Therefore, it was not possible to draw comparisons between participant data. It would be insightful to repeat the study with a bigger and more homogenous population sample, at least in the category of their diagnosis. Still, this study sample was representative of the types of patients being treated in the participating rehabilitation center and is therefore more relatable to the situation in practice. The results give an accurate indication for the treating therapists on which exercise they may prefer to use with their patient in question. Since there is no difference in total muscle activation between the sit-to-stand and squat exercise, the therapist may choose to include either one in a patient's training, depending on their specific status.

As the sit-to-stand exercise is already commonly used in older patients, it would be insightful to repeat the study and draw up a comparison between participant groups, e.g., age related or according to their level of fitness. This could give a clearer indication of which patient groups benefit the most from either exercise.

Another limitation of the study is that only total sEMG data was recorded and analyzed. While this does allow for an insight into the research question of investigating overall muscle activity during exercises, it does not give any indication on the timing of muscle coordination. Therefore, no statements can be made about the interplay and coordination of the leg muscles. Due to the limited availability of sensors, only four muscles could be measured at a time, so it was not possible to get a more detailed understanding of which muscles may be more or less active next to the vastus medialis and the vastus lateralis. As especially the hamstrings may be involved in compensatory movements (according to sEMG data of a patient at the Rehazentrum City BGK Hamburg, as obtained in the context of their rehabilitation therapy), it would be interesting to repeat the measurements with additional electrodes placed on other muscles.

Furthermore, the study protocol did not check for equal weight-bearing during the execution of the exercises. Even though participants were instructed to do so, the researchers only checked visually for equal weight distribution between the legs. This could be quantified by using a force plate or scales for the participants to stand on, but due to availability and safety concerns for the patients, it was not done in this study.

Additionally, the sEMG only allows for analysis of the neuromuscular electrical signals of the motor units. It is important to be aware that these results do not provide any information about muscle strength, which can be diminished to varying degrees after knee injuries of different severity and periods of immobilization. An additional strength test would be help correct for more severe strength deficits.

Conclusion

The results of this study show that the sit-to-stand exercise can elicit similar activity levels in the VMO and VL when compared to the more commonly used squat exercise and should not be overlooked in the creation of a knee rehabilitation training program.

Since the sit-to-stand exercise is more specific to everyday life tasks, based on the specificity principle of training, it could even support patients in a faster return to independent daily living and speed up their rehabilitation process after a traumatic knee injury.

Practical Recommendations

In practice the results of this study support the notion, that therapists can choose to incorporate either the sit-to-stand exercise or the squat exercise in their patients' training programs. Since they are both effective in eliciting quadriceps muscle activity, the exercise that is more specific to the patient's training goal and their abilities should be preferred. This study supports the idea, that the sit-to-stand is an ADL specific exercise, whose effectiveness in training is not limited to the older population. It should therefore also receive more attention in the education of (future) health care professionals and the design of rehabilitation protocols.

When repeating this pilot study on a larger scale, some alterations should be made to the design and protocol. A larger and more homogenous sample group should be recruited to be able to draw comparisons not just within an individual's data, but also between participants. This could allow for analysis of differences in muscle activity between the affected and unaffected side or between different muscle bellies. To broaden the scope of this study, more muscles could be investigated (e.g., the dorsal thigh muscles) and a quantifiable movement analysis may be insightful. These additional measurements could give insight into compensatory movement patterns of patients struggling with the correct execution of the exercise, which are often not visible to the therapist's eye.

The protocol itself could be improved by blinding the assessors, separating the role of executing researcher and analyst and controlling for equal weight-bearing during the exercises utilizing a scale or a force plate. In general, the design of a practical research and the statistical analysis of data should be practiced in more depth during the education of therapists.

While several studies are investigating the effectiveness of training exercises in healthy and athletic adults, there is a lack of studies on injured or unfit adults. More research in this field could help improve the quality of rehabilitation programs and ensure a speedier and more complete recovery of patients after injury.

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Appendices

Appendix A – Test Protocols Inclusion and Exclusion Criteria

Modified Single Leg Stance (54)

To test for full weight-bearing ability on either leg and to exclude serious postural or balance control problems, a modified single leg stance was performed. Participants were asked to stand on one leg for more than 20 seconds, with their hands on their hips and their eyes open. The weight-bearing leg was in slight flexion of roughly 10-15° while the contralateral foot was not allowed to be in contact with the floor or the other leg.

If test subjects failed to perform due to balance issues on the first try, a repetition of the exercise was allowed. If the participants were unable to perform the test in the second run, they were excluded from further testing. If pain arose (> 3/10 VAS) during the test it was stopped, and the participant was excluded from further testing.

For the execution in this study, participants were instructed to perform the test wearing shoes, as the measurements were also taken with them wearing shoes.

Weight Bearing Lunge Test (55,56)

To test available ankle dorsiflexion in a weight-bearing position, participants were instructed to stand barefoot facing a wall. They were then asked to lunge forward until their knee was in contact with the wall, without lifting the heel of the foot off the floor. The distance between the foot and the wall was adjusted until the point was found, where the knee was touching the wall and the heel of the foot was still on the ground. The maximum available distance between the big toe and the wall was then measured. Participants were allowed to touch the wall to retain their balance during the test.

If the distance was less than five centimeters on either side, or there was a difference of more than five centimeters between sides, participants were excluded from further testing.

Active Straight-Leg-Raise (57)

To measure the activation of the quadriceps muscle the loss of knee extension during an active straight leg raise (active SLR) can be observed. In supine, the patient is instructed to push through his heel, pull up their kneecap and then lift the whole leg, bending at the hip. The researcher measures a possible loss of knee extension, using a goniometer. A loss would indicate weakness or an activation deficit of the quadriceps muscle and an inability to keep the knee stable.

If a loss of extension of more than five degrees was observed, the quadriceps strength was deemed as not sufficient for this study and participants were excluded from further testing.

Appendix B – Measurement Protocol

Table 6 – Measurement protocol translated from German.

	Barefoot – patient supine	
Preparation	Shave area for electrodes	
Knee mobility	Goniometer (min. Ext/Flex 0/5/120°)	
Active straight leg raise	Possible with < 5° loss of knee extension	
Weight-bearing lunge test	> 5 cm	
	→ put on shoes – standing	
Single leg stance	(> 20 s) weight-bearing knee in slight flexion (10 – 15°)	
Ergometer	5 min warm-up (settings as in patient's individual training plan)	→ explain rough structure of experiment meanwhile
	→ back to treatment room	**5 min break**
Place electrodes	Clean skin (cotton towel + rubbing alcohol)	(rub vigorously to get rid of old skin cells, reddening of skin is good, increases impedance)
	Place electrodes following the SENIAM guidelines	
	→ go to leg press	
MVIC measurement leg press	Demonstration by researcher with explanation of test	
	Adjust seat and footrest to patient's height – ensure that knee flexion is at ~70° when patient presses at 50 % of max. force → goes to ~60° when they are pressing at 100 %	
	Practice run at 50 % of max. force	
	Maximum force measurement (don't motivate patient) – measure 8 seconds	
	→ back to treatment toom	**5 min break**
Sit-to-stand	Adjust seat height	Back of knee crease of patient
	Place camera	In picture: ground, feet, patient up until hip or chest height
	Demonstration by researcher	• Explain visual timer (2 s up and 2 s down) • Read out ***exercise instruction***
	Repeat important points	• Cross arms in front of chest • Feet at the same height

	Practice run: 4 repetitions	**2 min break**
	Measurement: 10 repetitions	
Exercise instruction: Sit down on the bench and stand back up, as you would do it at home. Keep your feet roughly at the same time and keep your arms crossed in front of your chest. Move at a steady velocity and use the visual timer as a guide – sit down as the point on the display goes down and stand up as the point moves back up.		
		5 min Pause
Squat	Mark foot position	As patient is sitting on the bench with his buttocks (thighs are not on the bench) and knees are at 90° → tape in front of the shoe = starting position feet for the squat
	Demonstration by researcher	• Explain visual timer (2 s up and 2 s down) • Read out ***exercise instruction***
	Repeat important points	• Cross arms in front of chest • Keep heels on the ground • Legs hip-width distance apart • Equal weight-bearing between both feet
	Practice run: 4 repetitions	**2 min Pause**
	Measurement: 10 repetitions	
Exercise instruction: Keep your feet parallel, at the tape line and hip-width distance apart. Distribute your weight equally between both feet and cross your arms in front of your chest. Now start bending your knees and bring your buttocks back, as if you were to sit down on a chair. Stop before your buttocks come in contact with the bench. Move at a steady velocity and use the visual timer as a guide – sit down as the point on the display goes down and stand up as the point moves back up.		

Materials	**Planning appointments per patient**
• EMG with electrodes • Cotton towel and rubbing alcohol • Shaver • Visual timer (set to 2 s, 22 reps) • Tape	• Plan 1 hour per patient • Plan before sports therapy (avoid fatigue)
Numbering of electrodes in *proEMG*	Naming of measurement files
1. Vastus medialis right 2. Vastus lateralis right 3. Vastus medialis left 4. Vastus lateralis left	• MVIC re #participant • MVIC li #participant • Sit to Stand #participant • Squat #participant

Appendix C – Electrode Placement

Figure 5 – Electrode placement during the experiment was done according to SENIAM guidelines and Rainoldi et al. 2004 (38,39).

SENIAM Guidelines for Electrode Placement (38)

Table 7 - SENIAM guidelines for electrode placement on the vastus medialis.

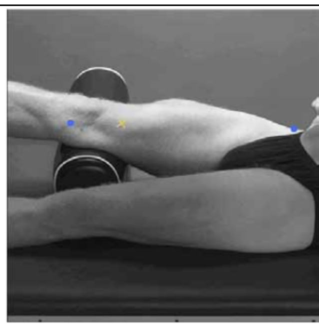
	Vastus Medialis	
Start Position	Sitting on table, knees in slight flexion, upper body slightly bent backward	
Location	at 80% of line *anterior spina iliaca superior – joint space in front of anterior border of the medial ligament*	
Orientation	Almost perpendicular to the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament	
Test	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.	

Table 8 – SENIAM guidelines for electrode placement for the vastus lateralis.

	Vastus Lateralis	
Start Position	Sitting on table, knees in slight flexion, upper body slightly bent backward	
Location	at 2/3 of line *anterior spina iliaca superior - lateral side of patella*	
Orientation	in the direction of muscle fibres	
Test	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion	

Adapted from http://www.seniam.org/; last accessed on 23-03-2021

Appendix D – Overview of Muscle Activity Ratios

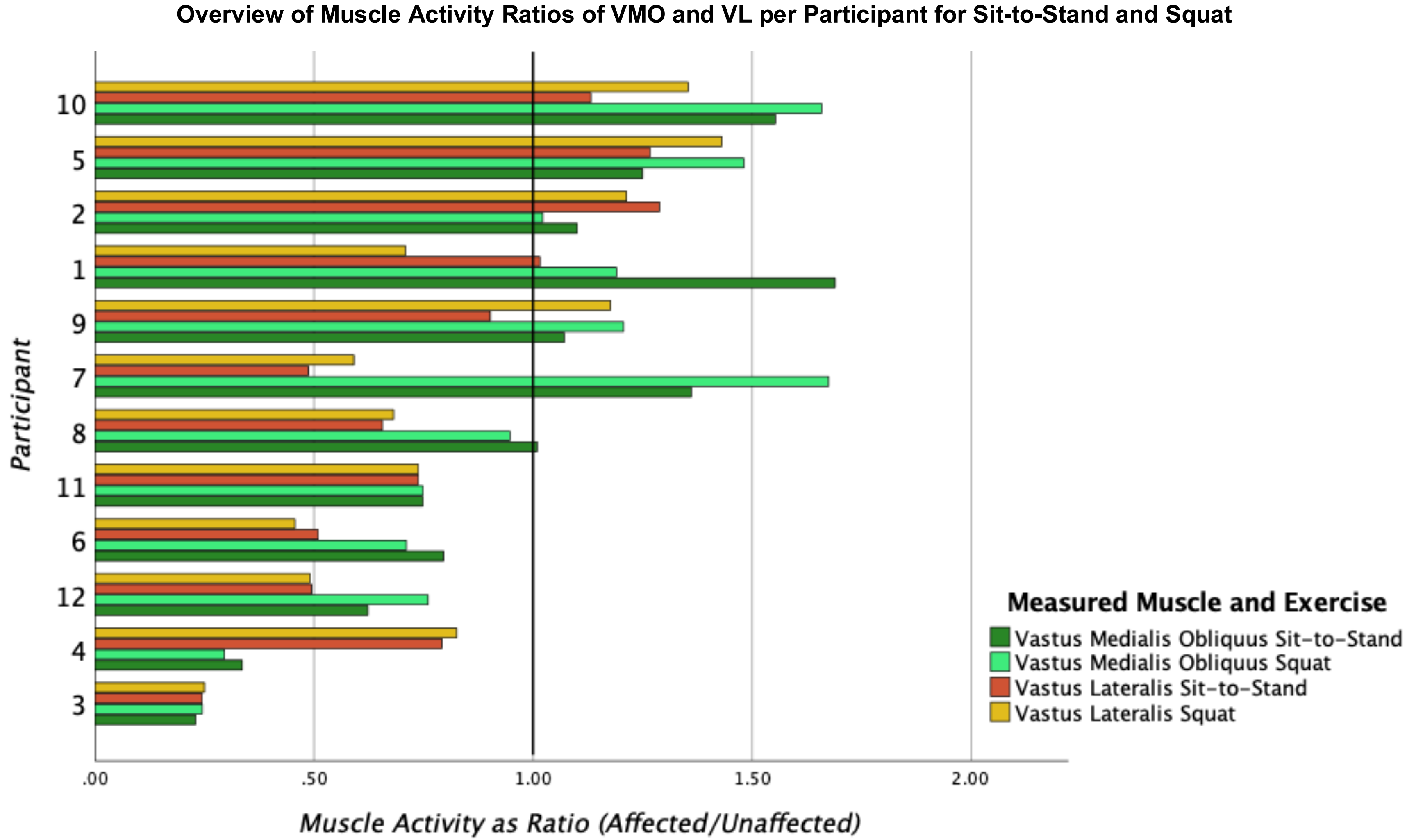


Figure 6 – Overview of muscle activity ratios per participant of vastus medialis obliquus ratio (affected/unaffected) and vastus lateralis ratio (affected/unaffected) for each exercise (sit-to-stand and squat). A ratio of ~1 shows equal muscle activity on both sides, a ratio of < 1 indicates less activity in the affected muscle and a ratio of > 1 indicates more activity in the affected muscle compared to the unaffected.

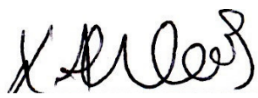
Appendix E – Ethical Testing Protocol

Step I: According to the WMO testing flowchart a compulsory examination of the Medical Research Act is not required.

Precautionary Measures Research Scheme

Project /subject/academic portion:	Graduation Assignment Bachelor Physiotherapy
Teacher/ coach:	Anne Griet Brader
Topic:	EMG Study of Quadriceps Activity in patients recovering from traumatic knee injuries
Starting and ending times of the research:	December 2020 – 19.04.2021
Description of the research (brief but complete):	EMG measurements are collected of the quadriceps activity (vastus medialis + lateralis) of patients, who are recovering from knee injuries, while they are performing two functional tasks: 1) Sit-to-Stand 2) Squat (20 reps each)

The undersigned declare, truthfully and without reservations, to have filled in the enclosed form in relation with the Graduation assignment research to be conducted within the context of the programme.

Name of student:	Signature:
Katharina Ahlers	

Date: 05.03.2021

	Check if applicable **A**		Answer the following questions if the checked the box is marked with a ➔ in the previous column. **B**	Can damage still occur here in all reasonableness? (check the correct box) **C**	
1 **Privacy / anonymity**				No	Yes
1.1 Do you know the names of test subjects? Do you have address information?	No ☑ ↙	Yes ➔	How is anonymity guaranteed? *(Think about not including personal data in a report, changing names and specifics, etc.)* When are the data destroyed, and who is responsible for this? If the name of the test subject or a company or the like are published nonetheless, do the involved parties get their explicit permission?	X	
1.2 Do you know the email address of the test subjects?	No ☑ ↙	Yes ➔	How do you ensure that the address is removed from your address book (sent items, contacts, inbox, other folders, etc.), because of spam or viruses? (further as in 1.1)	X	
1.3 Do you have (other) personal data?	No ↙	Yes ☑ ➔	Are these data necessary? And Why? **personal data (gender, diagnosis of injury, previous surgeries related to injury. These data are necessary to define the population group and be able to compare data across patients or not.** How is anonymity guaranteed? **Recordings and measurements were collected under a pseudonym.** When are data destroyed, and who is responsible for it? **At the end of the study (May 2021); the leading researcher at BGK Klinikum** Will the data in question be published (with explicit permission?) **Anonymized data will be included in the GA, as specified in the informed consent.**	X	
1.4 Will test subjects appear on a picture or on a video or sound recording?	No ↙	Yes ☑ ➔	Have test subjects been informed about this beforehand? **Yes, in the informed consent form** Who gets to see/hear this material? **Only the conducting researchers** Do test subjects give express authorisation for this? **Yes, in the informed consent form** How is anonymity guaranteed? **Recordings and measurements were collected under a pseudonym and patient's faces are not in the video.** When are data destroyed, and who is responsible for it? **At the end of the study (May 2021); the leading researcher at BGK Klinikum** Will the data in question be published (with explicit permission?) **No recordings will be published**	X	

1.5 Is one working with acquaintances of the researchers?	No ☑ ↙	Yes →	Is there is a risk of role confusion? Are problems conceivable in the area of privacy or, for example, conflicts of interest in the relationship which can arise due to a difficult test result? What is done to prevent such problems? What alternative solutions are considered, and why are they not applied?	X	

2 **Information and authorisation**					
2.1 Are test subjects asked for permission explicitly?	Yes ☑ ↙	No →	Why not?	X	
2.2 Are test subjects informed in advance of the goal of the study / the intervention?	Yes ☑ ↙	No →	Why not? Are test subjects informed after the fact?	X	

2.3 Are test subjects truthfully and clearly informed who the client is / what the interests of the client are?	Yes ☑ ↙	No →	Why not? Are test subjects informed after the fact?	X	
2.4 Can test subjects refuse participation?	Yes ☑ ↙	No →	Why not?	X	
2.5 Can test subjects stop at any moment / forego further participation?	Yes ☑ ↙	No →	Why not?	X	
2.6 Are test subjects informed clearly about what role you are working with them in? (For example to learn from them, as employee of a client)	Yes ☑ ↙	No →	Why not? Are test subjects informed after the fact?	X	
2.7 Are test subjects offered the possibility to be informed of results?	Yes ☑ ↙	No →	Why not?	X	

2.8 Are test subjects given incorrect information about the client, the goal of the study, or the like?	No ☑ ↙	Yes ➔	Why? Are test subjects informed after the fact?	X	
2.9 Are (some) test subjects minors?	No ☑ ↙	Yes ➔	Has authorisation been arranged with the parents/carers? If not, why not?	X	
2.10 Are (some) persons unable to give informed consent?	No ☑ ↙	Yes ➔	Is authorisation arranged with any other persons in charge? If not, why not?	X	
2.11 Is a protocol made that states how and in what wording test subjects are informed about points 2.1 to 2.8?	Yes ☑ ➔		Include the protocol. **See Appendix B**		
		No ➔	Why not?		

3 **Possible side effects**					
3.1 Has there been any misleading of test subjects during the study?	No ☑ ↙	Yes ➔	Why is this necessary? What is the nature of the deceit? When and how are test subjects informed (debriefing)?	X	
3.2 Does participation cause the test subject to have detrimental experiences psychologically, socially, physically or otherwise? Think here, *among other things*, of awareness of something unpleasant; embarrassing, frustrating or stressful; finding out about results unintendedly; etc.	No ☑ ↙	Yes ➔	What detrimental effects are possible? What is done to prevent these detrimental effects? What is done in terms of damage control? Are test subjects informed about this in advance?	X	

3.3 Can groups (this also includes vulnerable groups/minorities) have detrimental experiences because of their participation in e.g. research results or publicity about it?	No ☑ ↙	Yes ➔	What detrimental effects are possible? What is done to prevent these detrimental effects? What is done in terms of damage control? Are test subjects informed about this in advance?	X	
3.4 Can organisations and the like (for example a school or housing corporation that looks 'bad') be detrimentally affected by results or publicity related to the study?	No ☑ ↙	Yes ➔	What detrimental effects are possible? What is done to prevent these detrimental effects? What is done in terms of damage control? Are test subjects informed about this in advance? Are involved organisations aware of this?	X	
3.5 Can decisions based on research be taken (for instance by the client) that could be detrimental for certain people / groups of people?	No ☑ ↙	Yes ➔	What decisions can be detrimental to whom? What is done to prevent these detrimental effects? What is done in terms of damage control? Are other involved parties informed about this in advance?	X	
3.6 Can results/test results be shocking/unpleasant for those involved?	No ☑ ↙	Yes ➔	Are agreements made in advance about the discussion of the results? Are the options for admission, follow-up care or further referral arranged for?	X	

4. **Weighing pros and cons**				
If the text above includes issues through which test subjects or others could be wronged, there may be advantages in the research against this (improvement of people's situation, educational/learning goals, earnings, etc.). Are such advantages present?	Yes | No ➔	What are the advantages of this? To what degree do the damaging issues weigh against these advantages?	NA	

BG Klinikum Hamburg Rehazentrum City

Vergleich der Quadrizepsaktivität bei Sportübungen mit Alltagsbewegungen im Rahmen einer EMG-Studie

BG Klinikum Hamburg Rehazentrum City • Lange Mühren 1 • 20095 Hamburg

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Studienleitung:	Claudia Hennecke
Stellv. Studienleitung:	Melanie Meyer
Studiendurchführung:	Katharina Ahlers
Studienzentrum:	Rehazentrum City des BG Klinikums Hamburg, Lange Mühren 1, 20095 Hamburg

Patienteninformation und Einwilligungserklärung

Sehr geehrte Patientin, sehr geehrter Patient,

wir möchten Sie fragen, ob Sie bereit sind, an der nachfolgend beschriebenen Studie teilzunehmen.

Wissenschaftliche Studien sind notwendig, um Erkenntnisse über die Krankheiten, deren Ursachen und Behandlungsmöglichkeiten zu gewinnen. Die Studie, die wir Ihnen hier vorstellen, wurde von einer Ethikkommission zustimmend bewertet. Sie wird am Rehazentrum City des BG Klinikums Hamburg, Lange Mühren 1, 20095 Hamburg durchgeführt. Die Studienleitung erfolgt durch Claudia Hennecke, Leitung Therapie des Rehazentrums am BG Klinikum Hamburg sowie Frau Melanie Meyer, Physiotherapeutin des Rehazentrums City am BG Klinikum Hamburg.

Insgesamt sollen 15 Personen an der Studie teilnehmen. Ihre Teilnahme an dieser Studie ist freiwillig. Sie werden in diese Studie also nur dann einbezogen, wenn Sie dazu schriftlich Ihre Einwilligung erklären. Sofern Sie nicht an der Studie teilnehmen oder später aus ihr ausscheiden möchten, erwachsen Ihnen daraus keine Nachteile. Sie können jederzeit, auch ohne Angabe von Gründen, Ihre Einwilligung widerrufen.

Der nachfolgende Text soll Ihnen die Ziele und den Ablauf der Studie erläutern. Bei Interesse an einer Teilnahme an dieser Studie wird ein Therapeut das Aufklärungsgespräch mit Ihnen führen. Bitte zögern Sie dabei nicht, alle Punkte anzusprechen, die Ihnen unklar sind. Sie werden anschließend ausreichend Bedenkzeit erhalten, um über Ihre Teilnahme zu entscheiden.

Träger des Krankenhauses:
BG Klinikum Hamburg gGmbH

Geschäftsführer:
Christian Dreißigacker

Amtsgericht Hamburg HRB 138923
USt-IdNr.: DE1187 14007
IK: 260 200 217

Kontakt Geschäftsführung:
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Web: www.rzh-city.de

1. Warum wird diese Studie durchgeführt?

Durch diese Studie soll untersucht werden, wie die Oberschenkelmuskulatur bei kräftigenden Übungen für die Beine (Kniebeugen/Squats und funktionelles Aufstehen und wieder Hinsetzen) bei Patienten mit überstandenen Knieverletzungen zusammenarbeitet. Für unverletzte Testpersonen ist dies in mehreren Studien bereits erforscht und wir wollen untersuchen, ob die Aktivierung der Muskeln nach einer Knieverletzung anders abläuft.

2. Wie ist der Ablauf der Studie und was muss ich bei Teilnahme beachten?

Im Rahmen der Studie wird die Aktivität Ihrer Muskeln via eines Oberflächen-EMG (Elektromyographie) Messgerät untersucht. Dabei werden Ihnen Elektroden mit einem drahtlosen Sensor auf die Haut über dem zu untersuchenden Muskel geklebt und dessen elektrische Aktivität während einer Bewegung gemessen. Dieser Prozess ist schmerzfrei und behindert Sie nicht in Ihren Bewegungen. Vor dem Kleben der Elektroden wird das Hautstück gereinigt und rasiert.

Sie werden dann gebeten ausgewählte Bewegungsabläufe durchzuführen, die die Oberschenkelmuskulatur ansprechen, während die Messungen vorgenommen werden. Die Bewegungen werden mit einer Kamera aufgezeichnet, um die Signale später dem richtigen Bewegungsmoment zuordnen zu können. Das Bildmaterial wird lediglich zu diesem Zweck genutzt und nicht veröffentlicht.

Als Voruntersuchung werden die Mobilität des Kniegelenks und des oberen Sprunggelenks (OSG) gemessen und sie werden gebeten, den Einbeinstand für 20 Sekunden durchzuführen.

Pseudonymisiert werden folgende Daten erfasst und ausgewertet:

- Geburtsjahr
- Geschlecht
- Diagnose der Verletzung, evtl. frühere Verletzungen
- Daten aus den EMG Messungen
- Knie Mobilität, OSG Mobilität und Einbeinstand (während der Studie gemessen)

3. Welchen persönlichen Nutzen habe ich von der Teilnahme an der Studie?

Sie werden durch Ihre Teilnahme an dieser Studie keinen Nutzen für Ihre Gesundheit haben. Die Ergebnisse dieser Studie können dazu beitragen, dass für andere Patienten, die an Ihrer Erkrankung leiden, die Versorgung/Therapie verbessert wird.

4. Welche Risiken sind mit der Teilnahme an der Studie verbunden?

Bei elektromyographischen Untersuchungen an der Hautoberfläche treten in der Regel keine Komplikationen auf. Jedoch können die Klebeelektroden und die Reinigung der Haut mit Alkohol in seltenen Fällen Reizungen der Haut oder allergische Reaktionen verursachen.

5. Freiwilligkeit der Teilnahme

Die Teilnahme an der Studie ist freiwillig. Eine Teilnahme bzw. Nicht-Teilnahme hat keinen Einfluss auf Ihre medizinische Versorgung.

6. Wer darf an dieser klinischen Studie nicht teilnehmen?

Patienten, bei denen allergische Hautreaktionen auf Klebstoffe (z. B. Pflasterallergie) oder andere überschießende Hautreaktionen bekannt sind, dürfen nicht an der Studie teilnehmen.

7. Entstehen für mich Kosten durch die Teilnahme an der klinischen Studie? Erhalte ich eine Aufwandsentschädigung?

Durch Ihre Teilnahme an dieser klinischen Studie entstehen für Sie keine zusätzlichen Kosten. Leider ist aber auch keine Aufwandsentschädigung möglich.

8. Werden mir neue Erkenntnisse während der Studie mitgeteilt?

Über neue Ergebnisse, die aus Ihren Messungen resultieren könnten, werden Sie direkt im Anschluss der Messungen informiert.

9. Wer entscheidet, ob ich aus der Studie ausscheide?

Sie können jederzeit, auch ohne Angabe von Gründen, Ihre Teilnahme beenden, ohne dass Ihnen dadurch irgendwelche Nachteile bei Ihrer medizinischen Behandlung entstehen.

Unter gewissen Umständen ist es aber auch möglich, dass der behandelnde Arzt entscheidet, Ihre Teilnahme an der Studie vorzeitig zu beenden, ohne dass Sie auf die Entscheidung Einfluss haben.

10. Was geschieht mit meinen Daten?

Im Rahmen dieser Studie werden die erhobenen Daten in pseudonymisierter Form gespeichert und ausgewertet. Bei der Pseudonymisierung werden der Name und andere Identifikationsmerkmale durch eine mehrstellige Buchstaben- und/oder Zahlenkombination, auch Pseudonym oder Code genannt, ersetzt, so dass die personenbezogenen Daten ohne Hinzuziehung zusätzlicher Informationen nicht mehr einer spezifischen betroffenen Person zugeordnet werden können. Studienspezifische Fragebögen werden ebenfalls mit demselben Code versehen und dadurch pseudonymisiert. Alle Daten und Fragebögen sind gegen unbefugten Zugriff gesichert.

Zugang zur Zuordnungsliste, die eine persönliche Zuordnung des Studienteilnehmers ermöglicht und an einem vor unberechtigtem Zugriff geschützten Ort getrennt von den pseudonymisierten Daten aufbewahrt wird, haben neben der Studienleiterin **Claudia Hennecke** und ihrer Stellvertreterin **Melanie Meyer** nur von diesen ausdrücklich dazu autorisierte, zur Vertraulichkeit verpflichtete Personen am BG Klinikum Hamburg. Nach Abschluss der Studie wird die Zuordnungsliste gelöscht.

Sämtliche Daten aus den EMG-Messungen werden während der Durchführung der Studie in pseudonymisierter Form auf einem gesicherten Laptop des Rehazentrums des BG Klinikums gespeichert und analysiert, das nur für EMG Studien und Messungen genutzt wird. Während der EMG-Messungen werden zudem Ihre Bewegungen mit einer Kamera festgehalten, um später die Bewegungsmomente den gemessenen Daten zeitgenau zuordnen zu können. Dabei wird Ihr Gesicht nicht oder kaum zu erkennen sein und die Daten getrennt von jeglichen persönlichen Daten gespeichert. Dieses Bildmaterial wird NICHT veröffentlicht oder an Dritte weitergegeben und nur zur Analyse der Rohdaten verwendet. Nach Abschluss der Studie wird das Bildmaterial umgehend gelöscht.

Die Auswertung und Nutzung der Daten durch den Studienleiter und seine Mitarbeiter erfolgt nur in pseudonymisierter Form. Eine Weitergabe studienbezogener Daten zum Zwecke der Veröffentlichung der Studie im Rahmen einer Bachelorarbeit erfolgt nur und ausschließlich in anonymisierter Form an die kollaborierende Universität in den Niederlanden, Hanze Hogeschool Groningen. Die Veröffentlichung der Daten findet ausschließlich in anonymisierter Form statt.

Sämtliche Daten dieser Studie, die nicht in den Patientenakten selbst gespeichert sind, werden nach Abschluss der Studie gelöscht.

Bei einem Abbruch der gesamten Studie oder einem Abbruch einer einzelnen Teilnahme, haben Sie jederzeit das Recht die Löschung Ihrer studienbezogenen Daten zu verlangen.

Wir versichern Ihnen, Ihre personenbezogenen Daten absolut vertraulich zu behandeln und alle Bestimmungen des Datenschutzes einzuhalten. Auf der folgenden Seite erhalten Sie weitere Informationen zum Datenschutz sowie Ihre diesbezüglichen Rechte.

Informationen zum Datenschutz

Unser Umgang mit Ihren Daten und Ihre Rechte – Information nach Artikel 12ff. der Datenschutz-grundverordnung

Wer ist für die Datenverarbeitung verantwortlich und an wen kann ich mich wenden?

Verantwortlicher für die Durchführung der Studie ist:

Claudia Hennecke

Verantwortlicher für die Datenverarbeitung ist:

BG Klinikum Hamburg gGmbH
Bergedorfer Straße 10
21033 Hamburg
Tel.: 040 7306 0
E-Mail: mail@bgk-hamburg.de

Sie erreichen unseren betrieblichen **Datenschutzbeauftragten** unter:

BG Klinikum Hamburg gGmbH
Datenschutzbeauftragte
Bergedorfer Straße 10
21033 Hamburg
Tel.: 040 7306 1315
E-Mail: datenschutz@bgk-hamburg.de

Zu welchem Zweck verarbeiten wir Ihre Daten und auf welcher Rechtsgrundlage?

Die Nutzung der Daten erfolgt ausschließlich für die Durchführung der wissenschaftlichen Untersuchung mittels Oberflächen-EMG im Rahmen der Studie „Vergleich der Quadricepsaktivität bei Sportübungen mit Alltagsbewegungen im Rahmen einer EMG-Studie“. Die im Rahmen der Studie nach Einwilligung des Studienteilnehmers erhobenen personenbezogenen Daten, insbesondere Befunde, unterliegen der Schweigepflicht nach § 203 StGB und den datenschutzrechtlichen Bestimmungen. Ihre personenbezogenen Daten werden im Einklang mit den Bestimmungen der Europäischen Datenschutzgrundverordnung (DSGVO) und dem Bundesdatenschutzgesetz (BDSG) verarbeitet.

Die **Rechtsgrundlagen** zur Verarbeitung der Sie betreffenden personenbezogenen Daten bilden Ihre freiwillige schriftliche Einwilligung gemäß Art. 6 Abs. 1 S. 1 lit. a bzw. Art. 9 Abs. 2 lit. a DSGVO.

Wer hat Zugriff auf meine Daten? / Wer bekommt meine Daten?

Zugriff auf die Daten haben neben der Studienleiterin Claudia Hennecke und ihrer Stellvertreterin Melanie Meyer nur von diesen ausdrücklich dazu autorisierte, zur Vertraulichkeit verpflichtete Personen am BG Klinikum Hamburg. Empfänger der Daten sind die verantwortlichen Projektmitarbeiter im Rehazentrum City des BG Klinikums Hamburg sowie in anonymisierter Form der Studienpartner Hanze Hogeschool Groningen (University of Applied Science) zum Zwecke der Veröffentlichung der Studie im Rahmen einer Bachelorarbeit.

Wie lange werden meine Daten gespeichert?

Personenbezogene Daten werden nur bis zum Abschluss der Studie gespeichert. Nach Beendigung der Studie werden alle pseudonymisiert gespeicherten Daten anonymisiert.

Besteht für mich eine Pflicht zur Bereitstellung von Daten?

Die Teilnahme an der vorliegenden Studie ist völlig freiwillig. Eine Teilnahme bzw. Nicht-Teilnahme hat keinen Einfluss auf Ihre medizinische Versorgung. Ferner können Sie auch später jederzeit ohne Angaben von Gründen Ihre Teilnahme widerrufen und aus der Datensammlung ausscheiden ohne dass Ihnen dadurch Nachteile entstehen. Bitte beachten Sie, dass der Widerruf erst für die Zukunft wirkt und nicht die Rechtmäßigkeit der bis zum Widerruf verarbeiteten Daten berührt.

BG Klinikum Hamburg Rehazentrum City

Vergleich der Quadricepsaktivität bei Sportübungen mit Alltagsbewegungen im Rahmen einer EMG-Studie

Einwilligungserklärung

Hiermit bestätige ich, ____________________________________, geb. am ________________,
Name des Teilnehmers in Druckbuchstaben

dass ich in einem persönlichen Gespräch durch _______________________________________
Name der/des aufklärenden Therapeuten

ausführlich und verständlich über die oben genannte Studie aufgeklärt worden bin.

Ich habe darüber hinaus den Text der schriftlichen Patienteninformation erhalten, gelesen und verstanden. Insbesondere habe ich die Informationen über den Datenschutz und die Möglichkeit des Teilnahmeabbruchs zur Kenntnis genommen.

Ich hatte ferner die Gelegenheit, alle meine Fragen im Hinblick auf eine Teilnahme an der Studie zu stellen. Diese wurden zufriedenstellend und vollständig beantwortet. Die mir dabei erteilten Informationen habe ich inhaltlich verstanden und ich hatte ausreichend Zeit, meine Entscheidung zur Studienteilnahme zu überdenken und frei zu treffen.

Ich wurde darauf hingewiesen, dass meine Teilnahme freiwillig ist und dass ich das Recht habe, diese jederzeit ohne Angabe von Gründen zu beenden, ohne dass für mich oder meine Behandlung irgendwelche Nachteile entstehen. Den Widerruf kann ich gegenüber der Studienleiterin Claudia Hennecke oder ihrer Stellvertreterin Melanie Meyer jederzeit schriftlich erklären.

Mir ist bekannt, dass bei dieser klinischen Studie besondere Kategorien personenbezogener Daten gemäß Art. 9 DSGVO, insbesondere medizinische Befunde, über mich erhoben, gespeichert und ausgewertet werden sollen. Die Verwendung der Angaben erfolgt nach gesetzlichen Bestimmungen und setzt vor der Teilnahme an der Studie folgende freiwillig abgegebene Einwilligung voraus.

Datenschutzrechtliche Einwilligungserklärung

Ich willige ein, dass für den Zweck der oben genannten Studie besondere Kategorien personenbezogener Daten, insbesondere Angaben über meine Gesundheit, erhoben und in Papierform und/oder auf elektronischen Datenträgern im Rehazentrum City des BG Klinikums Hamburg, Lange Mühren 1, 20095 Hamburg aufgezeichnet werden. Diese Daten dürfen während der Durchführung der Studie in pseudonymisierter Form ausgewertet und zur weiteren wissenschaftlichen Auswertung in anonymisierter Form an Hanze Hogeschool Groningen (University of Applied Sciences) weitergegeben werden

Ich willige ein, dass meine personenbezogenen Daten während der Dauer der Studie aufbewahrt werden. Nach Beendigung der Studie werden meine personenbezogenen Daten anonymisiert oder gelöscht.

Ich bin unterrichtet, dass alle an der Studie beteiligten Mitarbeiterinnen und Mitarbeiter zur Vertraulichkeit und zur Schweigepflicht nach § 203 StGB verpflichtet sind und die geltenden Datenschutzbestimmungen einhalten. Eine unbefugte Weitergabe oder Veröffentlichung meiner personenbezogenen Daten ist nicht zulässig.

Mir ist bekannt, dass ich zur Abgabe der Einwilligungserklärung nicht verpflichtet bin und ich diese Einwilligungserklärung ohne Angabe von Gründen jederzeit mit Wirkung für die Zukunft widerrufen kann.

Der Widerruf ist

per E-Mail zu richten an: c.hennecke@bgk-hamburg.de oder m.meyer@bgk-hamburg.de

oder postalisch an: BG Rehazentrum City HH
z.Hd. Frau Hennecke
Lange Mühren 1
20095 Hamburg

Ich kann jederzeit beim Studienleiter oder seinem Stellvertreter Auskunft über die von mir erhobenen personenbezogenen Daten erhalten bzw. die Berichtigung oder die Löschung der Daten verlangen.

Ich erkläre mich bereit, an der oben genannten Studie freiwillig teilzunehmen.

Ein Exemplar der Patienteninformation sowie eine Kopie/Zweitschrift meiner Einwilligungserklärung wurden mir ausgehändigt.

____
Name der Patientin/des Patienten in Druckbuchstaben

Datum (eigenhändig) | Unterschrift der Patientin/des Patienten

Ich habe das Aufklärungsgespräch geführt und die Einwilligung des Patienten eingeholt.

Name des aufklärenden Therapeuten/der Therapeutin in Druckbuchstaben

Datum (eigenhändig) | Unterschrift des aufklärenden Therapeuten/der Therapeutin

Appendix G – Abbreviations

ACL	anterior cruciate ligament
ADL	activities of daily living
AROM	active range of motion
EMG	electromyogram
MCL	medial collateral ligament
MVIC	maximum voluntary isometric contraction
OA	osteoarthritis
PCL	posterior cruciate ligament
RMS	root mean square
sEMG	surface Electromyogram
STS	sit-to-stand
V	volt
VAS	visual analog scale
VM	vastus medialis muscle
VMO	vastus medialis obliquus
VL	vastus lateralis muscle