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THE RELIABILITY OF A NEW NORMALISATION METHOD FOR SURFACE EMG AMPLITUDE

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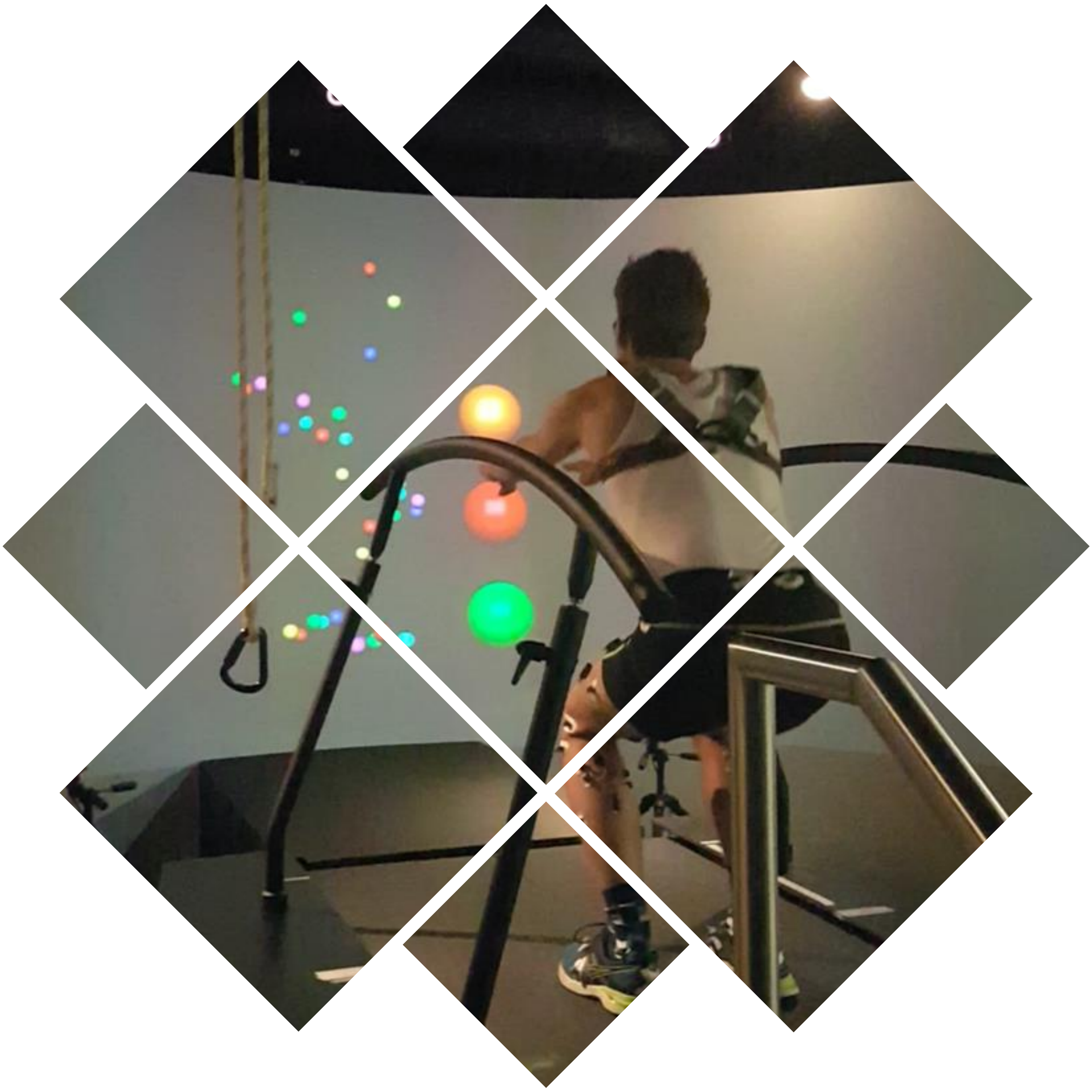

TESSA VAN ENTER & RUBEN DE GELDER

HEALTH TECHNOLOGY | HUMAN MOVEMENT TECHNOLOGY

The Hague University of Applied Sciences

The reliability of a new normalisation method for surface EMG amplitude

The within-session repeatability and reliability of a standardised normalisation value obtained with the surface EMG during a squat, ante- and retroflexion exercise.

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Preface

This thesis in front of you is made for the institution: Human and Technology, Human Movement Technology. The aim of this thesis was to find the within-session repeatability and reliability of a standardised normalisation value obtained with the surface EMG during a squat, ante- and retroflexion exercise

This study is conducted in a period of 14 weeks (from March 4th untill June 14th), for the Amsterdam UMC at the rehabilitation department located at the VUMC. During our study we were given the opportunity to see and participate in the studies which are executed at the Amsterdam UMC. To come to this report that lies before you we have enjoyed the help and support of some excellent dedicated professionals in the field of work:

At first we would like to thank our supervisor from the Amsterdam UMC, Marjolein Booij for the given opportunity to do this study at the Amsterdam UMC. We were grateful for the given possibilities by Marjolein Booij to use the equipment at the VRlab, get insights in other studies at the Amsterdam UMC and the ability to choose our own direction during the process.

Secondly we want to thank Jorine Koopman and Caroline Doorenbosch for their guidance during the making of our plan of approach. Thanks to their guidance we obtained a good preparation for our study, which facilitated an efficient start of our study.

Further we would like to thank our first and second assessor: Rochus van der Doef and Daniel van Leeuwen for their guidance and feedback during the entire process. They gave us new insides in this study and answer all the questions we had during this study.

We have worked hard to gain this end result, were we compared three different sEMG normalisation methods for five different muscles. This research will be useful in the rehabilitation by validating the reliability of three new sEMG normalisation methods when the MVIC is not possible.

We hope you find this report enjoyable and informative.

Tessa van Enter en Ruben de Gelder

12-06-2019

Content

Nederlandse samenvatting

Door de limitaties van de maximale vrijwillige isometrische contractie (MVIC) binnen de revalidatie bij individuen met pijn en een verlaagde motivatie, verder verliest de MVIC betrouwbaarheid wanneer dynamische taken geanalyseerd worden. Daarom is er een alternatieve normalisatie methode nodig binnen de revalidatie. Het doel van deze studie is om de herhaalbaarheid en betrouwbaarheid van een nieuwe gestandaardiseerde normalisatie waarde te bepalen, verkregen met oppervlakte elektromyografie (oEMG) van de Vastus Medialis (VM), Rectus Femoris (RF), Vastus Lateralis (VL), Biceps Femoris (BF) en Semitendinosus (ST) gedurende een squat, ante- en retroflexie oefening binnen één meting. Hiervoor is er bij 31 proefpersonen oEMG gemeten gedurende twee testen (pre- en post-test). Deze testen bestonden elk uit drie herhalingen van de squat, ante- en retroflexie welke drie seconden aangehouden werden. Intraclass correlatie coëfficiënt liet de hoogste herhaalbaarheid bij de squat zien, van “uitmuntend” (VL, VM en BF; ICC>0.90) tot “goed” (RF en ST; ICC >0.88). Als de spieren apart bekeken worden laat de RF ook uitmuntende herhaalbaard zien in de anteflexie en de ST gedurende retroflexie. De squat had ook de beste intra-betrouwbaarheid ($_{intra}$CV%), variërend van “uitmuntend” (VL, VM, BF en ST; $_{intra}$CV% <11%) tot “goed” (RF; $_{intra}$CV% = 17.0). Alleen de anteflexie liet een betere betrouwbaarheid zien bij de RF en ST (7.6% en 9.1%). De squat wordt aangeraden als betrouwbare normalisatie methode voor de VL, RF, VM, BF en ST. Voor een nog betere betrouwbaarheid wordt aangeraden om anteflexie voor de RF te gebruiken en voor BF en ST retroflexie.

Symbols and abbreviations

%	Percentage
°	Degrees
AD converter	Analog to Digital converter
BF	Bicep Femoris
BMI	Body Mass Index
CAST	Calibrated anatomical systems technique
DC	Direct current
GRAIL	Gait Real-time Analysis Interactive Lab
Hz	Hertz
ICC	Intraclass correlation coefficient
$_{inter}CV\%$	Inter-assay coefficient of variation
$_{intra}CV\%$	Intra-assay coefficient of variation
kg	Kilograms
m	Meters
min	Minutes
mm	Millimetres
mV	Millivolt
MVIC	Maximal Voluntary isometric contraction
OA	Osteo Arthritis
RF	Rectus Femoris
s	Seconds
S or SD	Standard deviation
sEMG	Surface Electromyography
SENIAM	Surface EMG for non-invasive assessment of muscles
SPSS	Statistical Package for the Social Sciences
ST	Semitendinosus
VL	Vastus Lateralis
VM	Vastus Medialis
VR	Virtual Reality
$\bar{x}$	Mean value

The repeatability and reliability of a new normalisation method for surface electromyography amplitude.

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Article Info

Keywords: Electromyography; EMG; Normalisation; squat; anteflexion; retroflexion; repeatability; reliability; within-session

Abstract

It is needed to find an alternative normalization method in rehabilitation due to limitations of the maximal voluntary isometric contraction (MVIC) method by individuals with pain or low motivation and the MVIC lose reliability when dynamic tasks are analysed. Therefore this study evaluated the within-session repeatability and reliability of a standardized normalization value, obtained with surface electromyography (sEMG) during squat, ante- and retroflexion for the Vastus Medialis (VM), Rectus Femoris (RF), Vastus Lateralis (VL), Biceps Femoris (BF) and Semitendinosus (ST). sEMG was measured in 31 participants during two trials (pre-and post-test) existing of three repetitions of the squat, ante- and retroflexion which were hold for 3 seconds. Intraclass correlation coefficient showed the overall highest values in squat, yield from “excellent” (VL, VM and BF; ICC >0.90) to “good” (RF and ST; ICC >0.88). However when analyses were done per muscle RF showed ”excellent” repeatability in anteflexion (ICC=0.98) and ST in retroflexion (ICC = 0.97). Likewise intra-subject reliability ($_{intra}$CV%) showed the best overall reliably in squat varying from “excellent” (VL, VM, BF and ST; $_{intra}$CV% <11%) to “good” (RF; $_{intra}$CV% = 17.0). Only anteflexion was better for RF and ST both with “excellent” reliability (7.6% and 9.1%). Inter-subject reliability for all exercises ranged from 32,9% to 58,9% respectively. This study recommends the squat as a reliable normalisation for the VL, RF, VM, BF and ST. However when an even more reliable method is desired, anteflexion for the RF and retroflexion for the BF and ST is recommended.

1. Introduction

Surface electromyography (sEMG) is a powerful non-invasive method to evaluate timing and muscle activation while performing several exercises, for example: walking[1], running[2], cycling[3] and rehabilitation exercises[4,5]. sEMG-electrodes are placed on the muscle and act as little microphones which display muscle activity in millivolts (mV)[6].

Though sEMG can easily be obtained, it is hard to see the true biological variation between two groups or individuals over time. The cause is found in variations of intrinsic and extrinsic factors affecting the amplitude of the raw sEMG signal[6–9]. The extrinsic factors comprise: the skin preparation; the distance between the sEMG-electrodes; the placement of the sEMG-electrodes on the muscle[10] and the skin temperature[11]. While intrinsic factors, which are even harder to control, vary due to the amount of tissue between the muscle and electrodes[12–15], the muscle fiber diameter, the muscle fiber type[16], the number of muscle fibers for each motor unit, fatigue[17], crosstalk[18], muscle fiber length and contraction velocity[19].

Since these intrinsic and extrinsic factors are hard to control the amplitude of the sEMG signal has to be normalised to a standardised reference value (sEMG normalisation)[8,9,20–24], as shown in equation 1.

$$\text{Normalised value}(\%) = \frac{\text{activity at certain circumstance (mV)}}{\text{reference value (mV)}} \times 100\% \quad [1]$$

In literature the importance of sEMG amplitude normalisation[8,25] has been acknowledged and can be achieved by making use of numerous methods. Nowadays the most commonly used sEMG normalisation method is the Maximal Voluntary Isometric Contraction (MVIC)[8,22,25–27] which is the golden standard and recommended by SENIAM[28].

However the MVIC has a few restrictions: First of all the MVIC assumes that the individual is able to provide a true maximal effort, although encouragement can be given the exerted force highly depends on the motivation of the individual, which may be affected by individuals who are unwilling, unable or can experience pain during a maximal effort, such as individuals who suffer from Osteo Arthritis (OA)[8,23,25,29–31].

Secondly it has been questioned whether the MVIC normalisation method is applicable when muscle activity during dynamic tasks are analysed due to the fact that the MVIC does not look at fluctuation of the joint angle, joint velocity[9] and muscle fibre movement with relation to the sEMG electrode on the skin during the MVIC and the analysed task[32,33].

Restrictions mentioned above raise questions about the effectiveness of the MVIC as a sEMG normalisation method. There have been many studies investigating alternative normalisation methods[34]. Including; submaximal isometric contractions[30,35], peak sEMG[1,35,36] and mean sEMG[1,31,36,37] during different procedures such as; cycling[32,38], walking[1], single leg stance[39], isokinetic squat jumps and 20m sprint[20]. An advantage of a dynamic normalisation method is that it provides a better representation than the isolated MVIC of the coordinated muscle activity during a functional task[1,39]. However for the methods described above; good balance is needed (single leg stance) or a high demand from the muscles is required (20m sprint and isokinetic squat jumps), this requires motivation and are therefore similarly limited as the MVIC method. Additionally these dynamic normalisation methods are time demanding to perform and hard to standardise within subjects, which makes these methods not applicable in rehabilitation.

Therefore a new low demanding, easy to perform and standardised, sEMG normalisation method is needed. The squat, ante- and retroflexion of the hip joint, could fulfill these requirements, as these tasks are frequently used in rehabilitation. To estimate if the squat, ante- and retroflexion are suitable movements for sEMG normalisation the reliability of the obtained sEMG signal in relation to the signals amplitude should be assessed according to Burden and Bartlett[21]. Likewise Ball and Scurr[20] showed that when an unreliable sEMG signal is used as a standardised normalisation reference value, it results in an even poorer reliability than using un-normalised sEMG during a dynamic test. Similar, Albertus-Kajee, et al[32] recommend that the following criteria should be fulfilled for the determination of an appropriate normalisation method:

Repeatability

Appropriate normalisation methods should be highly repeatable. A high repeatability ensures reliable results with a low variation when the same group of individuals is tested repeatedly over time which is important when testing or comparing a group of individuals pre- and post-intervention[7,32,40]. Intraclass correlation coefficient (ICC) is the most commonly used statistic test to indicate the repeatability of the obtained standardised reverence values[31,41–43]. An ICC close to one represents a small subject variance relative to between-subject variance[44]. The 95% confidence intervals, of the ICC, indicates in what range the ICC will be in when a new group of participants is measured[44]. Whereas the inter-subject coefficient of variance ($_{inter}$CV%) an extent of the ICC, indicates the consistency of the values within one measure between-subjects[45], which displays the variation between the subjects in relation to the total mean[22].

Reliability

Reliability ensures stability and consistency of measurements over time, which is free from errors. Therefore differences in the sEMG signal between measurements can be assigned to the intervention instead of the measurement errors[46]. The intra-subject coefficient of variance $_{intra}$CV% is a good indicator for “absolute” reliability as it is not affected by sample size or amplitude which makes it valid to extrapolate to future measurements[44]. The $_{intra}$CV% indicates the within-subject variance of one subject over multiple tests[40], where a low $_{intra}$CV% indicates a great reliability, consistency and less discordance over multiple tests[22].

Currently the repeatability and reliability of the ante- and retroflexion of the hip normalisation methods are unknown

Previous studies has found a higher repeatability and reliability during the squat method compared to the MVIC[7]. However in this study squats were performed with additional weights, which makes them not applicable in rehabilitation due to the high demand from the muscles. Similar results are expected from the unloaded squat, especially when additional (“external”) direct feedback is given on the joint angles. Likewise a high repeatability and reliability of the ante- and retroflexion is expected, as they are standardised, low demanding, and easily performed exercises.

Therefore the purpose of this study is to examine and evaluate the within-session repeatability and reliability of the standardised normalisation value obtained with the sEMG during a squat, ante- and retroflexion movement of the hip-join

2. Method

2.1 Participants

Thirty-one participants which were divided into two groups; *group 1:* 14 healthy young adults (7 male. age; 23.3 ± 1.36 years; mass: 72.5 ± 9.7 kg; height: 1.77 ± 0.10 m). *group 2:* 17 healthy elderly (10 male; age: 67.6 ± 4.1 years; mass: 76.2 ± 13.3 kg; height: 1.73 ± 0.1 m) were recruited to participate in the study, after signing an inform consent in accordance with the medical ethic commission of the VUmc. The separation in age was made to be able to compare results between the young and elderly. All participants were healthy, had a BMI below 35[13–15], no history with a neurological disorder, surgery or current injuries or pain of the lower extremities prior to data collection. All measurements have been performed on the GRAIL, Gait Real-Time Analysis Interactive Lab (ForceLink, Amsterdam, The Netherlands), situated in the VR-laboratory at the VU medical center at the rehabilitation department.

Fig 1, Placement of the light reflective markers and sEMG electrodes.

2.2 Participant preparation

Prior to data collection Ag/AgCl bipolar preamplified/ active sEMG electrodes (Interelectrode distance: 20mm; gain = 1V/mV; input impedance > 220 Ω); bandwith: 10-500Hz; diameter: 24mm; 16 bits AD-converter(ZeroWire; Aurion. Milano. Italy) were placed on the muscle belies of the Vastus Medialis (VM), Rectus Femoris (RF), Vastus Lateralis (VL), Biceps Femoris (BF) and Semitendinosus (ST). Following the location and placement recommendations of SENIAM (Surface EMG for non-invasive Assessment of Muscles)[47]. Prior to placement the skin was cleaned with an alcoholic swap and shaved. During the experiment sEMG electrodes were not replaced.

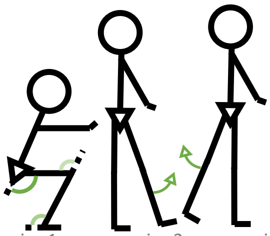

Fig 2, The three executed exercises in the pre- and post-test; 1) squat, 2)anteflexion and 3) retroflexion with angle definition indicated with coloured bows.

Then the participants were equipped with 42 light reflective markers, according to the "CAST" model[15,48] to calculate hip, knee and ankle kinematics and the Human Body Model[49] which enables the direct feedback on the joint angles during the squat using D-flow(figure 1)[50]. Participants received feedback by projecting three balls on the screen, each ball represented one joint angle (hip, knee and ankle; figure 3). When reaching the correct angle (hip between: 90°/110°; knee between: 82°/96°; ankle between 115°/126°), almost correct angle (hip between: 85°/90° and 110°/135°; knee between: 80°/82° and 96°/98°; ankle between 107°/115° and 126°/130°) and incorrect angles the balls turned green, orange and red respectively[51–53]. These angles were chosen by analysing multiple squats and determining the achievable angles from two individuals. Markers were tracked using a 10 camera optoelectronic movement recording system with an accuracy of <0.5mm (Vicon, Oxford, UK).

2.3 Experimental procedure

After a standardised warmup to minimalize influences of skin temperature differences[11,54,55] participants were asked to perform three exercises before (pretest) and after (posttest) a short walk exercise ±20 min on a single day (figure 2). The short walk exercise was used in another study. No encouragement and standardised instructions were given. Each exercise was performed three times, if needed a resting period between exercises was permitted.

For <u>exercise 1</u> participants were asked to perform a squat, during performance direct feedback was given on the right leg using D-flow (figure 3)[50]. Participants were asked to keep heels parallel to the treadmill, shoulder width apart, and arms pointing straight forwards. <u>Exercise 2</u> required the participant to lift their leg in anteflexion as high as possible until compensation in the knee or pelvis occurred. Here participants were asked to look forward, keep heels parallel to the treadmill, shoulder width apart and hands supported on the handlebars for balance purposes. Exercise 3 was similar to exercise 2 only this time the participant was asked to lift their leg in retroflexion. Each position was held for three seconds.

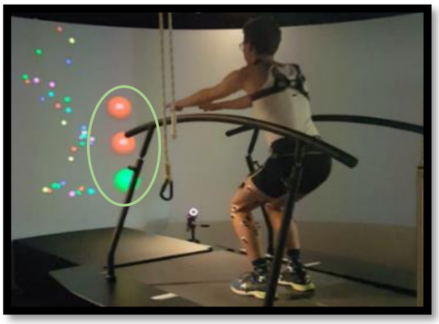

Fig 3, exercise 1 (the squat), with direct feedback given by three balls on the screen indicated with a circle.

2.4 Data sampling and reduction

sEMG and kinematic data were sampled at 1000 and 100 Hz respectively. The raw data was then processed in Bodymech[56,57]; were sEMG data was corrected for motion artefacts[58] and DC offsets[59] using a 20 Hz high pass filter (2nd order; Butterworth; zero phase lag). After rectification the sEMG data was smoothed. using a 6 Hz low pass filter (2nd order; Butterworth; zero phase lag)[25]. While the kinematic data was low pass filtered using a 6 Hz lowpass filter (2nd order; Butterworth; zero phase lag). Sagittal joint angles were calculated using Euler angles[56]. Then filtered data was loaded into Matlab (MATLAB2018a, The MathWorks, Inc., Natick, Massachusetts, United States) where mean joint angles and sEMG amplitude were calculated for each exercise over the two seconds where the angles of the right hip, knee and ankle were the most stable.

Finally mean joint angle and mean sEMG amplitude for each muscle across the three trials of each exercise were calculated.

2.5 Statistical analyses

All analyses were performed using the Statistical Package for the Social Sciences (IBM Corp. Released 2011. IBM SPSS Statistics for Windows. Version 20.0. Armonk. NY: IBM Corp.) and the level of significance was set at α=0.05.

Repeatability was tested using the intraclass correlation coefficient (ICC (Two-way mixed absolute agreement. average measure)) and the 95% confidence intervals[60]. The ICC score was defined as follows: values less than 0.50 indicate a "poor" repeatability, values between 0.50 and 0.75 indicate "moderate" repeatability, values between 0.75 and 0.90 indicate "good" repeatability and values above 0.90 indicate "excellent" repeatbility[60].

The CV% is calculated by dividing the standard deviation by the mean and multiplying the result by a 100 (Equation 2)[22]. The $_{inter}$CV% is calculated with the standard deviation and mean of all the tests, whereas the $_{intra}$CV% is calculated with the standard deviation and mean of the participant pre- and post-test.

$$CV\% = (s_{\chi}/\bar{x}) * 100 \qquad [2]$$

An $_{intra}$CV% smaller than 12% is marked as "excellent", between 12% and 20% is marked as "good" and more than 20% as "poor" reliability[32,61]. In contrast with the $_{intra}$CV%, the $_{inter}$CV% its reliability cannot be defined with classes. A higher $_{inter}$CV% than $_{intra}$CV% will be expected as the $_{inter}$CV% describes the entire group variance and the $_{intra}$CV% the participant variance[7,20,39].

3. Results

Mean and standard deviation for the joint angles of the hip, knee and ankle in the sagittal plane are shown in table 1.

Mean sEMG amplitude across all trials are detailed in figure 4 for each method. The VL and VM showed the highest activation in the squat, the RF in anteflexion and both hamstrings (BF and ST) in retroflexion.

Table 1
Mean ± SD of hip, knee and ankle (flexion)angle of the right leg from the pre- and post-squat, ante- and retroflexion exercises.

Joint	Squat*	Anteflexion	Retroflexion
Hip	83.2 ± 9.6	56.7 ± 8.0	-1.7 ± 5.7
Knee	84.7 ± 5.6	7.9 ± 7.7	19.3 ± 6.6
Ankle	114.3 ± 3.7	87.1 ± 11.3	78.0 ± 15.3

*Direct feedback was given

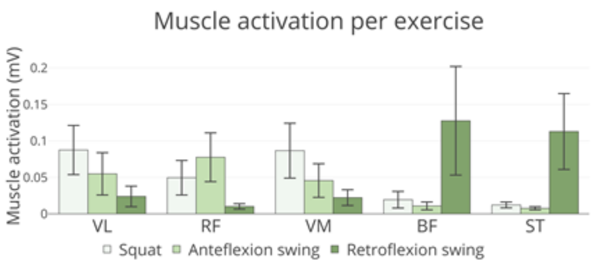

Fig 4, Mean and SD sEMG values for the VL, RF, VM, BF and ST from the pre-and post -squat, ante- and retroflexion exercises.

3.1 Repeatability

Overall the squat method showed the highest ICC values (table 2), with VL, VM and BF yield "excellent" and the lowest ICC being a "good" repeatability for RF and ST (ICC = 0.88 (0.74-0.95/0.94)). Only anteflexion showed a higher ICC for the RF (ICC = 0.98 (0.94-0.99)) representing a "excellent" repeatability and retroflexion showed a higher "excellent" ICC value for the ST (ICC = 0.97 (0.92-0.99)). None "poor" repeatability was found in the squat, ante- and retroflexion exercise.

3.2 Inter-subject reliability

The squat method showed the lowest overall $_{inter}$CV% varying from 32.9% to 58,9% as illustrated in table 3. Followed by the anteflexion with $_{inter}$CV% values varying from 28.9% to 52.9%, whereas the retroflexion showed the highest $_{inter}$CV% values varying from 36.9% to 59.0%.

3.3 Intra-subject reliability

The normalisation method with the overall lowest $_{intra}$CV% was the squat especially for the VL, VM and BF, with $_{intra}$CV% values ranging from 6.7% to 17%, as shown in table 4. Only anteflexion showed lower $_{intra}$CV% values for the RF(7.6%) and ST(12.4%). Retroflexion showed the overall highest $_{intra}$CV% ranging from 10.1% to 22.1%.

Table 2
Summary of the relative reliability (intraclass correlation coefficient (ICC)) for the VL, RF, VM, BF and ST from the pre- and post-squat, ante- and retroflexion exercises.

Muscle	Squat$	Anteflexion$	Retroflexion$
VL	**0.97 (0.92-0.99)**	0.83 (0.63-0.92)	0.78 (0.53-0.90)
RF	0.88 (0.74-0.95)	**0.98 (0.94-0.99)**	0.75 (0.46-0.89)
VM	**0.98 (0.95-0.99)**	0.83 (0.63-0.92)	0.77 (0.49-0.89)
BF	**0.99 (0.98-1.00)**	0.92 (0.81-0.96)	0.98 (0.94-0.99)
ST	0.88 (0.74-0.94)	0.88 (0.74-0.95)	**0.97 (0.92-0.99)**
Poor	Fair	Good	Excellent

* Classes: poor (<0.50), fair (0.5 - 0.75), good (0.75 - 0.90) or excellent (>0.9). Bolded numbers show the highest ICC for each muscle.
$*ICC* (95% Confidence intervals).

Table 3
Summary of muscle activations inter-participant variability (inter-participant coefficient of variation ($_{inter}$CV%)) for the VL, RF, VM, BF and ST from the pre- and post-squat, ante- and retroflexion exercises.

Muscle	Squat$	Anteflexion$	Retroflexion$
VL	**38.5**	52.9	59.0
RF	47.9	43.1	**36.9**
VM	**43.4**	50.5	48.5
BF	58.9	**49.6**	58.4
ST	32.9	**28.9**	46.1
Mean	**44.3**	45.0	49.8

* Bolded numbers show the lowest $_{inter}$CV% for each muscle.
$Mean $_{inter}$CV%

Table 4
Summary of muscle activations intra-participant variability (intra-participant coefficient of variation ($_{intra}$CV%) %) for the VL, RF, VM, BF and ST from the pre- and post- squat, ante- and retroflexion exercises.

Muscle	Squat$	Anteflexion$	Retroflexion$
VL	**8.7 ± 6.5**	14.4 ± 14.8	22.1 ± 17.2
RF	17.0 ± 15.7	**7.6 ± 7.2**	15.2 ± 14.6
VM	**7.8 ± 4.4**	19.3 ± 12.5	21.6 ± 20.8
BF	**6.7 ± 3.2**	12.4 ± 8.9	10.1 ± 9.6
ST	10.4 ± 7.6	**9.1 ± 8.7**	10.5 ± 6.7
	Poor	Good	Excellent

* Classes: poor (>20%), good (12%-20%) and excellent (<12%). Bolded numbers show the lowest $_{intra}$CV% for each muscle.
$ Mean ± standard deviation

4. Discussion

The aim of this study was to examine and evaluate the within-session repeatability and reliability of a standardised normalisation value obtained with the sEMG during a squat, ante- and retroflexion exercise.

4.1 Participant positioning

As stated by DeLuca[9] changes in muscle length gave large variation in the amplitude of the sEMG signal, therefore hip, knee and ankle joint angles were analysed to ensure a consistent functional demand from the muscles is asked to all participants. To decrease the influence of muscle length direct feedback was given[62,63], unfortunately this was only done for the squat. Because of this the squat possibly showed the lowest standard deviation for joint angles ranging from 3.7° to 9.6°, whereas retroflexion showed the highest variability with standard deviations ranging from 5.7° to 15.3°. According to Azegami et al[64] less than 5% sEMG amplitude difference was detected from the MVIC in the RF and BF, when knee angles vary from 75° to 90° during the squat. Yamane et al[65] stated that sEMG amplitude only differs by 1% of the MVIC in RF during anteflexion with hip joint angles between 45° to 60°. Similar results were found for the ST and BF during retroflexion between 0° to 30°[66]. The low variation in joint angle indicates that differences in sEMG amplitude can be addressed to true biological variation in muscle activation of the participants instead of variation in muscle length.

4.2 Repeatability

Normalisation methods should have high repeatability, which ensures similar results when testing a group repeatedly over time[24]. At first sight the squat method showed the overall highest repeatability with ICC values varying from "excellent" (VL, VM and BF; ICC >0.90) to "good" (RF and ST; ICC = 0.88). However the anteflexion method is preferable when only the RF is analysed which yield an "excellent" (ICC = 0.98) repeatability, the same is true for the ST with "excellent" repeatability (ICC = 0.97) in retroflexion. These findings suggest that single joint exercises give higher ICC values for biarticulair muscles than multiple joint exercises (squat). With the ante- and retroflexion only the hip joint has a big impact on the total joint variance, this was also observed by Norcross et al[39] , during the performance of a single leg stance.

Goodwin et al[67] mentioned that when comparing the repeatability and reliability of activities of daily life (walking[1], running[2] and cycling[3,24]) with newly learned activities caution should be taken, therefore only similar studies comparing within-day reliability can be used to when comparing results in this study. Previous research from Norcross et al[39] and Knutsen at al[22] found that MVIC showed higher ICC values than sub-maximal dynamic normalisation methods. This study showed similar results, where high muscle activation resulted in high ICC values. The single leg stance[39] as normalisation method showed slightly lower ICC values: 0.94, 0.90 and 0.80 for the RF, VL and BF respectively then this study. This might be attributed to the lower demand from the muscles, which are only activated to keep balance during the single leg stance. Likewise multiple body positions can be held for the performance of a single leg stance, which makes this method less standardised than ante- and retroflexion. The squat, ante- and retroflexion were designed as a substitute of the MVIC, therefore results were compared with ICC values obtained by Norcross et al[39] from healthy participants during the MVIC. Results found in this study were similar to the MVIC method. with ICC values of: 0.95, 0.98 and 0.99 for the RF, VL, and BF.

4.3 Inter-subject reliability

The $_{inter}$CV% was used to analyse the consistency between-participants over one measure[45]. $_{inter}$CV% can be used to analyse the relation of variation between-participants to the total mean[22]. A low $_{inter}$CV% shows homogeneity of the analysed group, which is desirable when obtaining a standardised normalisation value which enables between-participant comparisons. However when the $_{inter}$CV% is too low (close to zero), the groups true biological variance should be questioned[22].

The squat showed the overall best inter-subject reliability with $_{inter}$CV% from 32.9% to 58.9%. However the $_{inter}$CV% of the BF and ST values were lower in anteflexion (49.6% and 28.9%) and the RF in retroflexion (36.9%). These results conflict with results found by Norcoss et al[39] for the single leg stance which showed an $_{inter}$CV% of 136.9%, 165.5% and 135.1% for the RF, VL and BF respectively. This study showed lower $_{inter}$CV%, which means a higher group homogeneity is created while true biological variance is still obtained. This result can be explained by the low muscle demand asked during the single leg stance, which gives a lower mean value compared to the standard deviation and resulted in a high $_{inter}$CV% value[34,39]. High $_{inter}$CV% values were found by Norcross et al[39] during the MVIC (RF = 90.0%, VL = 92.1% and BF=118.0%). These results agree with DeLuca[9] who has shown that muscle activation above 80% of the MVIC becomes unstable and therefore becomes less reliable[9,29].

4.5 Intra-subject reliability

$_{intra}$CV% gives an indication of the reliability which ensures the stability and consistency of the measurement of the same participant over time. The squat showed the lowest overall $_{intra}$CV%. indicating an “excellent” reliability ranging from 6.7% to 10.4% for all muscles, except the RF which showed a “good” reliability (17.0%). Only the anteflexion has lower values for the RF and ST with “excellent” reliability (7.6% and 9.1%). These results suggest that the overall standardised normalisation value obtained during the squat exercise is the most reliable. These findings were in accordance with Burden[34] and Norcoss et al[39] suggestions that a higher sEMG amplitude results in lower $_{inta}$CV%. The same results were seen in the VL and VM during the squat and the RF in anteflexion which showed the lowest $_{intra}$CV% in exercises where the mean sEMG amplitude were the highest. Likewise ST and BF showed the highest sEMG amplitude during retroflexion however not the best $_{intra}$CV% but still an “excellent” reliability. These results do not agree with findings of Norcoss et al[39] during the single leg stance where the RF, VL and BF showed “poor” reliability, 34.4%, 54.6% and 59.4%, respectively. These high $_{intra}$CV% could have the same cause as the $_{inter}$CV% as described before. The $_{intra}$CV% showed higher values for the RF and VL and BF(20.3%, 14.5% and 9.0%) during the MVIC as shown by Norcross et al[39].

4.6 Limitations

There are several limitations in this study that should be addressed.

First of all it is not known what level of sub-maximal activation was needed during the exercises, as the bodyweight has a big impact on the required demand during the squat, ante- and retroflexion exercise[29,39], which removes true biological variation between-subjects[29].

Secondly the effect of extrinsic factors[6–9] like, crosstalk[18] and temperature can never fully be prevented[39], but were minimized by a standardised warm-up[11,54,55], electrode placement and skin preparation. All test were executed by the same researcher and sEMG activity was visually checked on the monitor. The last limitation is that the exercises were not executed randomly which could have resulted in fatigue. However this study was executed with healthy participants, where three unloaded squats should be low demanding, no participant indicated fatigue[9].

4.7 Further research

Further research is needed for a better understanding of the squat, ante- and retroflexion as normalisation method, the following research recommendations were found during this study.

First of all the fundamental reason of sEMG normalisation is to enable comparisons between-tests and between-participants. However in this study only the within-session repeatability and reliability is assessed. A following research could address the between-day repeatability and reliability of the squat, ante- and retroflexion exercises, as the participant performance will change over time[42].

Secondly the effect of feedback on the repeatability and reliability of the normalisation method is yet unknown. Al-Amriet al[62] showed that feedback during the squat improves consistency of the squat movement. In this study no feedback was given during the ante- and retroflexion, the maximal hip angle during ante- and retroflexion varies between-participants[68]. However direct feedback can be given on the knee and hip angle to ensure no compensation in knee and lower back is made during the ante- and retroflexion exercises[68], however the ante- and retroflexion already showed excellent repeatability and reliability without feedback. In this study only the right leg is analysed[69], so the effect of the dominant leg or injured leg on the repeatability and reliability of the movement is unknown. Furthermore one participant was eliminated from this study because of great loss in hip marker visibility due to the fact that the belly was covering the markers in the deep squat position. This problem can be prevented by applying extra cluster markers on the Crista Iliaca.

Additionally Dwyer et al[70] and Fukagawa et al[71] suggested that for a better representation of the test population, comparisons should be made between sex and age of the sEMG and kinetics values. In this study no important difference were found in the $_{intra}$CV% between sex and age, however not all elderly were able to reach the prescribed angles during the squat, because of reduced flexibility and strength of the elderly[72]. As mentioned before, differences in joint angles have a small effect on the sEMG obtained during the normalisation tasks. When the participants consist of just the elderly it is advised to use a bigger knee angle during the squat, due to the obvious physical limitations of the participants.

Lastly, future research should also involve repeatability and reliability analyses in the patient group with lower limb injuries. In research from Knutsen et al[22] mean dynamic contraction were compared (within-day) between healthy individuals and ACL individuals in a balance task for the Gastrocnemius. Here ICC were 0.66 and 0.39; $_{intra}$CV% 26.5 and 29.8; and $_{inter}$CV% 37.2 and 38.2, respectively. These results show that injuries decrease repeatability and reliability, however it is expected that the repeatability and reliability of the MVIC will reduce even more than dynamic methods, as described and explained in the introduction. The squat is the most repeatable and reliable normalisation method for all muscles, if there is limited time to perform the normalisation tasks and direct feedback can be given. However when it is not possible to provide direct feedback the ante- and retroflexion exercises are preferred, as the repeatability and reliability of the squat without direct feedback is unknown.

5. Conclusion

This study tested the within-session repeatability and reliability of a standardised normalisation value obtained with the surface EMG during a squat, ante- and retroflexion exercise. Results of this study recommended the squat as a reliable normalisation when the MVIC is not preferred for the VL, RF, VM, BF and ST. For an even more optimal method the anteflexion should be used for the RF and retroflexion for the BF and ST. The statements above are only valid when sEMG data is obtained and processed as in this study.

6. Acknowledgements

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8. Attachments

Attachment 1: Project plan

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Studievoortgang
Behaalde studiepunten in de modules 9 t/m 11 36
Minor:Pre-master,Bewegingswetenschappen
afgerond (ja)
Stage 2 afgerond (31 januari): ECBT
Totaal aantal behaalde vrije STPs: 36 punten
Openstaande toetsen (+ module): Stage II

Naam: Ruben de Gelder
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Studievoortgang
Behaalde studiepunten in de modules 9 t/m 11: 36
Minor: Pre-master, Bewegingswetenschappen+ Orthopedie afgerond (ja)
Stage 2 afgerond (28 Febr): Basalt
Totaal aantal behaalde vrije STPs: 60 punten
Openstaande toetsen (+ module): Stage II

1. Introduction

Title: : *the squat movement as reliable EMG-normalisation method.*
Datum: 22-2-2019
Professional role: researcher/analyst
Extern project: yes
Contact: AUMC; Marjolein Booij,
Email: m.booij@vumc.nl

This thesis will take place at Amsterdam University Medical Center (Amsterdam UMC) in the gait-center. The Amsterdam UMC does a lot of research. One of their topics is to look into gait analyses. When complicated problems during walking are detected, which cannot be solved with the normal methods, the doctor can send the patient to the gait center to execute the gait analysis. During a gait analysis the ground reaction-force, joint kinematics and muscle activity are recorded. The AUMC has the possibility to make use of an overgroundlab or the GRAIL (gait real-time analyses interactive lab). The GRAIL is a treadmill which consists of two splitbelts with two forceplates underneath to calculate the ground reaction force for each individual leg. To measure the 3D-joint kinematics *the AUMC uses the VICON system* (Vicon, Oxford, UK) *with reflective markers on the body.*

Osteoarthritis (OA) can appear on every age but when getting older the number in which OA occurs increases. From radiologicals- epidiologicals points of view, 80% of the population older than 70 suffers from OA[73]. OA is the most common form of joint disease, and the knee is one of the most commonly affected joints. When having OA the cartilage becomes rough and thin, the bone underneath the cartilage reacts by growing thicker and broader. All the tissues within the joint become more active , the body is trying to repair the damage. With OA the repair does not work as well and your knee becomes damaged[74]. When the OA gets worse a patient will mainly experience pain and starting stiffness. When experiencing pain it is most likely that a patient will avoid painful movements such as walking.

Therefore it is interesting to research the difference in walking between people with and without knee OA. The AUMC has started a research that investigates the differences during walking 1) between people with OA and people without OA and 2) the difference within the OA group to search for progress after surgery.

There are multiple aspects to analyse during walking, for instance the differences in angle and angle velocity or ground-reaction force. Another way is by muscle activation. This is measured with electromyography (EMG), which will be used in this research. EMG is a tool that is used to measure the action potentials of motor units in the muscle expressed in microvolts (µV), in other words muscle activation[6]. To measure EMG, EMG-electrodes are placed on the muscle 'The EMG electrodes are like little microphones which listen to muscle activation'[6].

When it is desirable to compare two groups or individuals over time it is important to minimize variation in the EMG-signal that is caused by intrinsic and extrinsic factors[6,7]. The extrinsic factors are caused during the experiment for example: the skin preparation, the distance between the EMG-electrodes, the placement of the EMG-electrodes on the muscle and the temperature[8].

Intrinsic factors are harder to control than extrinsic factors. Intrinsic factors are: the amount of tissue between the muscle and electrodes, the muscle fiber diameter, the muscle fiber type, the number of muscle-fibers for each motor unit and the muscle fiber length[8].

These intrinsic and extrinsic factors are not controllable and change within-individuals over time, between individuals or by replacement of the EMG-electrodes. Because these variation are hard to control it is difficult to say something useful about the amplitude of the EMG when comparing EMG between two or more different measurements of an individual, or between individuals over time. For this reason it is not possible to compare the muscle activation of people with knee OA and people without OA and within the knee OA group. To overcome these problems EMG normalisation is needed[8]. EMG normalisation is a process that rescales the amplitude of the signal, it rescales the measured potential in µV and represses it as a percentage of the muscle activation at a standardised procedure[8,20].

Nowadays the commonly used standardised procedure is the maximal voluntary contraction (MVC), this is also the golden standard[8,22]. During the MVC the joint on which the muscle that needs to be normalised has a function over is fixated at a prescribed angle. These prescribed angles are close to the joint angle during the task that needs to be normalised. When the joint is fixated the person is asked to give a maximal isometric contraction. The maximum measured potential is used as the reference value for normalisation. The EMG-data is rescaled with this reference value using equation [1]:

$$\text{Normalised value}(\%) = \frac{\text{reference value (mV)}}{\text{activity at certain circumstance (mV)}} \times 100\% \qquad [1]$$

The MVC has a few limitations: Patients with spasms (cerebral palsy) cannot control their muscle selectively and therefore they cannot keep their joint at the prescribed angles[8,29]. Also people with pain (OA) cannot deliverer the maximal voluntary contraction because this can cause too much pain which reduces their motivation to give a maximal contraction[25,29]. Because of these factors a maximal voluntary contrarian from an prescribed angle will lose reliability. Therefore another normalisation method is needed to compare people with knee OA with people without knee OA and to find progress after surgery.

For this reason new tests are executed by the AUMC to find another normalisation method for people with and without OA. During these tests, reflective markers were placed according to the CAST VICON[75] method (calibrated anatomical systems technique), and electrodes were placed on the two big muscle groups around the knee joint. Four movements were executed during the test: 1) the squat, 2) anteflexion, 3) retro flexion and 4) balancing on one leg with a resting time of thirty minutes between the movements. After a thirty minute break wherein multiple cooling down walks were performed. This study will only focus on the squat movement because this is the only movement that uses extension and flexion around the knee joint which is the researched joint. The squat was performed three times before and three times after the 30 minutes of rest were multiple small walks were performed on the GRAIL *(figure 1).* When the subjects performed the squat they received direct feedback if the squat was performed correctly. When subjects performed the squat correctly the subjects saw three balls turning green, one green ball for one second. So in total three seconds and three green balls for every squat. The squat was performed correctly if the angle of the ankle was between 115°. and 130°., the knee between 82°. and 96°. and the hip between 90°. and 110°. The EMG-data from the squat movement will be used to determine the reference value. For now these tests are only done with a group of people without OA, therefore only the group without OA will be included in this research. Following *Dobsom et al*[76] the group with knee OA will be able to execute the squat test without problem, here the sit-to-stand movement is recommended as a performance based test which is comparable to the squat movement.

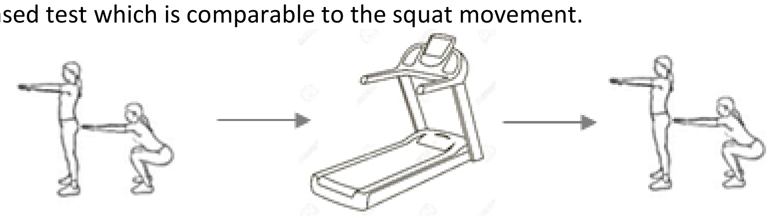


Figure 1, subjects executed three squats, walked on the GRAIL and performed another three squats.

Specific questioning

The research question for this study is: *Is the squat movement a reliable EMG-normalisation method?*

To answer the research question the following sub questions will be answered:

- What is the *intra* subject-reliability of the *kinematics* during the squat movement?
- What is the *inter* subject-reliability of the *kinematics* during the squat movement?
- What is the *intra* subject-reliability of the *EMG normalisation reference value* obtained during the squat?
- What is the *inter* subject-reliability of the *EMG normalisation reference value* obtained during the squat?
- Does it matter if the normalisation method is performed before or after the gait analyses?

The expected results are shown below and substantiated with already performed literature:

- The squat provides acceptable EMG reliability for all muscles and is performed with a repeatedly angle and angle velocity. Following *Knudson et al*[22] the squat is a good method to measure EMG around the knee joint. *Ball and Scurr*[20] found in their research that the jumping squat movement provides acceptable EMG reliability for within and between subjects, the squat is a comparable movement.
- When the walking no fatigue will occur, the squat movement before and after walking on the GRAIL will show comparable result. Following *Hong et al*[77] a kids muscles will fatigue after walking for 20 minutes with a backpack with 15% of their bodyweight. In this research healthy grownups walked for a shorter period of time without a backpack.

2. Method

This paper is part of a study focussed on knee OA. The first goal of this study is to find the difference in muscle activation between a group of healthy subjects and a group suffering from OA during the walking. And the second objective is to determine changes in muscle activation overtime, of an OA patient after surgery. EMG will then be measured before and after the surgery to determine if the muscles start working more efficient during walking.

Measurements

Forty subjects will be analysed, divided into two groups. *Group 1:* 19 healthy young adults (9 male, BMI 22.7±3.0, age 23±1.8) and *group 2:* 21 healthy elderly (13 male, BMI 25.6±3.2 age 67.2±4.9). The age criteria is 18 – 25 years for the younger group and 55 – 75 years for the older group. Exclusion criteria for all participants are BMI>35 for measurement reliability purposes, joint replacements or knee injuries, cognitive or vision impairment that will affect execution or understanding of the gait adaptation test and impairments that will affect the gait pattern and dependency on a walking aid. The VAS-scale pain in lower extremities over the last week should be below a score of 3 (with a score of 0 being no pain and 10 being worst pain).

As described in the introduction, the subjects has performed the squat test twice. Three squats (pretest) have been performed before the 30 minutes of rest with short walks on the GRAIL and three squats (posttest) have been performed after the rest period, this data will be analysed. The output variables of these test are shown in *table 1*:

Table 1, the output variables of the testing's

The muscle activation of the:	*The sagittal angles of the:*
M. Rectus Femoris (µV)	Ankle (α)
M. Rectus Femoris (µV)	Knee (α)
M. Femoris Lateralis (µV)	Hip (α)
M. Femoris Medialis (µV)	
M. Biceps Femoris (Longus, Brevis) (µV)	
M. Semimembranosus and M. Semitendinosus (µV)	

The first task of this this research is the preparing of the data (1). When the data is prepared, the squat movement will be analysed (2). Followed by the EMG normalisation (3). The reliability tests for the squat movement and the achieved EMG-normalisation reference values will be determined (4). For the reliability the intra(within subjects) and inter(between subjects) reliability of the obtained values of the pre- and post-test will be determined. The previous findings will then be integrated into a Matlab program (MATLAB2018a, The MathWorks, Inc., Natick, Massachusetts, United States) which automatically normalises EMG-data according to the most reliable method (5).

1. Data-processing

The data will be prepared with the Vicon pipelines. This makes it possible to analyse the data in MATLAB R2018B®.

The squat

Literature study

The database for this research literature are Google scholar, the HHS library and Pubmet. The following keywords will be used (single and combined)**:** Squat, OA**,** performance based test, sit-to-stand and comparison. References used in the found articles will also be investigated.

Best squat

Three squats are performed before and three after walking. The squat is performed correctly if the angle of the ankle is between 115° and 130°, the knee between 82° and 96° and the hip between 90°and 110° *(figure 2).* When these angles are achieved for three seconds, the squat is performed correctly and the subject see three red dots turning green (one for every angle). Only these three seconds in the deepest static squat position will be analysed and used for the statistical tests.

Figure 2, the hip-angle, the, knee-angle and ankle-angle.

The best executed squat from the before and after measurement needs to be acquired for comparison. The before and after measurement with the smallest angle displacement can then be compared. Per squat the three seconds in the prescribed angles will be analysed in the static position.

Statics for this step are explained in *step 4*.

2. EMG-normalisation

Literature study

The database for this research literature are Google scholar, the HHS library and Pubmet. The following keywords will be used (single and combined)**:** Normalisation, maximal voluntary contraction (MVC), inter individual, reliability, electromyography(EMG) , osteoarthritis (OA)**,** comparison. References used in the found articles will also be investigated for this research.

Processing data

The raw EMG-dataset is already rectified and filtered, the next step is to apply the normalisation methods on this processed EMG-data. Three dynamic normalisation methods will be applied: mean, peak and average on the three seconds of the best executed squats.

Statics for this step are explained in *step 4*.

3. Statistical test for the kinematics and EMG

To see if the obtained values of the kinematics and if the EMG are reliable, several statistic test can be used. First the normality of the dataset will be tested with the Krukal-Wallis test, the skewness and the kurtosis. Then the homogeneity with the Levene's test. If these values are smaller than 0.05 a non-parametric test will be executed otherwise a parametric test. Common statistical methods used to asses reliability includes Pearson's moment correlation (r) (parametric) and intra-class correlation coefficients (ICC)[20]. An ICC between 1 and 0.8 is marked as a ''good'' correlation, between 0.79 and 0.6 as a ''fair" correlation and everything below 0.6 as a "bad" correlation. To compare within subject (inter-class) measurements the typical error of measurement (TEM) or standard error of measurement (SEM),(CV%) will be used. A %CV smaller than 5% is marked as "excellent", between 5 and 12% is found as "good" and more than 16% is found as "poor" correlation.
When the data is not significantly divided the non-parametric variant: the Spearman test can be used. A disadvantage of the ICC method is that not all data points from the EMG-signal and the angles can be put in an ICC equation. Another statistical method that is not limited to this problem is the CMC (coefficient of multiple correlation), this method can compare the whole curve. During this thesis a literature study will be done to determine the best statistical method.

4. *Matlab script*

A Matlab-model will be created, which automatically normalises EMG-data according to the most reliable method. To do this the following steps will be done with the help of a Matlab-script:

a. Three seconds of the EMG-data(μV) of the best executed squat will be imported.
b. The Matlab-script will calculate the normalisation value of this imported file automatically.
c. The EMG- data(μV) that has to be normalised will be imported into the Matlab-file.
d. The Matlab-script will execute the most reliable normalisation method.
e. The Matlab-script will export the normalised data (%).

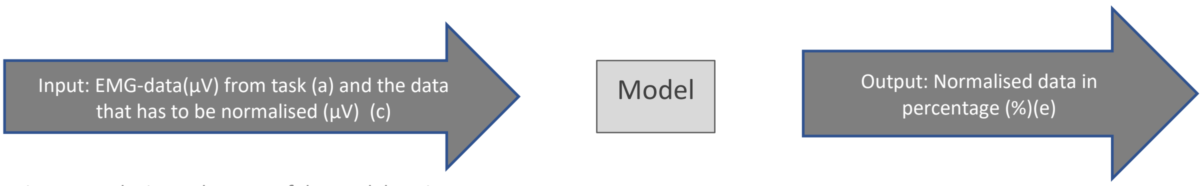


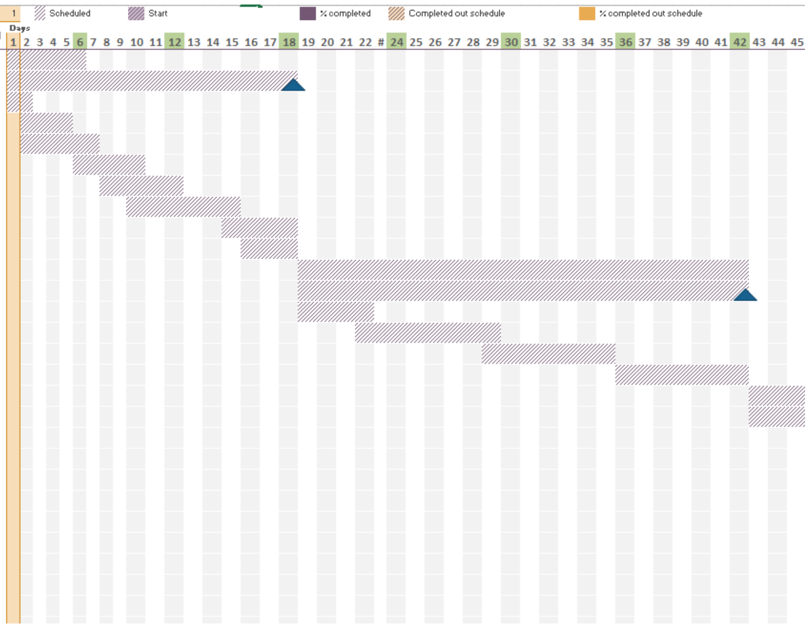
Diagram 1, the in- and-output of the Matlab-script

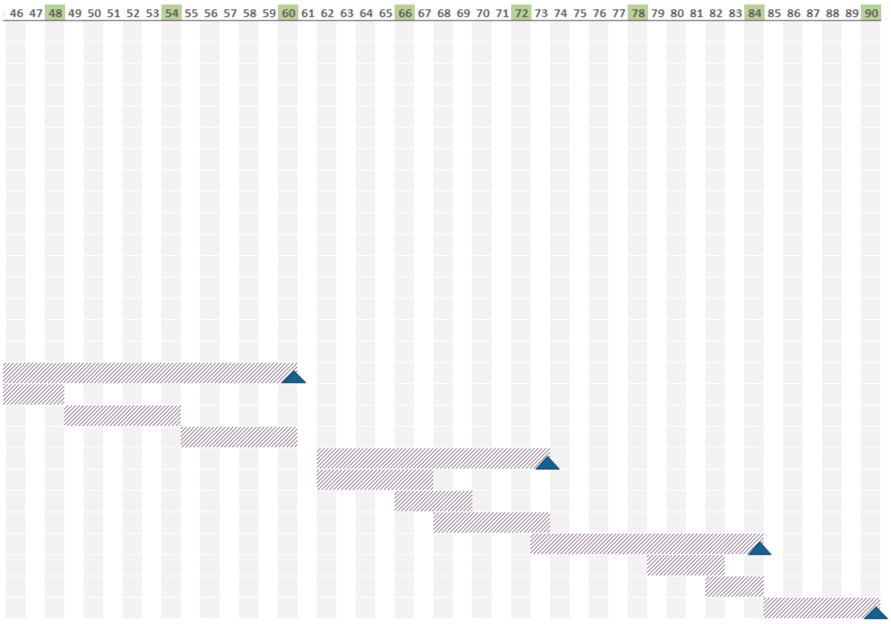
For this theses contact with the following organisation or persons are useful:

- *Human Kinetics Technology*: Koopman,J.
- *Human kinetics Technology*: Lagerberg, A
- *Human Kinetics Technology*: Doorenbosch, C.A.M.
- *Human Kinetics Technology:* Doef van der, R.
- *AUMC:* Marjolein Booij

Attachment 1.1, Time schedule

ACTIVITEIT	Start of planning	Duration (schedule	Start Activity	Actual time	% Completed
Arrange everything	1	6	0	0	0%
literature study	1	18	0	0	0%
Grill	1	2	0	0	0%
Analyse motion	2	4	0	0	0%
Compare movements	2	6	0	0	0%
EMG Noise	6	5	0	0	0%
EMG measurements	8	5	0	0	0%
EMG Normalisation	10	6	0	0	0%
Statistic	15	4	0	0	0%
Evaluation statistics	16	3	0	0	0%
Method	19	24	0	0	0%
Programming	19	24	0	0	0%
Import data	19	4	0	0	0%
Compare movements	22	8	0	0	0%
EMG Normalisation	29	7	0	0	0%
EMG Comparison	36	7	0	0	0%
Results	43	18	0	0	0%
Compare movements	43	6	0	0	0%
Compare EMG normalisation	49	6	0	0	0%
Pre- and posttest	55	6	0	0	0%
Statistic	62	12	0	0	0%
Pre – posttest reliability	62	6	0	0	0%
Validity	66	4	0	0	0%
Interclasscorrelation	68	6	0	0	0%
Documentation	73	12	0	0	0%
Discussion	79	4	0	0	0%
Conclussion	82	3	0	0	0%





Attachment 1.2, the EMG-normalisation method

Affecting influences following Sousa et al[29] are: inertial effects at the onset of the test, patient fatigue, patient posture, synergistic contribution, patient motivation, pain, neuro-muscle-skeletal dysfunctions and neurologic conditions

Table 2:The normalisation methods and their characteristics.

Isometric	**Explanation**	**Limitation**
Maximal voluntary contraction method (MVC)	$\frac{value}{Max(isometric)} * 100\%$	- Max not possible for older patients or patients with symptoms. - Affecting influences - Poor reliability - Not dynamic
Submaximal voluntary method (SVM)	$\frac{value}{subMax} * 100\%$	- Inter-subject coefficient of variation increases - Value can be lower than the obtained - Affecting influences - Not dynamic
Reference voluntary contraction method	*Any change in EMG amplitude indicates a true increase or decrease in the neural drive.*	- Affecting influences - Not dynamic
Isokinetic	**Explanation**	**Limitation**
Maximal voluntary contraction method (MVC)	$\frac{value}{Max(isokinitic)} * 100\%$	- Less reliable than the other methods
Dynamic actions	**Explanation**	**Limitation**
Mean dynamic method	$\frac{value}{average(quiet, active)} * 100\%$	- Removes true biological variation within group - More susceptible to systems with low noise ration or represent baseline noise in movement - No indication of what he activity level means
Peak dynamic method	*Indicates at what periods during the activity the muscle is most active*	- Removes true biological variation within group - No indication of what he activity level means

Attechment 1.3, Personal learning goals:

Beroepsgerichte competenties Tessa:

1. **Communicatie**

Specifiek: leren: goed mondeling en schriftelijk uitdrukken met een heldere rapportage.
Meetbaar: met mijn mede afstudeerder overleggen en met mijn begeleiding.
Acceptabel: een beetje feedback is altijd nuttig maar de grote lijnen moet ik zelf kunnen.
Realistisch: ja als afgestudeerde bewegingstechnologie moet ik deze competentie goed bezitten
Tijdgebonden: om de 2 weken overleggen hoe het gaat en half juni (afstudeerdatum) moet ik deze competentie bezitten.
Evaluatie: De communicatie met de begeleiders ging goed. Echter ben ik soms nog te conflict vermijdend geweest jegens mijn medestudent. Ik houd er niet van om een conflict aan te gaan maar moet soms meer voor mezelf opkomen. Volgens mij is de wijze van samenwerking tussen Ruben en mij goed verbeterd. Ruben houdt meer rekening met mijn wensen en ik geef steeds beter aan wat ik vind.

2. **Management**

Specifiek: leren: zelfstandig plannen, organiseren, coördineren en evalueren , eigen netwerk opzetten, managen.
Meetbaar: wekelijks kijken of de planning die ik heb gehaald haalbaar was, reflecteren om de 2 weken op de andere punten met mijn mede-afstudeerder.
Acceptabel: ja
Realistisch: ja als afgestudeerde bewegingstechnologie moet ik deze competentie goed bezitten
Tijdgebonden: om de 2 weken overleggen hoe het gaat en half juni (afstudeerdatum) moet ik deze competentie bezitten.
Evaluatie: tussentijds zijn planningen gemaakt en hier hadden we ons ook goed aan gehouden. Tevens zijn de begeleiders goed betrokken bij deze planningen.

Persoonsgebonden competenties:

1. **Initiatief en aanpassingsvermogen:**

Specifiek: leren: sociaal en communicatief functioneren en mij niet opzij laten zetten.
Meetbaar: om de 2 weken feedback vragen
Acceptabel: ja
Realistisch: ja als afgestudeerde bewegingstechnologie moet ik deze competentie goed bezitten
Tijdgebonden: om de 2 weken overleggen hoe het gaat en half juni (afstudeerdatum) moet ik deze competentie bezitten.
Evaluatie: tijdens het afstuderen heb ik veel aanpassingsvermogen getoond, plannen zijn vaak veranderd (soms met enige tegenzin). Initiatief van Ruben en mij naar de begeleiders verliep erg goed en zonder problemen. Mijn medestudent en ik hadden soms vooraf beter kunnen overleggen voor meer duidelijkheid over onze verwachtingen. Stukken zijn vaak weer aangepast, beter overleg had veel tijd en ergernis kunnen besparen. Dit wil ik in het vervolg beter doen.

2. **Carrièreperspectief**

Specifiek: realistisch beeld schetsen van de beroepspraktijk en een goed carrière perspectief.
Meetbaar: door eerder een sportgerichte stage te hebben gedaan en nu richting de revalidatie te gaan heb ik een goed beeld bij beide richtingen zo kan in na mijn master: Humen Movement Science een goede richting voor mij uitkiezen.
Acceptabel: ja
Realistisch: ja als afgestudeerde bewegingstechnologie moet ik deze competentie goed bezitten
Tijdgebonden: om de 2 weken overleggen hoe het gaat en half juni (afstudeerdatum) moet ik hier meer inzicht over hebben.
Evaluatie: ik heb een realistisch beeld van de onderzoekspraktijk en het carrièreperspectief in de revalidatie verkregen.

Beroepsgerichte competenties Ruben:

1. **Communicatie**

Specifiek: Duidelijk overbrengen van gevonden resultaten zodat de toehoorder het snapt.
Meetbaar: Vragen aan mijn gesprekspartner of hij mij kan volgen en hoe ik dit mogelijk kan verbeteren.
Acceptabel: Ja, de resultaten moeten met de stagebegeleider besproken worden.
Realistisch: Als Bewegingstechnoloog moet je in een begrijpelijke manier resultaten kunnen bespreken in een multidisciplinair overleg.
Tijdgebonden: Aan het einde van mijn afstuderen moet ik minimaal 8 gesprekken gehad hebben.
Evaluatie: Gedurende mijn afstuderen hebben wij elke week een overleg gehad met Marjolein Booij onze afstudeerbegeleider. In dit overleg bespraken we onze voorgang, resultaten en plannen voor de volgende week. De eerste weken was het voor mij nog lastig om beknopt en duidelijk uit te leggen wat wij gedaan hadden en welke resultaten wij gevonden hadden. Dit verbeterde elke week totdat dit goed ging, waarna Marjolein goed begreep wat wij gedaan hebben en waar wij mee bezig zijn geweest.

2. **Management**

Specifiek: zelfstandig mijn project kunnen plannen, netwerk opbouwen en mijn eigen werk kunnen evalueren.
Meetbaar: Wekelijks kijken of de planning behaalt wordt en mijn resultaten met mijn begeleider bespreken.
Acceptabel: Ja, de resultaten moeten met de stagebegeleider besproken worden.
Realistisch: Als afgestudeerde Bewegingstechnoloog moet er zelfstandig gewerkt kunnen worden.
Tijdgebonden: Elke week overleggen met mijn stagebegeleider wat de voortgang is en of de doelen behaald zijn.
Evaluatie: Gedurende mijn afstuderen heb ik samen met Tessa een planning gemaakt met onze taken, deze hebben wij bijna altijd kunnen volgen. Aan het eind van onze afstuderen hebben we het 2x aan moeten passen doordat de voorgestelde feedback tijd eigenlijk te kort was voor de agenda van onze begeleiders. Verder heb ik veel mee kunnen kijken met andere onderzoek die plaatsvinden op het Amsterdam UMC en werden wij uitgenodigd op twee conferenties van het Amsterdam UMC.

Persoonsgebonden competenties:

1. **Initiatief en aanpassingsvermogen:**

Specifiek: Niet alle taken gedurende het afstuderen op mij nemen maar ook taken uit handen durven te geven.
Meetbaar: Elke week feedback aan Tessa vragen of ik mijn taken uit handen durf te geven.
Acceptabel: ja
Realistisch: ja als afgestudeerde bewegingstechnologie moet je durven om taken uit handen geven.
Tijdgebonden: Aan het eind van mijn stage moet Tessa het gevoel hebben dat ik niet alle taken uit haar handen wil halen.
Evaluatie: Gedurende mijn afstuderen heb ik geprobeerd om meer taken uit handen te geven, dit is helaas niet goed gelukt. Door mijn perfectionisme wilde ik aan het eind van ons onderzoek ons verslag meer aanpassen, waardoor ik niet alles aan Tessa kon overlaten. Om dit op te lossen had ik eerder tevreden kunnen zijn of mijn ideeën beter uitleggen aan Tessa waardoor zij deze ook snapt.

Attachment 2: Test protocol

GAFKA – Protocol made and excecuted by: Manja van Wissen and Dominique de Rochemont

1. Preparation (Pre-patient)

a. Spullen:

- Tape plakken. stoel klaarzetten. stopwatch pakken en pilon klaarzetten in loophal
- Marker trappetje uit behandelkamer kinderen halen
- Start het systeem op
- Kalibreer het systeem met de wand en vlaggetje
- Leg 40 markers klaar met plakkers (2 extra)
- Leg EMG boxen #1-14 klaar. Opgeladen?

b. Vicon:

- Maak een patiënt + sessie aan: GAFKA01 (GAFKA + pp nummer) + session01
- Subject (poppetje+)
- Attach model: LowerLimb_Trunk_HBM2_Cast_oct2017_MJBtoes
- FP Gain moet 10 zijn (niet minder) & EMG pin 21-35. gain 2.5
  - FP vertical = signaal 2 en 8
- Zero level eerst in Vicon. daarna pas in Dflow applicatie
- Voor T-pose en ROM → Capture tools – Auto Capture Setup – Advanced – **uncheck**: Start/Stop on remote trigger& Click ‘Arm’ so it shows ‘Disarm’ and lock 🔓🔒

c. Dflow:

- Start EMGnorm test applicatie:
- Applicatie locatie: C:\CAREN Resource\Projects\KneeFIG – GAFKA\Applications\EMGnormTest V3 dd20180103.caren
- F2 Runtime console: hardware: connect Nexus dmv pijltje rechts en connect Forceplates. dan acknowledge en “Next >>”
- Subjectinfo: ID = zelfde naam als in GAFKA applicatie = GAFKAxx (xx=nummer patiënt)
- T-pose runnen in Vicon. voordat je op kalibratie drukt in Dflow
- Gek genoeg moet je de applicatie starten. resetten en weer starten. Dan werken alle drie de bollen goed

F2: Aansturing = Runtime Console
F7: Waar de video’s (en txt) worden opgeslagen
F11: log

2. Preparation (Patient)

- Lab laten zien
- Uitleg aan deelnemer wat er gaat gebeuren
- Heeft u eerder aan wetenschappelijk onderzoek meegedaan?
- Voorbereiding
- Moe → pauze!

❖ **Toestemmingsformulier (Informed consent tekenen!)**

3. Pre-measurements

- Gewicht
- Lengte
- Omtrek schoen (aangedane been)
- Lengte schoen (aangedane been)
- Omtrek onderbeen (breedste gedeelte)
- Omtrek bovenbeen (breedste gedeelte)

→ Invullen op de laptop (inclusief: aangedane zijde. geb. datum. artrose in andere gewrichten etc.)

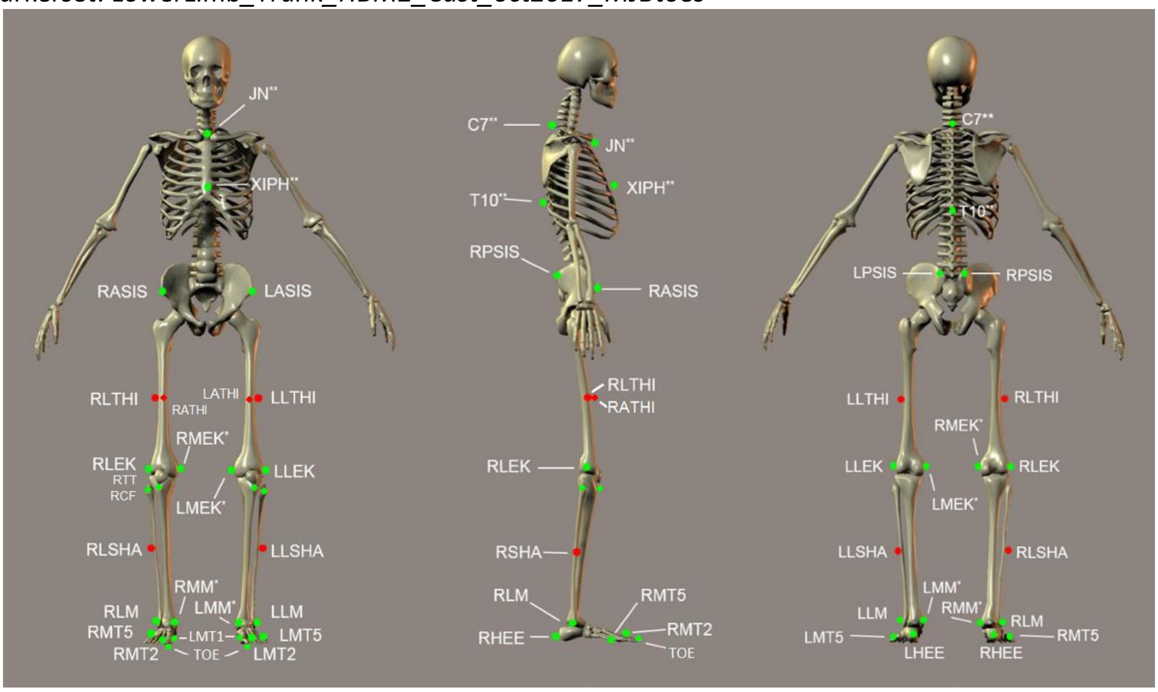
4. Warming up

Een warming op van verschillinde oefeningen die elk twee maal worden uitgevoerd, bestaande: timed up and go, 40 meter fast pace walk, 30-Second Chair Stand Stair Climb(9 tredes omhoog en onlaag).
Toilet break?

5. sEMG en reflectieve markers plakken

1. Huid schoonmaken met alcohol
2. Scheren
3. Electrodes (ZeroWire; Aurion. Milano. Italy) plakken op het rechterbeen volgens SENIAM
    a) *Vastus medialis(VM)*
    b) *Rectus Femoris(RF)*
    c) *Vastus lateralis(VL)*
    d) *Biceps Femoris(BF)*
    e) *Semitendinosus(ST)*
4. Markers plakken zoals in *tabel1* en *figuur 1*

Markerset: LowerLimb_Trunk_HBM2_Cast_oct2017_MJBtoes



Figuur 1, marerplacement.

Table 1, Marker Placement Lowerlimb & Trunk: HBM2 & CAST

C7	7th cervical vertebra	Bend head forward. most pronounced vertebra is Spinous Process of 7th cervical vertebra. Check: bring head back upright and then rotate head. C7 will move. 1st thoracic vertebra won't.
T10	10th thoracic vertebra	On the Spinous Process. at level of the bottom of the shoulder blades (with arms handing down). Make sure it is in the middle.
XIPH	Xiphoid process	Lower edge of sternum. Make sure it is in the middle
JN	Jugular notch	Upper edge of sternum. Make sure it is in the middle.
LASIS RASIS	Left/Right ASIS	Palpate from below the anterior superior iliac spine. Place marker on most pronounced part.
LPSIS RPSIS	Left/Right PSIS	Placed on the skin on most pronounced part on dimple (if visible).
LGTRO RGTRO	Left/Right greater trochanter	Technical marker only. Palpate from distal while pushing hip outward ('model pose') or rotate the leg.
LLTHI	Left lateral thigh	On the lateral side of thigh; ±1/3 in line LGTRO – LLEK just below the swing of the hand. The anterior/ posterior position critical for definition upper leg.
RLTHI	Right lateral thigh	On the lateral side of thigh; ±2/3 in line LGTRO – LLEK just below the swing of the hand. The anterior/ posterior position critical for definition upper leg.
LATHI	Left anterior thigh	Technical marker only. On the anterior side of thigh at same height as LLTHI. Exact location not relevant. but not in line with other markers.
RATHI	Right anterior thigh	Technical marker only. On the anterior side of thigh at same height as RLTHI. Exact location not relevant. but not in line with other markers.
LLEK RLEK	Left/Right lateral epicondyle knee	Placed on the lateral epicondyle of the left knee.
LMEK RMEK	Left/Right Medial epicondyle knee	Placed on the medial epicondyle of the knee along an imaginary line that passes through the transfemoral axis.
LFH RFH	Left/Right fibula head	Most pronounced part. just underneath LEK. Palpate from distal direction
LTT RTT	Left/Right tibial tuberositas	In the medial/lateral most pronounced middle. underneath patellar tendon insertion. Palpate from distal direction.
LLSHA RLSHA	Left/Right lateral shank	On the lateral side of the shank. Halfway LEK and LM.
LLM RLM	Left/Right lateral malleolus ankle	Most pronouncing part along an imaginary line that passes through the transmalleolar axis
LMM RMM	Left/Right medial malleolus ankle	Most pronouncing part along an imaginary line that passes through the transmalleolar axis.
LHEE RHEE	Heel / dorsal calcaneus	Placed in the middle of the posterior aspect of the calcaneus at the same height above the plantar surface of the foot as MT2. MT2 and LHEE used to calculate line of the foot for progression.
LMT5 RMT5	Left/Right 5th metatarsal	On top of 5th metatarsal head.
LMT2 RMT2	Left/Right 2nd metatarsal	Placed on top of the distal ends of the caput of the 2nd metatarsal bone. on joint line midfoot/toes.
LMT1 RMT1	Left/Right 1st metatarsal	On top of 1st metatarsal head.
LTOE RTOE	Left/Right tip of toe	On top of tip of 1st toe.

6. Referentie oefeningen

***Table 2**, referentie oefeningen*

Oefening & Vicon naam	*Intructie*	*opdracht*
Rest	Patiënt	Patiënt moet ontspannen op een stoel zitten. Let op EMG kastjes. voorzichtig zitten.
Tpose	Patiënt	Patiënt neemt TPose aan in het midden van de loopband. let hierbij op de plaatsing van de voeten en afstand van de mediale markers van de knie (breedte van voetplaatsing om markers uit elkaar te halen).
	Vicon	Reconstruct – Autolabel Static – Scale Subject VSK – Static Skeleton Calibration – Save
ROM	patiënt	Patiënt loopt van achter naar voor op de loopband met ongeveer 3 á 4 stappen. Let op het tape. zijn start en eind punt zodat de patiënt niet op de rollers staat.
	Vicon	Reconstruct – Label – Functional Skeleton Calibration – Save
Squat	Patiënt	Patiënt oefent eerst met een squat oefening om alle 3 de bolletjes groen te krijgen. Bij de oefening mogen de leuningen vastgehouden worden. Tijdens de meting de armen vooruitsteken. De groenen bolletjes staan voor de enkel. knie en heuphoek. De patiënt doet 3x een squat beweging. waarbij alle 3 de bolletjes groen moeten blijven voor 3 seconden.
	Vicon	Reconstruct – Label – Functional Skeleton Calibration – Save
	D-flow	- Applicatie locatie:C:\CAREN Resource\Projects\KneeFIG – GAFKA\Applications\EMGnormTest V3 dd20180103.caren - F2 Runtime console: hardware: connect Nexus dmv pijltje rechts en connect Forceplates. dan acknowledge en "Next >>" - Subjectinfo: ID = zelfde naam als in GAFKA applicatie = GAFKAxx (xx=nummer patiënt) - T-pose runnen in Vicon. voordat je op kalibratie drukt in Dflow - Gek genoeg moet je de applicatie starten. resetten en weer starten. dan werken alle drie de bollen goed
Anteflexi on	Patiënt	De patiënt moet zijn been gestrekt naar voren optillen en hierbij rechtop blijven staan. Er mag geen compensatie van de heup. bekken of rug ontstaan. De patiënt moet het been 3 seconde optillen en dit 3x per been uitvoeren (rechts en links). De patiënt moet de leuning vasthouden.
Retroflexi e	Patiënt	De patiënt moet zijn been gestrekt naar achteren optillen en hierbij rechtop blijven staan. Er mag geen compensatie van de heup. bekken of rug ontstaan. De patiënt moet het been 3 seconde optillen en dit 3x per been uitvoeren (rechts en links). De patiënt moet de leuning vasthouden.
zero	D-flow	- Applicatie GAFKA starten in Dflow en vervolgens *ZERO level van forceplate in Vicon.* Vervolgens ook ZERO level in de GAFKA applicatie in Dflow. - *Instructies Dflow:* Applicatie locatie C:\CAREN Resource\Projects\KneeFIG – GAFKA\Applications\GAFKA_MJB V3 dd20190115.caren - Check Auditive Scoring! → geluid aan?

7. Treadmill lopen voor ander onderzoek

Voorbereiding lopen:

- Light gate uitleggen
- In het midden lopen. niet op de middenlijn (linker en rechter band)
- Self-paced uitleggen (niet te snel lopen!)
- Stepping stones test (130% snelheid en korte stap aangedane been. lange stap niet aangedane been)

Vicon:

- Ga **Live** in nexus/Vicon
  - Trial name : Trial01 **(Eenmalig aanmaken. vervolgens wordt dit verder in D-flow gerund)**
  - Capture tools – Auto Capture Setup – Advanced – **check**: Start/Stop on remote trigger & Click 'Arm' so it shows 'Disarm' and lock 🔓🔒
- Checks tijdens applicatie:
  - Let op rode bolletje of je daadwerkelijk wel iets opneemt. Bij familirisatie is er geen rood bolletje zichtbaar.
  - 2 en 8 FP zichtbaar dat ze werken.
  - EMG goede signalen zichtbaar (blokjes van activatie)
  - Benen door elkaar: ctrl R (vicon/nexus computer)

Als er een crash is: Vicon nexus trial**b**02 ipv trial02 : want gaat meestal het fout in Baseline stepping stones.

Dflow: In gestarte applicatie KneeFIG-GAFKA (zie zero)

- F2 Runtime console: hardware: connect Nexus dmv pijltje rechts en connect Forceplates. dan acknowledge en "Next >>"
- Subjectinfo: ID = zelfde naam als in GAFKA applicatie = GAFKAxx (xx=nummer patiënt)
- T-pose runnen in Vicon. voordat je op kalibratie drukt in Dflow
- Default tab: Footsize. Leglength aandrukken voor de start OPside (right or left)
- Druk op play om het systeem te starten
- Wanneer de patiënt lekker loopt dan activate selfspeed (SP) en override speed uitklikken.
- Bij elke aanmeting aangeven wanneer de patiënt nog 1 minuut moet lopen.
- Na pauzes. resume klikken. De loopband start zonder aftellen!

Table 3, Protocol gevolgd in D-flow

Taak	Tijd
Familiarisatie: self-paced. start met vaste snelheid	3min
Pauze (indien nodig)	
Baseline (op self selected speed lopen)	3min
Stepping Targets – Baseline Precies stappen. feedback in groen en geluid	½min
Stepping Targets - Asymmetrisch (130%. -/+ 20%) Precies stappen. feedback in groen en geluid	3min
Pauze (indien nodig)	
Baseline	1min

8. Stap 6 herhalen voor de post-test

Attachment 3: Vicon processing

First makers were tracked with Vicon, the following steps explain how this works in Vicon Nexus 2.5.

1) Turn on the 3 highest switches to start up the Gaitway computer
2) Push 2 times CRL and open Mocep
3) Open Nexus in the desktop
4) Go to Data management in the communication window (4) and open the recoding that is needs to be processed
5) Click on Quality in the communication window (4). the screen below will appear in the communication window. It shows the percentage of gaps per marker.

6) Click in tools (3) on 

7) Check if the right current pipeline is used.
8) Click with on the right button and click on Reconstruct and then with the left button on Run selected Op. A green checkmark will appear when this step is fulfilled.
9) Click with on the right button and click on Label and then with the left button on Run selected Op. A green checkmark will appear when this step is fulfilled.

10) Click in tools (3) on 

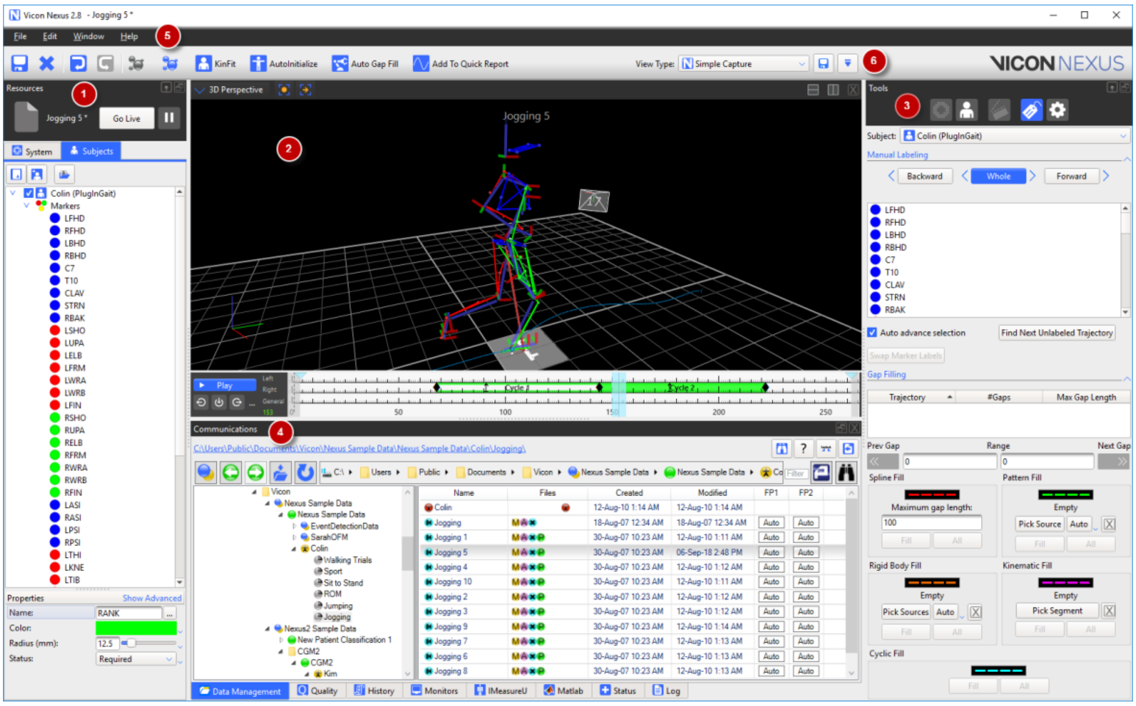


Fig 1. screen Vicon Nexus

11) Here gaps bigger than 5 frames can be filled. The most preferable method is the Rigid Body Fill *(figure 2.a).* here three markers can be used to determine the placement of the one missing. The three markers used to calculate the missing one need be on the same body segment as the marker missing.
When the rigid body method is not possible the Pattern Fill method*(figure 2.b)* can be used. Here one marker on the same body-segment that makes the same movement is used to determine the placement of the missing marker.
The last option when the Pattern fill method does not work is the spline Fill method(figure 2.c). here the length of the gap needs to be filled in the bar. A line will be calculated between the positions known.

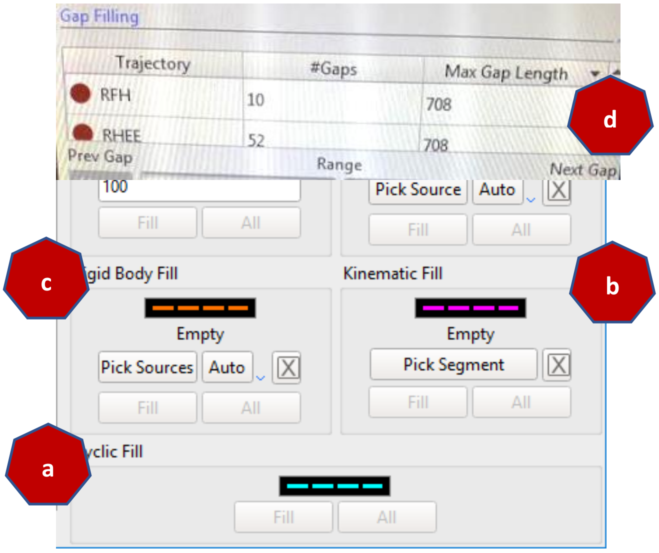


Fig 2. gap filling methods

a. Open graph by clicking on this icon in the view plane(2) . A second view plane will appear. Then click on the in the 3D perspective of the lowest view plane(2) and click on graph. In this graph the X and Y axes of the markers is shown. 
b. Click on the marker where the gaps need to be filled (figure2.d). First try to use the Rigid body method chose the three markers on the same body-segment as the one missing markers with *Pick sources.* Gaps can then be filled per gap per marker(Fill) or all at once (All)
C. Check if the Rigid body fill works. fill will then turn darker. When fill does not turn darker one of the three chosen markers can first be filled with this method and then the previous one can be retried. If this this try is not successful use the Pattern Fill method and chose a marker on the same body segment that makes the same movement(with Pick segment). When neither of these methods work use Spline Fill
D. First use Fill and look in the graph to determine if the gap is filled correct. Then use fill for al big gaps and determine if it was filled correct.
E. Fill all gaps bigger than 5 frames
12) Click with on the right button and click on Fill Gaps - Woltring and then with the left button on Run selected Op. A green checkmark will appear when this step is fulfilled. Gaps smaller than 5 frames will then be filled.
13) Run the recoding and see is it looks correct.
14) Check in Quality in the communication window (4). if markers labels is a 100% and is turned black. If not make a notation of what marker is missing and when.
15) Click with on the right button and click on Save Trial –C-3D +VSK and then with the left button on Run selected Op. A green checkmark will appear when this step is fulfilled. In the data management in the communication window (4). a P will appear by the file.

Attachment 4: Matlabscript

Receiving the data

```
clc
clear all
close all

%% init
%laat het bestand in
load('C:\Users\ruben\Desktop\AUMC\Matlab_Data_Preofpersonen\pg43\Anteflexion.mat')

% Loads all the jointangles
for i = 1:length(BODY.JOINT)
   angles(:,i) = BODY.JOINT(i).AnatomyRefKinematics.RotationAngles(1,:)';
end

% loads all the EMG-signals
for i = 1:length(BODY.MUSCLE) % loads all the EMG-signals
   muscles(:,i) = BODY.MUSCLE(i).Emg.Envelope(:,1)';
end

% correct the angles to the measured angles
angles(:,[4,7]) = angles(:,[4,7])+90;
angles(:,[3,6]) = angles(:,[3,6])*-1;

% label body segments
TRUNK = 1; RHIP = 2; RKNEE = 3; RANKLE = 4;
         LHIP = 5; LKNEE = 6; LANKLE = 7;

%label Muscles
RRF=1; RLV=2; RMV=3; RLH=4; RMH=5; RLG=6; RMG=7;
LRF=8; LLV=9; LMV=10; LMH=11; LLH=12; LMG=13; LLG=14;
angle = 1; muscle = 2;

% making the time axis for the angles
n = [length(angles(:,1)),length(muscles(:,1))];
fs = [BODY.CONTEXT.SampleFrequency,1/BODY.MUSCLE(1).Emg.TimeGain];
N(1).row = [1,1:(n(angle))-1]; N(2).row=[1,1:(n(muscle))-1];
t(1).row = [N(angle).row/fs(angle)]';  t(2).row=[N(muscle).row/fs(muscle)]';

% referentie waardes
task = 'squat' % anteflexion or retroflexion
if task=='squat';
   refg = [0,0; 90,110; 82,96; 115,130; 90,110; 82,96; 115,130]; % squat
   refc = (refg(:,1)+refg(:,2))/2; %target angles for the Squat
   refn = [0,0; 50,150; 50,150; 100,150;50,150; 50,150; 100,150;]; % squat
elseif task=='anteflexion';
   refc = [0;45;0;90;0;0;90]; % target angles for the Anteflexion
   refg = [0,0; 45,90; -10,20; 75,105; 45,90; -10,20; 75,105;]; %green target anteflexion
   refn = [0,0;45,100;-10,15;80,100;45,100;-10,10;80,100]; % anteflexion
elseif task=='retroflexion';
   refg = [0,0; 45,90; -10,20; 75,105; 45,90; -10,20; 75,105;]; %green target anteflexion
   refc = [0;-20;0;90;0;0;90]; % target angles for the Retroflexion
   refn = [0,0;-30,target;-10,10;80,100;-30,target;-10,10;80,100]; % retroflexion
else
  error('task cant be analysed')
end
```

Detecting the exercises

```
%% when taget is reached
x=1;
%do all calculations for three windows 1, 1.5 and 2 seconds
for deltat = [fs(1)*1,fs(1)*1.5,fs(1)*2]
  for i = 1:n
    for j = 1:7
      %check if the rightleg is in the target angles
      if angles(i,j)<refn(j,2) && angles(i,j)>refn(j,1)
        green(i,j)=1; % orange
      else
        green(i,j)=0; % red
      end
    end
    if sum(green(i,[2]))==1;
      green(i,8)=1;
    end
    green(i,9)=0; % Later used to check if the next deltat frames is still inside the targets
  end
  %% different Deltat
  for i = 1:n-deltat
    %calculates the variation in angle for each angle
    for j = 1:7
      anglesvar(i,j) = sqrt(var(angles(i:i+deltat,j)));
    end
    % how manny angles are in the target zone
    total(i)=sum(green(i:i+deltat,8)); %
    % in targetzone for at least delta time
    if sum(green(i:i+deltat,8)) == deltat + 1
      green(i,9)=1;
    end
  end
  % standardize angle variation
  anglesvar(:,1:7)=anglesvar(:,1:7)./max(anglesvar(:,1:7));
  anglesvar(:,8) = sum(anglesvar(:,2:4),2);
  % detects starts and ends of the exercise
  [y,beginsquatx] = findpeaks(diff(green(:,9)));
  [y,eindsquatx] = findpeaks(-diff(green(:,9)));
  % if exercise has started before recording has started
  if beginsquatx(1)>eindsquatx(1)
    beginsquatx = [1;beginsquatx];
  end
  % if record has stopt before exercise finish
  if eindsquatx(end)<beginsquatx(end)
    eindsquatx(end+1)= n-deltat
  end
  squats = length(eindsquatx); % amount of repetitions
  for i = 1:squats % finds the lowest angle variation.
    minvary(i)= min(anglesvar(beginsquatx(i):eindsquatx(i),8));
    minvarx(i) = (find(anglesvar(beginsquatx(i):eindsquatx(i),8) == minvary(i)) + beginsquatx(i));
  end
  clear anglest; clear musclest;
  for i = 1 : squats % makes a 3D matrix for each repition
    anglest(:,:,i) = angles(minvarx(i):minvarx(i)+deltat,:);
    musclest(:,:,i) = muscles(minvarx(i)*10:minvarx(i)*10+deltat*10,:);
  end
```

Calculating the variables

```
%% 3 different methods
  %gem off 3 trials
  meanvmean = mean(mean(musclest),3);
  meanvpeak = mean(max(musclest),3);
    % closed to green
  meanangle = mean(anglest(:,2:4,:));%%....->middle of green
  deltaangle = sqrt((refc([2:4],:)'-meanangle).^2);
  totaloffset = sum(deltaangle);
  bestsquatgreen = find(totaloffset==min(totaloffset));
  greenvmean = mean(musclest(:,:,bestsquatgreen));
  greenvpeak = max(musclest(:,:,bestsquatgreen));
  % smallest delta Right
  maxangle = sum(max(anglest(:,2:4,:)));
  minangle = sum(min(anglest(:,2:4,:)));
  delta = maxangle-minangle;
  bestsquatdelta= find(delta==min(delta));
  deltavmean = mean(musclest(:,:,bestsquatdelta));
  deltavpeak = max(musclest(:,:,bestsquatdelta));
  clear meanangle
  meanangle(:,:)= mean(anglest(:,:,[1:3]));
  stdangle(:,:)= std(anglest(:,:,[1:3]));

  %% plot the data
% Gives an indication of the performed task and shows the time windows that
% will be used for the analyses.
  figure(1)
  for j = 1:3
    subplot(4,3,j)
    title(BODY.JOINT(j+1).Name)
    hold on
    plot(angles(:,j+1),'r')
    plot(angles(:,j+4),'b')
    plot([0,length(angles(:,1))],[refn(j+1,1),refn(j+1,1)],'k')
    plot([0,length(angles(:,1))],[refn(j+1,2),refn(j+1,2)],'k')
    for i = 1:squats
      plot([minvarx(i),minvarx(i)+deltat],[deltat/5,deltat/5])
    end
  end
 for j = 1:7
    subplot(4,3,j+3)
    title(BODY.MUSCLE(j).Name)
    hold on
    plot(muscles(:,j),'r')
    for i = 1:squats
      plot([minvarx(i)*10,(minvarx(i)+deltat)*10],[deltat/3000,deltat/3000])
    end
  end
% compute variables
totalmeanangle(:,:,x)=[meanangle]'; %x = timerange so 1, 1.5 and 2
totalstdangle(:,:,x)=[stdangle]';
datadeltavmean(x,:)=[deltavmean];
datadeltavpeak(x,:)=[deltavpeak];
datagreenvmean(x,:)=[greenvmean];
datagreenvpeak(x,:)=[greenvpeak];
datameanvmean(x,:)=[meanvmean];
datameanvpeak(x,:)=[meanvpeak];
bestsquat(:,x)=[bestsquatdelta,bestsquatgreen];
x=x+1;
end
```

Exporting the variables

```
%% Angles
z=(q-1)*9+1
squatsave=[1,1,1,1.5,1.5,1.5,2,2,2;1,2,3,1,2,3,1,2,3;]';
meansave = [totalmeanangle(:,:,1);totalmeanangle(:,:,2);totalmeanangle(:,:,3)];
stdsave = [totalstdangle(:,:,1);totalstdangle(:,:,2);totalstdangle(:,:,3)];
datasave = [squatsave,meansave,stdsave]; xlswrite('meanangle.xls',datasave,'Anteflexionz',['A',num2str(z)])

%% Data export
q=(q-1)*18+1
% create the data structure to find your data back in the EXCEL sheet
Bestsquat=[bestsquat(1,:),bestsquat(1,:),bestsquat(2,:),bestsquat(2,:)]';
Select = [1,1,1,1,1,1,2,2,2,2,2,2,3,3,3,3,3,3]';
Time = [1,1.5,2,1,1.5,2,1,1.5,2,1,1.5,2,1,1.5,2,1,1.5,2]';
EMG = [1,1,1,2,2,2,1,1,1,2,2,2,1,1,1,2,2,2]';

% create matrix with the data
meandeltaangle =
[totalmeanangle(Bestsquat(1),:,1);totalmeanangle(Bestsquat(2),:,2);totalmeanangle(Bestsquat(3),:,3);totalmeanangle(B
estsquat(4),:,1);totalmeanangle(Bestsquat(5),:,2);totalmeanangle(Bestsquat(6),:,3)];
meangreenangle =
[totalmeanangle(Bestsquat(7),:,1);totalmeanangle(Bestsquat(8),:,2);totalmeanangle(Bestsquat(9),:,3);totalmeanangle(B
estsquat(10),:,1);totalmeanangle(Bestsquat(11),:,2);totalmeanangle(Bestsquat(12),:,3)];
meanmeanangle =
[mean(totalmeanangle(:,:,1));mean(totalmeanangle(:,:,2));mean(totalmeanangle(:,:,3));mean(totalmeanangle(:,:,1));mea
n(totalmeanangle(:,:,2));mean(totalmeanangle(:,:,3))];
meaneigangle = [meandeltaangle;meangreenangle;meanmeanangle];
eig = [Select,Time,EMG];
Data = [datadeltavmean;datadeltavpeak;datagreenvmean;datagreenvpeak;datameanvmean;datameanvpeak];

% write the data into an EXCEL sheet.
xlswrite('ICCR.xls',Bestsquat,"Anteflexionz",['D',num2str(q)])
xlswrite('ICCR.xls',eig,"Anteflexionz",['A',num2str(q)])
xlswrite('ICCR.xls',Data(:,[1:7]),"Anteflexionz",['E',num2str(q)])
xlswrite('ICCR.xls',meaneigangle,"Anteflexionz",['L',num2str(q)])
```