Inter-rater and intra-rater reliability of isotonic exercise monitoring device for measuring active knee extension

Chonnanid Limsakul [1], Kiattisak Sengchuai [2], Rakkrit Duangsoithong [2], Nattha Jindapetch [2], Jermphiphut Jaruenpunyasak [Corresp. 3]

[1] Department of Rehabilitation Medicine, Faculty of Medicine, Prince of Songkla University, Hat yai, Songkhla, Thailand

[2] Department of Electrical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla, Thailand

[3] Department of Biomedical Sciences and Biomedical Engineering, Faculty of Medicine, Prince of Songkla University, Hat Yai, Songkhla, Thailand

Corresponding Author: Jermphiphut Jaruenpunyasak
Email address: jjermphi@medicine.psu.ac.th

Background. The goal of this study was to assess the reliability of electromyography and range of motion measurements obtained using a knee exercise monitoring system. This device was developed to collect data on knee exercise activities.

Methods. Twenty healthy individuals performed isotonic quadriceps exercises in this study. The vastus medialis surface electromyography (sEMG) and range of motion (ROM) of the knee were recorded during the exercise using the isotonic knee exercise monitoring device, the Mobi6-6b, and a video camera system. Each subject underwent a second measuring session at least 24 hours after the first session. To determine reliability, the intraclass correlation coefficients (ICCs) and standard error of measurement (SEM) at the 95 percent confidence interval were calculated, and a Bland–Altman analysis was performed.

Results. For inter-rater reliability, the ICCs of the mean absolute value (MAV) and root mean square (RMS) of sEMG were 0.73 (0.49, 0.86) and 0.79 (0.61, 0.89), respectively. ROM had an ICC of 0.93 (0.02, 0.98). The intra-rater reliability of the MAV of the sEMG was 0.89 (0.71, 0.96) and the intra-rater reliability of RMS of the sEMG was 0.88 (0.70, 0.95). The ROM between days had an intra-rater reliability of 0.82 (0.54, 0.93). The Bland–Altman analysis demonstrated no systematic bias in the MAV and RMS of sEMG, but revealed a small, systematic bias in ROM (-0.8311 degrees).

Conclusion. For sEMG and range of motion measures, the isotonic knee exercise monitoring equipment revealed moderate to excellent inter- and intra-rater agreement. However, the confidence interval of ROM inter-rater reliability was quite large, indicating a small agreement bias; hence, the isotonic knee exercise monitor may not be suitable for measuring ROM. This isotonic knee exercise monitor could detect and collect information on a patient's exercise activity for the benefit of healthcare providers.

Inter-rater and intra-rater reliability of isotonic exercise monitoring device for measuring active knee extension

Chonnanid Limsakul[1], Kiattisak Sengchuai[2], Rakkrit Duangsoithong[2], Nattha Jindapetch[2], and Jermphiphut Jaruenpunyasak[3]

[1]Department of Rehabilitation Medicine, Faculty of Medicine, Prince of Songkla University, 15 Karnjanavanich Road Hat Yai Songkhla 90110 Thailand
[2]Department of Electrical Engineering, Faculty of Engineering, Prince of Songkla University, 15 Karnjanavanich Road Hat Yai Songkhla 90110 Thailand
[3]Department of Biomedical Sciences and Biomedical Engineering, Faculty of Medicine, Prince of Songkla University, 15 Karnjanavanich Road Hat Yai Songkhla 90110 Thailand

Corresponding author:
Jermphiphut Jaruenpunyasak[3]

Email address: jjermphi@medicine.psu.ac.th

ABSTRACT

Background. The goal of this study was to assess the reliability of electromyography and range of motion measurements obtained using a knee exercise monitoring system. This device was developed to collect data on knee exercise activities.

Methods. Twenty healthy individuals performed isotonic quadriceps exercises in this study. The vastus medialis surface electromyography (sEMG) and range of motion (ROM) of the knee were recorded during the exercise using the isotonic knee exercise monitoring device, the Mobi6-6b, and a video camera system. Each subject underwent a second measuring session at least 24 hours after the first session. To determine reliability, the intraclass correlation coefficients (ICCs) and standard error of measurement (SEM) at the 95 percent confidence interval were calculated, and a Bland–Altman analysis was performed.

Results. For inter-rater reliability, the ICCs of the mean absolute value (MAV) and root mean square (RMS) of sEMG were 0.73 (0.49, 0.86) and 0.79 (0.61, 0.89), respectively. ROM had an ICC of 0.93 (0.02, 0.98). The intra-rater reliability of the MAV of the sEMG was 0.89 (0.71, 0.96) and the intra-rater reliability of RMS of the sEMG was 0.88 (0.70, 0.95). The ROM between days had an intra-rater reliability of 0.82 (0.54, 0.93). The Bland–Altman analysis demonstrated no systematic bias in the MAV and RMS of sEMG, but revealed a small, systematic bias in ROM (-0.8311 degrees).

Conclusion. For sEMG and range of motion measures, the isotonic knee exercise monitoring equipment revealed moderate to excellent inter- and intra-rater agreement. However, the confidence interval of ROM inter-rater reliability was quite large, indicating a small agreement bias; hence, the isotonic knee exercise monitor may not be suitable for measuring ROM. This isotonic knee exercise monitor could detect and collect information on a patient's exercise activity for the benefit of healthcare providers.

INTRODUCTION

Globally, the elderly population is predicted to grow from over 700 million in 2019 to over 1.5 billion in 2050 (UN, 2019). This group is afflicted by a variety of degenerative diseases, most notably osteoarthritis (OA). The knee joint is one of the most frequently affected locations of OA in this population (Cui et al., 2020), impacting approximately 650 million people worldwide (CDC, 2020). Osteoarthritis of the knee (OA knee) can severely limit daily activities and can cause disability since it directly affects walking ability (Liu et al., 2017). Therapeutic exercise is a key component of treatment for OA of the knee (Kolasinski et al., 2020; Esselman and Lacerte, 1994; Wiles et al., 2018; Kim et al., 2015). Research indicates that strengthening the quadriceps muscles might help alleviate discomfort and restore function to the knee joint (Anwer and Alghadir, 2014; Hislop et al., 2020; Zeng et al., 2021). The vastus medialis oblique

46 (VMO; (Fink et al., 2007; Hart et al., 2012)) is the most frequently atrophying quadriceps muscle. As a
47 result, strengthening the VMO (Zeng et al., 2021) may help to slow the course of knee OA. Numerous
48 guidelines advocate performing quadriceps exercises with proper technique at least 3-4 times per week
49 (Kwok et al., 2015) with a total of 10-15 repetitions each day (Vincent and Vincent, 2012).

50   During the COVID-19 pandemic, the amount of hospital-based therapeutic exercises significantly
51 decreased (Boldrini et al., 2020) because of social distancing and the hospital safety policies in place.
52 Some hospitals switched to providing therapeutic exercise via telemedicine (Yu et al., 2020), but treatment
53 opportunities of any type are still lacking in hospitals. Home-based exercise is a practical way for patients
54 to perform exercises themselves, and it is more sustainable than hospital-based exercise. Current knee
55 OA recommendations also include home-based therapeutic exercises. Knee surface electromyography
56 (sEMG), knee range of motion (ROM), and the force, power, and speed of the knee exercises performed
57 should all be observed to monitor knee OA patients (Heywood et al., 2019).

58   According to a prior study (Sengchuai and Jindapetch, 2020), the isotonic exercise monitoring device
59 (shown in Figure 1) monitors knee sEMG and ROM during isotonic exercise, recording and tracking the
60 progression of each patient on a web-based platform. This device allows patients to perform the exercises
61 by themselves, and healthcare providers can simply read the metrics of the exercise without having to
62 observe them being performed at all. During isotonic exercise, the sEMG (Vigotsky et al., 2018) indicates
63 muscle contraction and the ROM (Hancock et al., 2018) measures the movement of the knee. With these
64 two metrics, healthcare providers are able to determine the isotonic exercise progression of each patient

Figure 1. Isotonic exercise monitoring device and its peripheral equipment: (a) sandbag, (b) isotonic exercise monitoring device, (c) triaxial accelerometer channel for knee angle measurement, (d) sEMG channel, (e) graphic user interface (GUI).

65   Before using the isotonic exercise monitor in clinical applications, we need to determine if the
66 device is qualified to measure isotonic exercise with good reproducibility and validation. Therefore,
67 our study aims to validate this device's functions (sEMG and ROM measurement) with the current
68 standard instruments. To verify these two functions, we performed a comparative analysis of sEMG
69 measurements of the right VMO using the isotonic exercise monitoring device and a Mobi6-6b wireless
70 sEMG instrument (Phinyomark et al., 2012; Thiamchoo and Phukpattaranont, 2022). The ROM of
71 knee flexion and extension was also measured using the isotonic exercise monitoring device and the
72 computer vision method (Duangsoithong et al., 2019). The experiment was conducted using a Con-Trex
73 dynamometer for continual knee movement (Con-Trex; (Ema et al., 2018)). The inter-rater and intra-rater
74 reliability of the sEMG parameters and ROM measurements were compared by statistical analysis using
75 intraclass correlation coefficients (ICCs; (Koo and Li, 2016; Remigio et al., 2017)) and by a Bland–Altman
76 analysis (Giavarina, 2015).

77   Overall, this study's objective was to use the isotonic exercise monitor to record the knee sEMG
78 and ROM of healthy volunteers and compare the results to the measurements recorded using the current

79 standard measuring devices.

MATERIALS AND METHODS

Subjects

Healthy volunteers were recruited to participate in the study. Eligible subjects were at least eighteen years of age, had full ROM in both knees and had no history of musculoskeletal or neurological problems affecting either leg. The research team advertised the details of the study at Prince of Songkla University, and all eligible subjects who contacted the research team were recruited to the study. All subjects cooperated well and provided written informed consent. The study protocol was approved by the institutional ethics committee of the Faculty of Medicine, Prince of Songkla University, and was in accordance with the Declaration of Helsinki (REC 60-284-11-1).

Using ICC based on multiple raters (k=2), the expected effect size to assume differences in EMG and ROM measurement in an isotonic exercise monitoring device compared with standard protocols was computed (Koo and Li, 2016). We estimated the power (1-β) by defining the expected reliability (ICC, $\rho 1$) as 0.6, the significance level (α) as 0.05, and a power of 0.90 (Bujang and Baharum, 2017). The sample size estimate indicated that at least 20 subjects were required, but to account for potential dropouts, this study enrolled a total of 24 subjects. However, four subjects were removed because the sEMG signal could not be detected; in one example, the patient's subcutaneous tissue was thick, obscuring the sEMG measurement. Table 1 summarizes the characteristics of the final twenty study participants, stratified by gender.

Table 1. Summarizes the characteristics of the study participants, stratified by gender

Characteristics	All subjects (N=20)	Males (N=11)	Females (N=9)
BW (kg) mean ± sd	65.27 ± 13.39	68.59 ± 10.68	61.21 ± 15.81
BH (cm) mean ± sd	167.24 ± 10.11	173.77 ± 5.47	159.26 ± 7.89
BMI (kg/m^2) mean ± sd	23.42 ± 4.61	22.73 ± 3.50	24.06 ± 5.64
Age (yrs) mean ± sd	30.10 ± 6.96	30.64 ± 6.44	29.44 ± 7.89

Note: BW: body weight in kilogram (kg) units, BH: body height in centimetre (cm) units, BMI: body mass index in kg/m^2 units, yrs: years, and sd: standard deviation.

Study design

This was an experimental study. To determine the inter-rater reliability of the isotonic exercise monitoring device, sEMG and ROM measurements were obtained and compared with standard instruments: the Mobi6-6b wireless system and the computer vision method, respectively. For intra-rater reliability, the subjects were tested one day apart using the same protocol. In both experiments, the speed, time, and force of the exercises were controlled by the Con-Trex. All measurement devices were synchronized to the time alignment of the Con-Trex to accurately determine the period of knee extension and flexion. Experienced physical therapists monitored the experiment and were in charge of the Con-Trex to ensure both safety and reliability.

Standard instruments

We used three main instruments in this study to verify the results of the isotonic exercise monitoring device. The Con-Trex dynamometer, used in this experiment to control the exercises, is popular among exercise monitoring devices because it can monitor isokinetic, isometric, and isotonic activities. Previous studies have shown it has excellent reliability for knee exercises (Maffiuletti et al., 2007) with an ICC of 0.99 for knee extension and an ICC of 0.78-0.81 for knee flexion.

We used the Mobi6-6b wireless system, a wireless device with multiple channels and applications, to measure the sEMG in this study. A previous study (Sae Jong et al., 2021) revealed that, when given a

115 variety of sEMG measures for facial muscle signal detection, such as mean absolute value (MAV), root
116 mean square (RMS), and frequency domain, the Mobi6-6b had 98% accuracy in syllable recognition.
117 We used computer vision as the standard for measuring knee range of motion. There are numerous
118 applications employing computer vision for monitoring human activities such as sitting posture (Kulika-
119 jevas et al., 2021), human gait (Yu et al., 2021), and foot recognition (Duangsoithong et al., 2019). One
120 study showed that applying deep learning through a convolutional neural network (CNN) gave a high,
121 98% accuracy for recognizing the region of interest (ROI) of the foot in images, which could then be
122 employed to monitor the foot during knee exercises.

Experimental procedures
124 The methods of this experiment consisted of two main steps: preparation and exercise, as shown in
125 Figure 2.
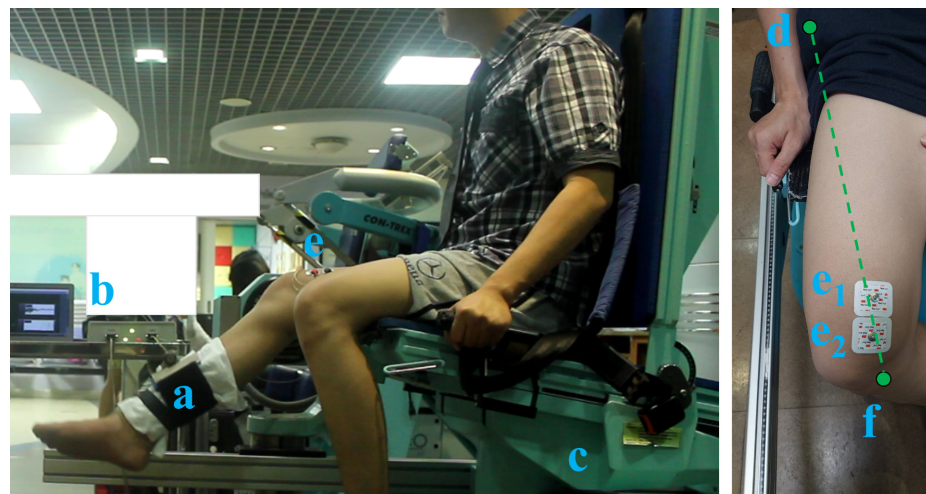
Figure 2. Experimental settings of the: (a) Con-Trex's lever arm, (b) isotonic exercise monitoring
device, (c) Con-Trex device, (d) anterior superior iliac spines, (e_1 and e_2) electrode placement (e_1: 80%
of the distance between (d) and (f), e_2: 20 mm next to e_1), and (f) anterior border of the medial ligament
of the knee.

126 To prepare for the isotonic knee exercises, each subject completed a series of warm-up exercises
127 followed by five minutes of brisk walking (Kim et al., 2014) and then a five-minute rest period. After the
128 rest period, the subject was seated on the Con-Trex station in a comfortable posture, and his/her back was
129 strapped to the back rest for safety. The subject's knee position was set to 90 degrees of flexion. Because
130 of limited space and the distance between the camera and the subject, we tested only the subject's right
131 leg. Next, the lever arm of the Con-Trex was attached to the ankle. The skin beyond the VMO muscle was
132 then cleaned with an alcohol pad to remove dirt and oil. This procedure additionally reduced electrode
133 impedance mismatch (Toledo-Peral et al., 2018). The team of researchers (J.J. and K.S.) then attached
134 the two sEMG electrodes to the skin just past the VMO muscle with the isotonic exercise monitoring
135 device. Specifically, the two active electrodes were attached on the line between the anterior superior
136 iliac spine and the joint space in front of the anterior border of the medial ligament, following SENIAM
137 guidelines (De Luca, 1997; Hermens et al., 2000). The distance between the two electrodes was 20 mm.
138 One reference electrode was placed on the C7 spinous process. Following electrode placement, the triaxial
139 accelerometer of the isotonic exercise monitor was strapped around the right ankle below the edge of the
140 Con-Trex's lever arm to measure knee ROM. Finally, the researchers configured the parameters of the
141 isotonic exercise monitoring device as shown in Table 2. The researchers also set up the video camera
142 system two metres away from the subject with a lateral view perpendicular to the subject.
143 For the exercise procedure, the one-repetition maximum (1-RM) of each subject was measured by
144 having each subject perform just one isotonic knee extension exercise, followed by a five-minute rest
145 period (Freitas de Salles et al., 2009; Lin et al., 2008). The subject then performed two isotonic knee
146 exercise repetitions at 25% of his/her 1-RM to become familiar with the measurement and to check
147 the sEMG signal and ROM measurements from the isotonic exercise monitoring device, followed by

148 another five-minute rest period. The subject then performed six isotonic knee exercise repetitions using
149 the Con-Trex device, with the isotonic exercise monitor recording the sEMG and ROM of the knee, and
150 the computer vision program also measuring the ROM of the knee. Following this, the subject rested for
151 another five minutes (Freitas de Salles et al., 2009; Lin et al., 2008), during which the researchers (J.J. and
152 K.S.) replaced the sEMG cable of the Mobi6-6b device's electrodes with those from the prior experiment,
153 configuring the Mobi6-6b device parameters as illustrated in Table 2. The subject then performed six
154 isotonic knee exercise repetitions using the Con-Trex device, with the Mobi6-6b device recording the
155 sEMG signals. At the end of the experiment, the sEMG electrodes on the skin were removed, and the
156 location of the electrode attachment was marked for the next experiment for each subject. All subjects
157 returned 24 hours later and performed the same experiment to evaluate the intra-rater reliability of the
158 isotonic exercise monitoring device compared with standard protocols. All data were automatically
159 collected by all instruments used in the experiment.

Table 2. Configuration of each device in this experiment

Device	Measurement	Configuration	Outcome measure
Con-Trex	N/A	Isotonic knee flexion/extension exercise with 25% of 1-RM	N/A
Mobi6-6b	sEMG	One channel with one pair of electrodes for sEMG (sampling rate: 1,024 Hz) Amplifier: 1,000-fold	MAV RMS
Canon EOS 550D with computer vision method	Video	Digital camera mounted on a tripod with 1 metre height and 2 metres away with a perpendicular orientation (sampling rate: 30 frames per second) Resolution: 18 megapixels 1,920x1,080 pixels and the flash disabled.	ROM
Isotonic exercise monitor	sEMG ROM	Two channels with one pair of electrodes for sEMG (sampling rate: 1,000 Hz) and triaxial accelerometer on the ankle (sampling rate: 100 Hz) Amplifier: 1,500-fold	MAV RMS ROM

Data analysis

161 The motor unit action potential (MUAP) is the combination of all muscle fiber action potentials from a
162 single motor unit (Raez et al., 2006). In this study, the MUAP was detected by a skin surface electrode
163 positioned on the VMO muscle. At the electrode, the raw sEMG was detected and amplified. Differential
164 amplifiers are often utilized as first stage amplifiers. Before collection, low- or high-frequency noises and
165 other signal noises were filtered from the signal as demonstrated in Figure 3.
166 The raw sEMG signal from the isotonic exercise monitoring device was first amplified 1,500-fold and
167 then filtered by the bandpass filter circuits at 10-500 Hz. The notch filter circuits subsequently reduced
168 the 50 Hz as powerline noise (Akwei-Sekyere, 2015) in the sEMG. Next, this sEMG was sampled at
169 a frequency of 1,000 Hz as part of the software used to gather data into the computer. The signal was
170 also filtered with an infinite impulse response (IIR) bandpass filter at 10-500 Hz and then normalized
171 to a standard value by dividing the maximal peak of sEMG during muscle contraction, according to
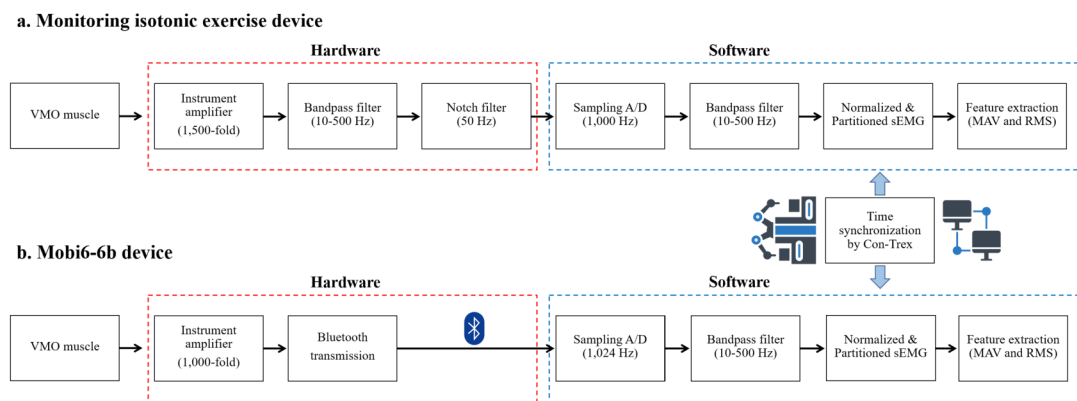
a. Monitoring isotonic exercise device

b. Mobi6-6b device

Figure 3. Feature extraction process of sEMG in: (a) the isotonic exercise monitoring device and (b) the Mobi6-6b device.

the methods of prior studies (Biviá-Roig et al., 2019; Gagnat et al., 2020). Time synchronization by Con-Trex was then used to partition this sEMG by knee extension periods. Finally, the MAV and RMS were extracted from the sEMG signal and calculated using the following two equations:

$$MAV = \frac{1}{N} \sum_{i=1}^{N} |X_i| \tag{1}$$

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^{N} X_i^2} \tag{2}$$

Here, MAV is the mean absolute value of the sEMG signal, N is the number of sEMG samples, X_i is the sEMG amplitude at the i index, and RMS is the root mean square of the sEMG signal. The raw sEMG signal from the Mobi6-6b was amplified 1,000-fold and then transferred using Bluetooth technology. In the subsequent procedure, the computer received wireless sEMG data with a sample rate of 1,024 Hz, which was then filtered with an IIR bandpass filter at 10-500 Hz. Finally, the sEMG features were extracted using the same methods that were used with the isotonic exercise monitoring device.

To calculate ROM, as illustrated in Figure 4, a triaxial accelerometer (±2 g range) of the isotonic exercise monitor was strapped around the right ankle of the subject and then sampled at 100 Hz. The roll (ϕ_a) and pitch (θ_a) angles (Narkhede et al., 2021; Franco et al., 2021) were then calculated using the following equations:

$$\phi_a = \arctan(a_y/a_z) \tag{3}$$

$$\theta_a = \arctan\left(\frac{-a_x}{a_y \sin\phi + a_z \cos\phi}\right) \tag{4}$$

Here, a_x, a_y, and a_z are represented linear accelerations determined along three orthogonal axes, respectively.

The ROM was measured from the starting angle of knee flexion to the final angle of knee extension based on the time-synchronization of Con-Trex recordings.

During knee exercise, the subject was recorded using a digital camera (Canon EOS 550D) as part of the computer vision approach. The digital camera was also mounted on a tripod that was one metre height and perpendicular to the subject. There are six primary ROM calculation processes based on convolution neural networks in object detection (Hakim and Fadhil, 2021). First, an image of the knee at its initial angle of flexion was cropped from the top left to the bottom right using sliding windows to find
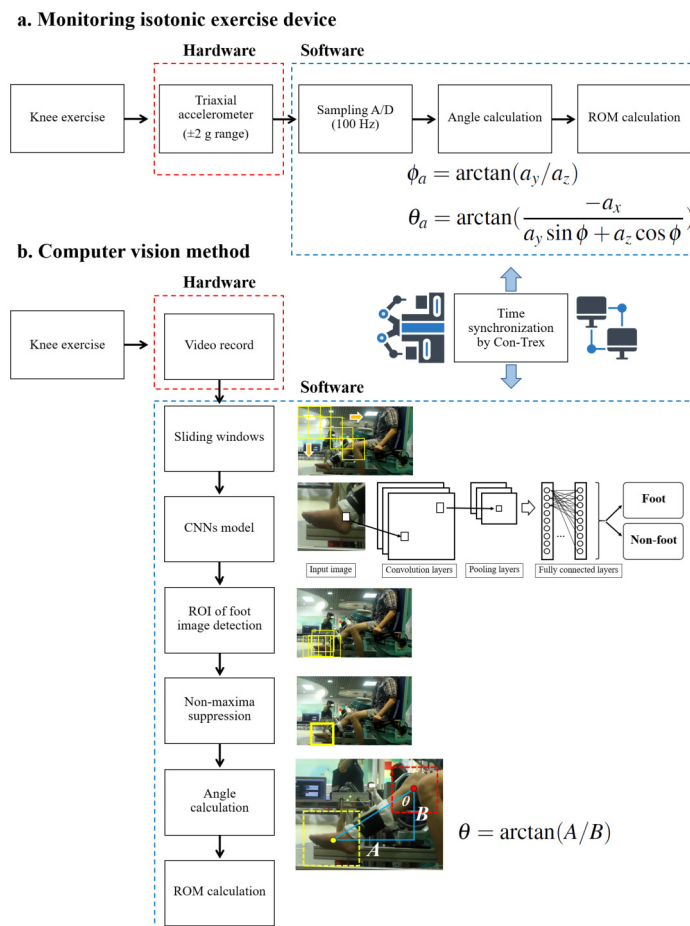
Figure 4. ROM calculation process in: (a) the isotonic exercise monitoring device and (b) the computer vision method.

the located foot ROI in the image. According to the methods outlined in a previous study (Duangsoithong et al., 2019), a pre-trained convolutional neural networks (CNNs) model was then used to classify each cropped image to determine whether it contained a foot or not. If this CNNs model predicted the that image contained a foot, the ROI was stored in memory until the end of the last sliding cropped image. The algorithm then picked a single ROI from several overlapping entities, a process known as non-maxima suppression (Rothe et al., 2015). Next, the centroid of the foot ROI and the fixed location of the knee joint was labelled by the team researcher (J.J.). In this experiment, the knee joint of the subject was fitted into the Con-Trex lever arm's rotating point. The location of the camera and the Con-Trex both remained the same. The angle of the knee joint along the Y-axis was calculated using the ROI of the foot and the location of the knee joint, as shown in Equations 5 and illustrated in Figure 5. Then, the final knee extension degree was noted, as labeled by the Con-Trex. The ROM was then determined by subtracting the end degree of knee extension from the beginning angle of knee flexion. After calculating the range of motion, the video of the participant's exercise was deleted immediately. Only the final ROM calculation of the participant was stored on the computer.

$$\theta = \arctan(A/B) \tag{5}$$

Here, θ is the angle of the knee joint, A is the distance on the X-axis between the centroid of the foot ROI and the location of the knee joint, and B is the distance on the Y-axis between the centroid of the foot ROI and the location of the knee joint.

The mean value of both devices on each day was calculated to evaluate the inter-rater and intra-rater reliability using ICCs. The research team proposed a method for interpreting ICCs, which has been used in
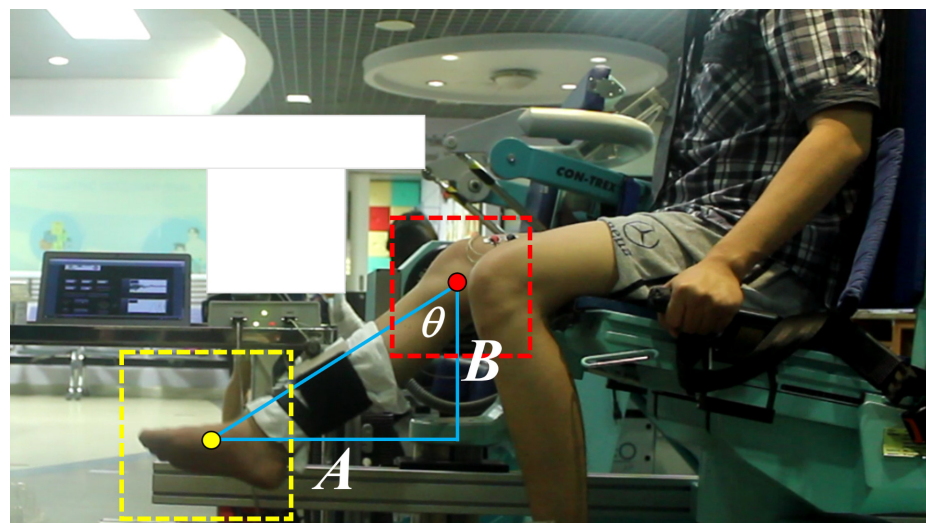
Figure 5. Example of knee joint angle calculation using the trigonometry rules in Equations 5 where θ is the angle of the knee joint.

many published studies (Koo and Li, 2016). An ICC value higher than 0.90 indicates excellent reliability.
ICC values between 0.75-0.90 and 0.50-0.75 indicate good and moderate reliability, respectively. Lastly,
ICCs less than 0.5 indicate poor reliability. The Bland-Altman plot analysis was conducted to demonstrate
the agreement between the isotonic exercise monitor and the standard measurement devices. Systematic
bias was determined using the 95% CI of mean difference (Gerke, 2020). If zero is included in the 95%
CI, no systematic bias may be inferred. A narrow 95% CI (LoA95) indicates more stability. We utilized
all analyses using the R Program (Vienna, Austria) version 4.0.3.

RESULTS

The results of our experiments show that the isotonic exercise monitoring device could be used to monitor
knee exercises under supervision. The mean values of the sEMG parameters and ROM are shown in
Table 3; the average MAV and RMS were 0.17 and 0.21, respectively. The mean knee ROM value was
87.18 ± 1.79 degrees, which was similar to the knee ROM values of healthy volunteers (Saranya et al.,
2019).

Table 3. Results of inter-rater and intra-rater reliability of the isotonic exercise monitor

	Mean (SD)	Inter-rater ICCs (95% IC)	SEM_1	Intra-rater ICCs (95% IC)	SEM_2
MAV	0.17 (0.04)	0.73 (0.49, 0.86)	0.02	0.89 (0.71, 0.96)	0.01
RMS	0.21 (0.03)	0.79 (0.61, 0.89)	0.01	0.88 (0.70, 0.95)	0.01
ROM	87.18 (1.79)	0.93 (0.02, 0.98)	0.47	0.82 (0.54, 0.93)	0.76

Note: ICCs: intraclass correlation coefficients, SEM_1: standard error of measurement of Inter-rater ICCs
(95% IC), SEM_2: standard error of measurement of Intra-rater ICCs (95% IC), MAV: mean absolute value
of sEMG signal, RMS: root mean square of sEMG signal, and ROM: range of motion of knee joint.

The inter-rater ICCs of the MAV and RMS between the isotonic exercise monitor and the Mobi6-6b
were 0.73 (95% CIs 0.49, 0.86) and 0.79 (95% CIs 0.61, 0.89), respectively. These results show moderate
and good reliability of sEMG measurements between the two devices. Furthermore, the between-day
intra-rater ICCs of the MAV and RMS of the isotonic exercise device were 0.89 (95% CIs 0.71, 0.96) and
0.88 (95% CIs 0.70, 0.95), respectively, indicating the sEMG data had good reliability between the two
testing days (Koo and Li, 2016).
The inter-rater ICCs of ROM between the isotonic exercise monitor and the computer vision method
was 0.93 (95% CIs 0.02, 0.98), indicating excellent reliability. The intra-rater reliability of the ROM
between days was 0.82 (95% CIs 0.54, 0.93), illustrating good reliability of the device (Koo and Li, 2016).

235   The Bland-Altman plot compared two experimental measurements in three parameters: MAV, RMS,
236 and ROM. At first, the mean difference of MAV between the isotonic exercise monitoring device and the
237 Mobi6-6b was 0.0058 (95% CI = -0.0027, 0.0143) (Figure 6). The width of LoA95 was -0.0463 to 0.0580.
238 Figure 7 shows the RMS parameter. The mean difference between the isotonic exercise monitoring device
239 and the Mobi6-6b was 0.0017 (95% CI = -0.0054, 0.0088). The width of LoA95 ranged from -0.0419 to
240 0.0452. Lastly, the Bland–Altman analysis indicated that the mean ROM difference between the isotonic
241 exercise monitoring device and the computer vision method was -0.8311 (95% CI = -0.9000, -0.7622).
242 The width of LoA95 was -1.2533 to -0.4089, as shown in Figure 8.
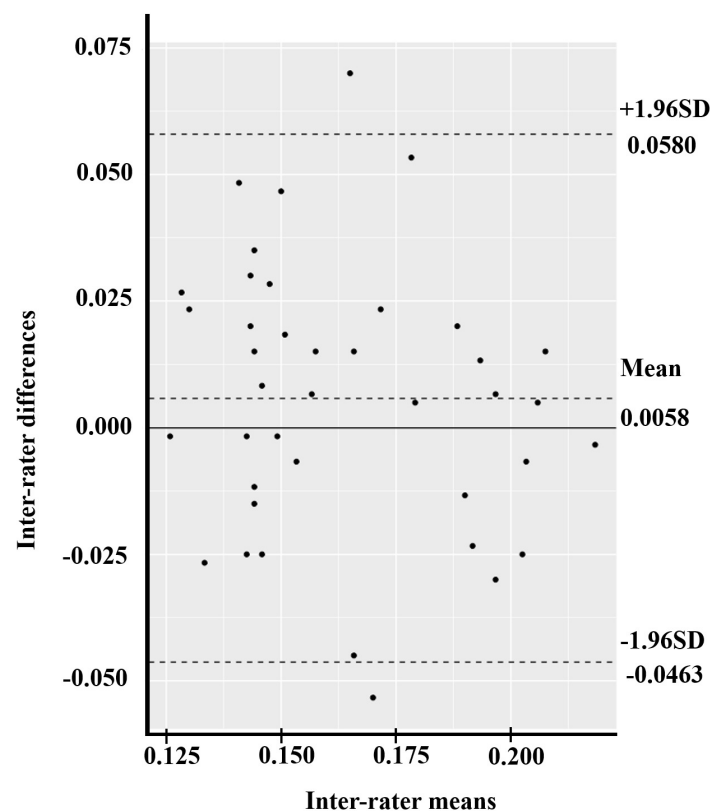
Figure 6. The Bland–Altman plot of the inter-rater agreement of MAV between the isotonic exercise monitoring device and the Mobi6-6b (n = 40).

DISCUSSION

244 This isotonic exercise monitoring device tested in this study was developed in a laboratory for the purpose
245 of monitoring knee exercises. As required by sEMG instrument standards, this study established that this
246 device may be used in healthy volunteers for real-time exercise monitoring without major consequences,
247 such as serious joint or muscle injury (Tankisi et al., 2020). The MAV and RMS of the isotonic exercise
248 monitoring device revealed moderate to good inter-rater reliability when compared to the Mobi6-6b
249 device. Additionally, the results demonstrated the excellent reliability of the ROM calculated using
250 the isotonic exercise monitor compared to ROM values acquired using the computer vision method. In
251 terms of between-day intra-rater reliability, the sEMG and ROM measurements were shown to have
252 good reliability. Moreover, the Bland–Altman plot of the MAV and RMS showed no systematic bias
253 (Gerke, 2020). Because our results show that the tested isotonic exercise monitor accurately records
254 standard sEMG measurements, which are beneficial for signal recognition in high-precision measurements,
255 categorization of limb position, and analysis of motion movement (Sae Jong et al., 2021; Thiamchoo and
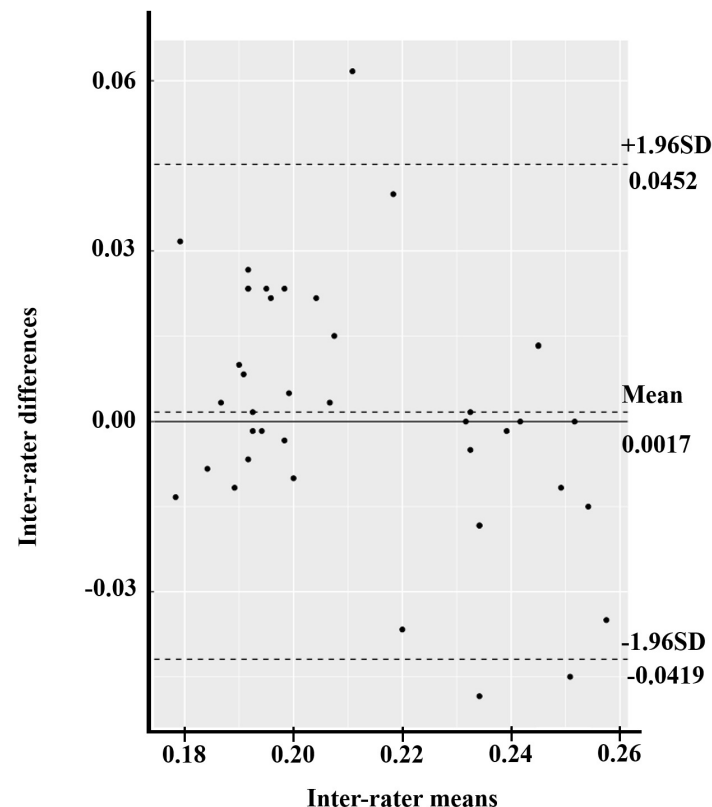
Figure 7. The Bland–Altman plot of inter-rater agreement of RMS values between the isotonic exercise monitoring device and the Mobi6-6b (n = 40).

Phukpattaranont, 2022), we conclude that the isotonic exercise monitoring device and its parameters could be used in clinical practice as a tool for monitoring knee rehabilitation. For example, it might be used to monitor a training station in a general primary care unit. Additionally, this isotonic exercise monitor offers objective data monitoring, real-time biofeedback, and automatic data recording as shown in Figure 1.

While the ROM's inter-rater reliability was excellent, its confidence interval was large (0.02,0.98; (Thangjai et al., 2020; Hazra, 2017)) due to the angle's scale being highly sensitive. In this experiment, the computer vision algorithm also detected the centroid of the foot image while calculating knee range of motion, instead of using the ankle's lateral malleolus (Hancock et al., 2018). However, the Bland–Altman plot pointed out a small, -0.8311 degrees bias in the ROM measurement, with a narrow 95% CI. According to a previous study (Guzik et al., 2020), a typical minimal clinical important differences (MCID) of knee ROM values is about 6.81 degrees. The tested isotonic exercise monitor may be good for monitoring exercise, but is not suited for use as a high-precision measuring instrument.

Numerous exercise devices combining robotic and computer systems have been created in recent years (Hu et al., 2021; Zhang and Liu, 2021). Advances in information processing have also substantially improved treatment evaluation options. Using existing exercise devices, we can observe the progression of significant exercise parameters such as force and range of motion. The Con-Trex is a standard exercise monitor, which has been shown to be reliable in several previous studies (Maffiuletti et al., 2007; Ema et al., 2018). In accordance with the Con-Trex, the isotonic exercise monitor was able to analyze objective data that might assist in determining exercise activities.

There are some limitations of the study. No satisfaction questionnaires were administered to the study participants prior to or following the use of this isotonic exercise monitor. The sample size of this study was also rather small.

In future work, this monitoring device could be reduced in size to accommodate mobile monitoring
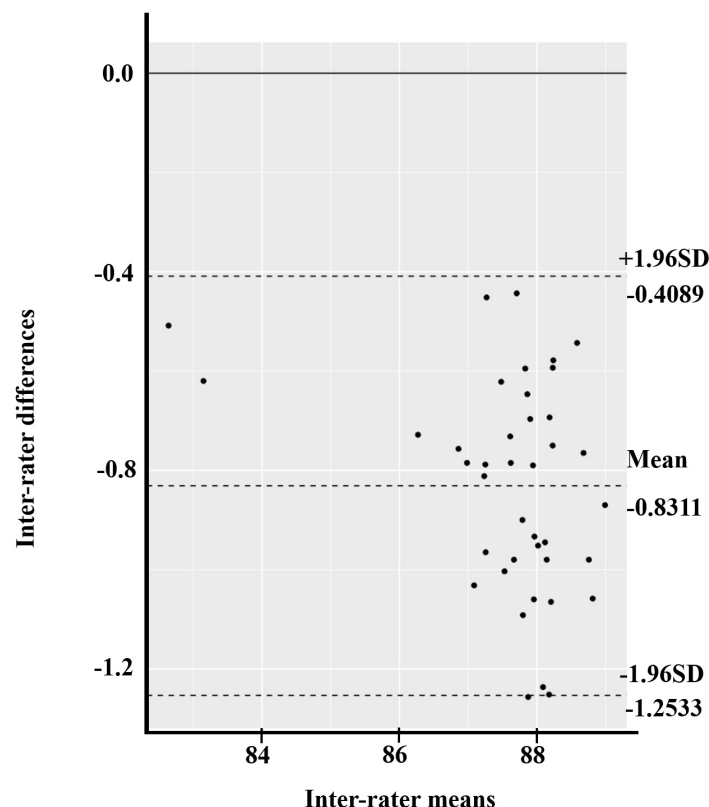
Figure 8. The Bland–Altman plot of inter-rater agreement of ROM values between the isotonic exercise monitoring device and the computer vision method (n = 40).

279 applications. Furthermore, additional research on specific subsets of patients, including older adults,
280 should be done to determine the device's efficacy in rehabilitation programs.

CONCLUSION

282 This study confirms the reliability of an isotonic exercise monitoring system for knee rehabilitation.
283 The results show that the sEMG parameters and ROM calculated with this device have moderate to
284 excellent inter-rater reliability with the results of standard monitoring devices. The tested monitoring
285 device also illustrated good intra-rater reliability between the two study days. The Bland–Altman analysis
286 showed there was no systematic bias of MAV and RMS values, but did show a small bias in ROM values
287 between the isotonic exercise monitoring device and the computer vision results. Therefore, this isotonic
288 exercise monitor could not be used as a high-precision knee ROM measuring device, but may be used to
289 track a patient's exercise and to report the patient's exercise metrics to healthcare providers. For future
290 research, this device should be made smaller and interfaced with mobile phones for home-based exercise
291 monitoring.

ACKNOWLEDGMENTS

REFERENCES

Akwei-Sekyere, S. (2015). Powerline noise elimination in biomedical signals via blind source separation and wavelet analysis. *PeerJ*, 3:e1086.

Anwer, S. and Alghadir, A. (2014). Effect of isometric quadriceps exercise on muscle strength, pain, and function in patients with knee osteoarthritis: a randomized controlled study. *Journal of physical therapy science*, 26(5):745–748. 24926143[pmid].

Biviá-Roig, G., Lisón, J. F., and Sánchez-Zuriaga, D. (2019). Determining the optimal maximal and submaximal voluntary contraction tests for normalizing the erector spinae muscles. *PeerJ*, 7:e7824.

Boldrini, P., Bernetti, A., Fiore, P., and SIMFER Executive Committee, S. C. f. I. A. (2020). Impact of covid-19 outbreak on rehabilitation services and physical and rehabilitation medicine physicians' activities in italy. an official document of the italian prm society (simfer). *European Journal of Physical and Rehabilitation Medicine*, 56(3).

Bujang, M. A. and Baharum, N. (2017). A simplified guide to determination of sample size requirements for estimating the value of intraclass correlation coefficient: a review. *Archives of Orofacial Sciences*, 12(1).

CDC (2020). Osteoarthritis (oa). https://www.cdc.gov/arthritis/basics/osteoarthritis.htm. Accessed: 2021-01-30.

Cui, A., Li, H., Wang, D., Zhong, J., Chen, Y., and Lu, H. (2020). Global, regional prevalence, incidence and risk factors of knee osteoarthritis in population-based studies. *EClinicalMedicine*, 29-30:100587.

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2):135–163.

Duangsoithong, R., Jaruenpunyasak, J., and Garcia, A. (2019). Foot recognition using deep learning for knee rehabilitation.

Ema, R., Suzuki, M., Kawaguchi, E., Saito, I., and Akagi, R. (2018). Effects of sex and joint action on voluntary activation. *PeerJ*, 6:e5968.

Esselman, P. C. and Lacerte, M. (1994). Principles of isokinetic exercise. *Physical Medicine and Rehabilitation Clinics of North America*, 5(2):255–268.

Fink, B., Egl, M., Singer, J., Fuerst, M., Bubenheim, M., and Neuen-Jacob, E. (2007). Morphologic changes in the vastus medialis muscle in patients with osteoarthritis of the knee. *Arthritis Rheum*, 56(11):3626–3633.

Franco, L., Sengupta, R., Wade, L., and Cazzola, D. (2021). A novel imu-based clinical assessment protocol for axial spondyloarthritis: a protocol validation study. *PeerJ*, 9:e10623.

Freitas de Salles, B., Simão, R., Miranda, F., da Silva Novaes, J., Lemos, A., and Willardson, J. M. (2009). Rest interval between sets in strength training. *Sports Medicine*, 39(9):765–777.

Gagnat, Y., Brændvik, S. M., and Roeleveld, K. (2020). Surface electromyography normalization affects the interpretation of muscle activity and coactivation in children with cerebral palsy during walking. *Front. Neurol.*, 11:202.

Gerke, O. (2020). Reporting standards for a bland–altman agreement analysis: A review of methodological reviews. *Diagnostics*, 10(5).

Giavarina, D. (2015). Understanding bland altman analysis. *Biochem. Med. (Zagreb)*, 25(2):141–151.

Guzik, A., Drużbicki, M., Wolan-Nieroda, A., Turolla, A., and Kiper, P. (2020). Estimating minimal clinically important differences for knee range of motion after stroke. *Journal of Clinical Medicine*, 9(10).

Hakim, H. and Fadhil, A. (2021). Survey: Convolution neural networks in object detection. *Journal of Physics: Conference Series*, 1804(1):012095.

Hancock, G. E., Hepworth, T., and Wembridge, K. (2018). Accuracy and reliability of knee goniometry methods. *Journal of Experimental Orthopaedics*, 5(1):46.

Hart, H., Ackland, D., Pandy, M., and Crossley, K. (2012). Quadriceps volumes are reduced in people with patellofemoral joint osteoarthritis. *Osteoarthritis and Cartilage*, 20(8):863–868.

Hazra, A. (2017). Using the confidence interval confidently. *Journal of Thoracic Disease*, 9(10).

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., and Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *J. Electromyogr. Kinesiol.*, 10(5):361–374.

Heywood, S., McClelland, J., Geigle, P., Rahmann, A., Villalta, E., Mentiplay, B., and Clark, R. (2019). Force during functional exercises on land and in water in older adults with and without knee osteoarthritis: Implications for rehabilitation. *The Knee*, 26(1):61–72.

351 Hislop, A. C., Collins, N. J., Tucker, K., Deasy, M., and Semciw, A. I. (2020). Does adding hip exercises
352   to quadriceps exercises result in superior outcomes in pain, function and quality of life for people
353   with knee osteoarthritis? a systematic review and meta-analysis. *British Journal of Sports Medicine*,
354   54(5):263–271.

355 Hu, N., Wang, A., and Wu, Y. (2021). Robust adaptive pd-like control of lower limb rehabilitation robot
356   based on human movement data. *PeerJ Computer Science*, 7:e394.

357 Kim, K., Lee, T., Kang, G., Kwon, S., Choi, S., and Park, S. (2014). The effects of diverse warm-up
358   exercises on balance. *Journal of physical therapy science*, 26(10):1601–1603.

359 Kim, M.-K., Choi, J.-H., Gim, M.-A., Kim, Y.-H., and Yoo, K.-T. (2015). Effects of different types of
360   exercise on muscle activity and balance control. *Journal of Physical Therapy Science*, 27(6):1875–1881.

361 Kolasinski, S. L., Neogi, T., Hochberg, M. C., Oatis, C., Guyatt, G., Block, J., Callahan, L., Copenhaver,
362   C., Dodge, C., Felson, D., Gellar, K., Harvey, W. F., Hawker, G., Herzig, E., Kwoh, C. K., Nelson, A. E.,
363   Samuels, J., Scanzello, C., White, D., Wise, B., Altman, R. D., DiRenzo, D., Fontanarosa, J., Giradi,
364   G., Ishimori, M., Misra, D., Shah, A. A., Shmagel, A. K., Thoma, L. M., Turgunbaev, M., Turner, A. S.,
365   and Reston, J. (2020). 2019 american college of rheumatology/arthritis foundation guideline for the
366   management of osteoarthritis of the hand, hip, and knee. *Arthritis & Rheumatology*, 72(2):220–233.

367 Koo, T. K. and Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients
368   for reliability research. *Journal of Chiropractic Medicine*, 15(2):155–163.

369 Kulikajevas, A., Maskeliunas, R., and Damaševičius, R. (2021). Detection of sitting posture using
370   hierarchical image composition and deep learning. *PeerJ Comput. Sci.*, 7(e442):e442.

371 Kwok, I. H. Y., Paton, B., and Haddad, F. S. (2015). Does Pre-Operative physiotherapy improve outcomes
372   in primary total knee arthroplasty? - a systematic review. *J Arthroplasty*, 30(9):1657–1663.

373 Lin, H.-T., Hsu, A.-T., Chang, J.-H., Chien, C.-S., and Chang, G.-L. (2008). Comparison of emg activity
374   between maximal manual muscle testing and cybex maximal isometric testing of the quadriceps femoris.
375   *Journal of the Formosan Medical Association*, 107(2):175–180.

376 Liu, Q., Niu, J., Li, H., Ke, Y., Li, R., Zhang, Y., and Lin, J. (2017). Knee symptomatic osteoarthritis,
377   walking disability, nsaids use and all-cause mortality: Population-based wuchuan osteoarthritis study.
378   *Scientific Reports*, 7(1):3309.

379 Maffiuletti, N. A., Bizzini, M., Desbrosses, K., Babault, N., and Munzinger, U. (2007). Reliability of knee
380   extension and flexion measurements using the con-trex isokinetic dynamometer. *Clinical Physiology*
381   *and Functional Imaging*, 27(6):346–353.

382 Narkhede, P., Walambe, R., Poddar, S., and Kotecha, K. (2021). Incremental learning of lstm framework
383   for sensor fusion in attitude estimation. *PeerJ Computer Science*, 7:e662.

384 Phinyomark, A., Phukpattaranont, P., and Limsakul, C. (2012). Feature reduction and selection for emg
385   signal classification. *Expert Systems with Applications*, 39(8):7420–7431.

386 Raez, M. B. I., Hussain, M. S., and Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: detection,
387   processing, classification and applications. *Biol. Proced. Online*, 8(1):11–35.

388 Remigio, W., Tsai, N., Layos, L., and Chavez, M. (2017). Inter-rater and intra-rater reliability of the fluid
389   goniometer for measuring active knee flexion in painful knees; correlations do not mean agreement.
390   *Journal of Physical Therapy Science*, 29(6):984–988.

391 Rothe, R., Guillaumin, M., and Van Gool, L. (2015). Non-maximum suppression for object detection
392   by passing messages between windows. In Cremers, D., Reid, I., Saito, H., and Yang, M.-H., editors,
393   *Computer Vision – ACCV 2014*, pages 290–306, Cham. Springer International Publishing.

394 Sae Jong, N., de Herrera, A. G. S., and Phukpattaranont, P. (2021). Multimodal data fusion of electromyo-
395   graphy and acoustic signals for thai syllable recognition. *IEEE Journal of Biomedical and Health*
396   *Informatics*, 25(6):1997–2006.

397 Saranya, S., Poonguzhali, S., and Saraswathy, G. (2019). Muscle activation based estimation of knee joint
398   angle using surface electromyography signals. In *2019 IEEE International Conference on Distributed*
399   *Computing, VLSI, Electrical Circuits and Robotics (DISCOVER)*, 2019 IEEE International Conference
400   on Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER).

401 Sengchuai, K. and Jindapetch, N. (Thailand Patent 16629, Aug 21, 2020.). Psu knee exercise device.

402 Tankisi, H., Burke, D., Cui, L., de Carvalho, M., Kuwabara, S., Nandedkar, S. D., Rutkove, S., Stålberg,
403   E., van Putten, M. J., and Fuglsang-Frederiksen, A. (2020). Standards of instrumentation of emg.
404   *Clinical Neurophysiology*, 131(1):243–258.

405 Thangjai, W., Niwitpong, S.-A., and Niwitpong, S. (2020). Confidence intervals for the common

406   coefficient of variation of rainfall in thailand. *PeerJ*, 8:e10004.

407   Thiamchoo, N. and Phukpattaranont, P. (2022). Evaluation of feature projection techniques in object grasp
408   classification using electromyogram signals from different limb positions. *PeerJ Computer Science*,
409   8:e949.

410   Toledo-Peral, C. L., Gutiérrez-Martínez, J., Mercado-Gutiérrez, J. A., Martín-Vignon-Whaley, A. I.,
411   Vera-Hernández, A., and Leija-Salas, L. (2018). semg signal acquisition strategy towards hand fes
412   control. *Journal of Healthcare Engineering*, 2018:2350834.

413   UN (2019). *World Population Ageing 2019 Highlights*. United Nations.

414   Vigotsky, A. D., Halperin, I., Lehman, G. J., Trajano, G. S., and Vieira, T. M. (2018). Interpreting
415   signal amplitudes in surface electromyography studies in sport and rehabilitation sciences. *Frontiers in
416   Physiology*, 8.

417   Vincent, K. R. and Vincent, H. K. (2012). Resistance exercise for knee osteoarthritis. *PM & R : the
418   journal of injury, function, and rehabilitation*, 4(5 Suppl):S45–S52. 22632702[pmid].

419   Wiles, J. D., Taylor, K., Coleman, D., Sharma, R., and O'Driscoll, J. M. (2018). The safety of isometric
420   exercise: Rethinking the exercise prescription paradigm for those with stage 1 hypertension. *Medicine*,
421   97(10).

422   Yu, J., Zhang, S., Wang, A., Li, W., and Song, L. (2021). Musculoskeletal modeling and humanoid control
423   of robots based on human gait data. *PeerJ Computer Science*, 7:e657.

424   Yu, J. C., McIntyre, M., Dow, H., Robinson, L., and Winston, P. (2020). Changes to rehabilitation service
425   delivery and the associated physician perspectives during the covid-19 pandemic: A mixed-methods
426   needs assessment study. *American Journal of Physical Medicine & Rehabilitation*, 99(9).

427   Zeng, C.-Y., Zhang, Z.-R., Tang, Z.-M., and Hua, F.-Z. (2021). Benefits and mechanisms of exercise
428   training for knee osteoarthritis. *Frontiers in Physiology*, 12.

429   Zhang, B. and Liu, P. (2021). Control and benchmarking of a 7-dof robotic arm using gazebo and ros.
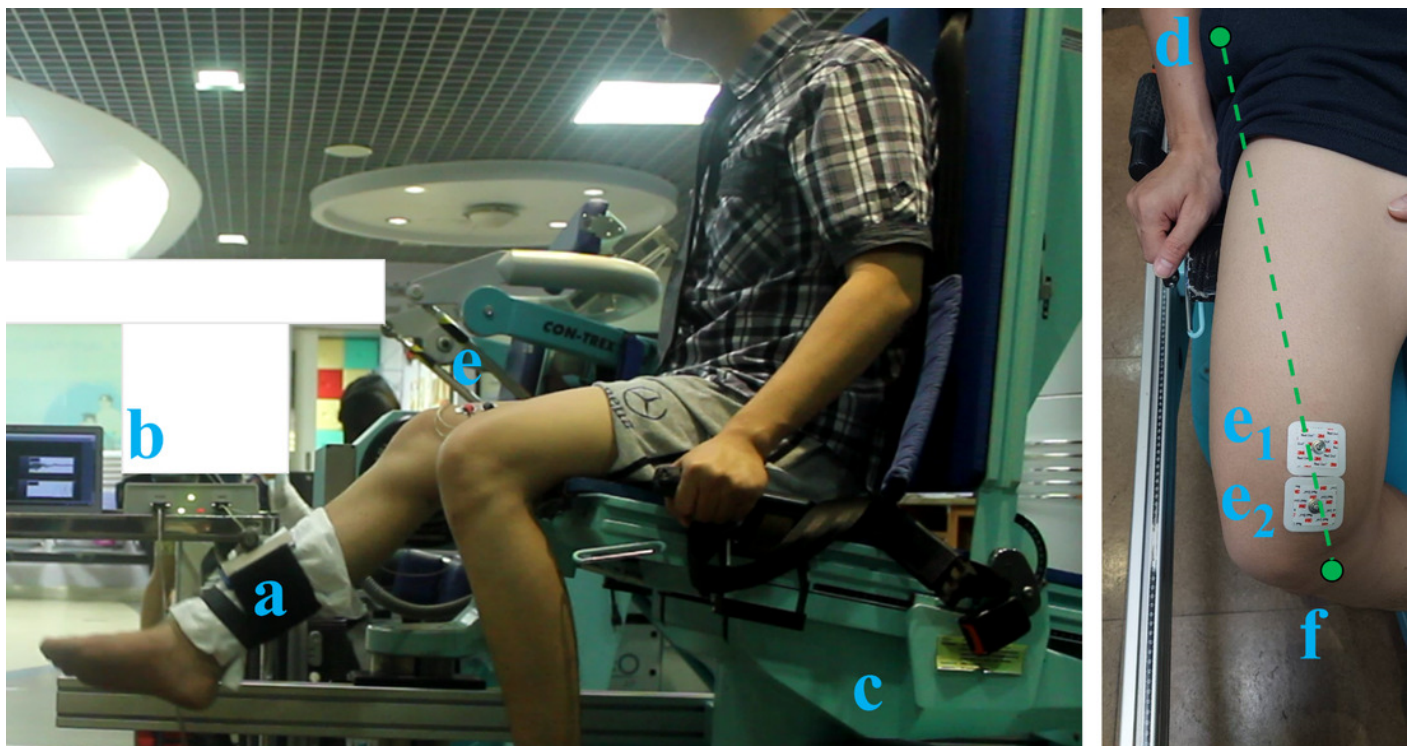430   *PeerJ Computer Science*, 7:e383.

Figure 1

Isotonic exercise monitoring device and its peripheral equipment: (a) sandbag, (b) isotonic exercise monitoring device, (c) triaxial accelerometer channel for knee angle measurement, (d) sEMG channel, (e) graphic user interface (GUI).
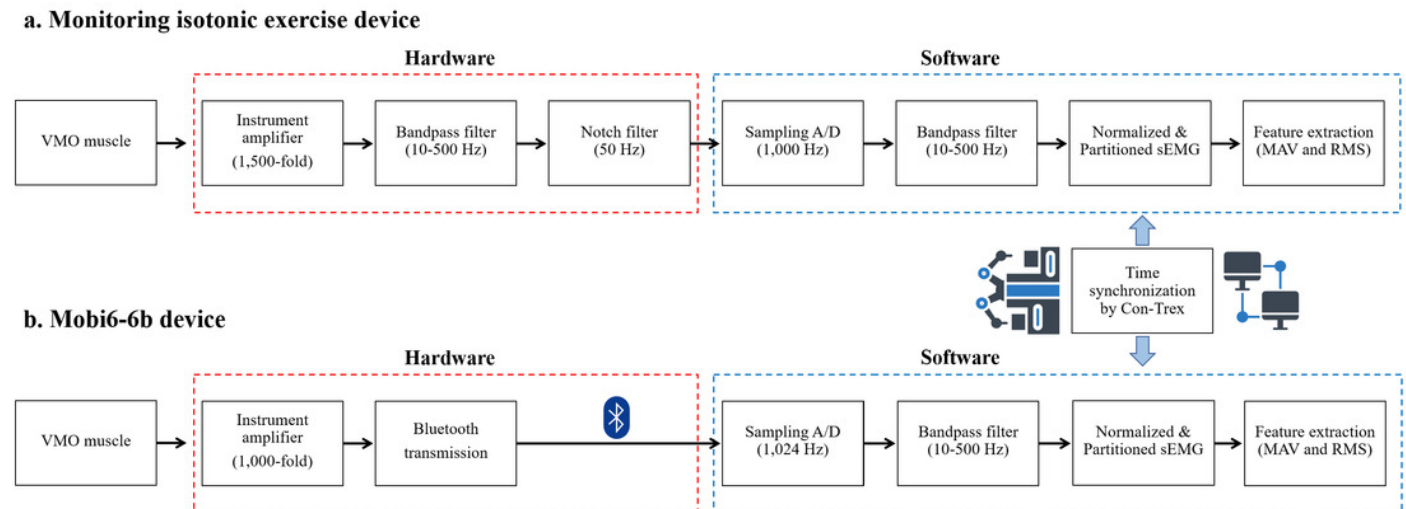
Figure 2

Experimental settings of the: (a) Con-Trex's lever arm, (b) isotonic exercise monitoring device, (c) Con-Trex device, (d) anterior superior iliac spines, (e1 and e2) electrode placement (e1: 80% of the distance between (d) and (f), e2: 20 mm next to e1),

Figure 3

Feature extraction process of sEMG in: (a) the isotonic exercise monitoring device and (b) the Mobi6-6b device.
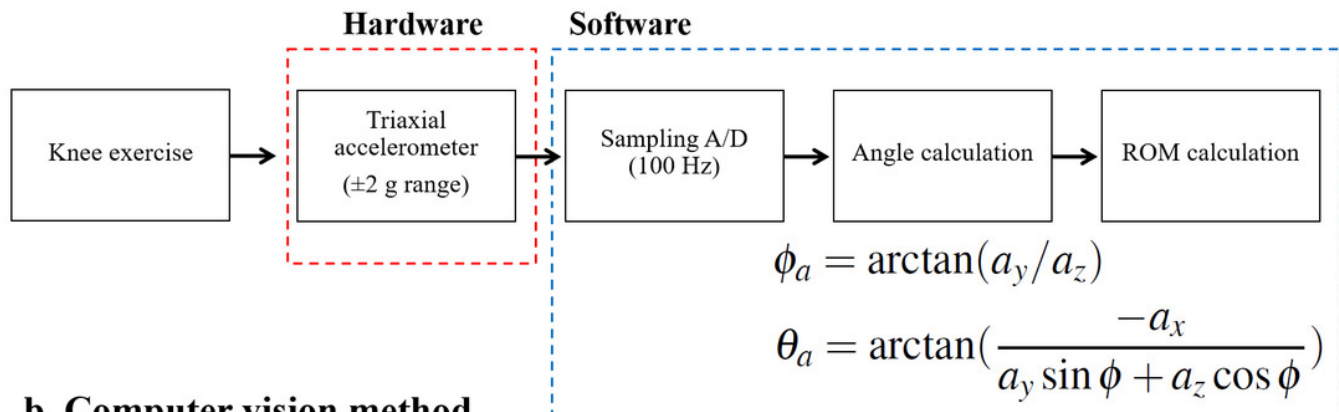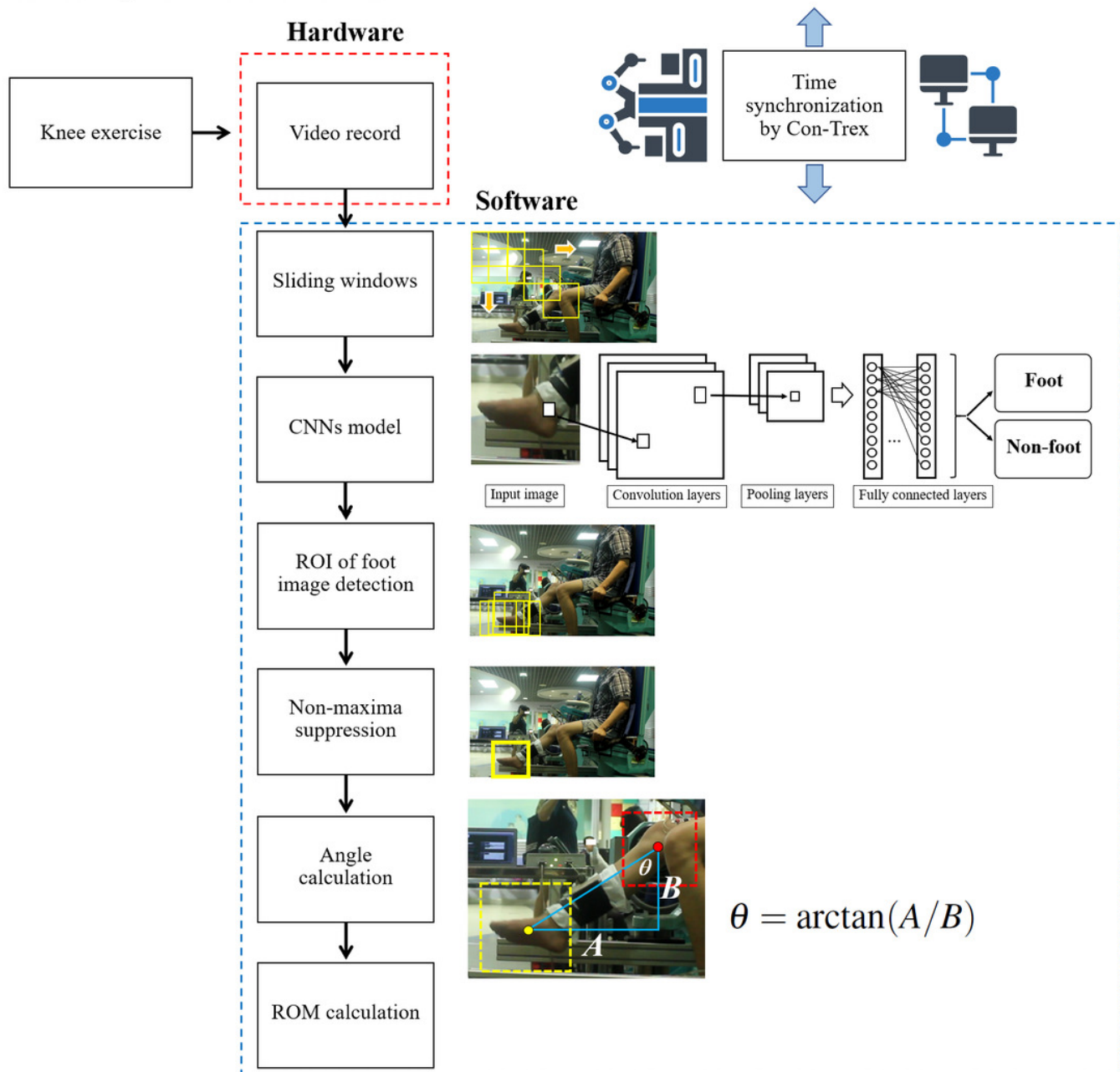
a. Monitoring isotonic exercise device

Hardware			Software			
VMO muscle	Instrument amplifier (1,500-fold) → Bandpass filter (10-500 Hz) → Notch filter (50 Hz)		Sampling A/D (1,000 Hz) → Bandpass filter (10-500 Hz) → Normalized & Partitioned sEMG → Feature extraction (MAV and RMS)			

Time synchronization by Con-Trex

b. Mobi6-6b device

Hardware			Software			
VMO muscle	Instrument amplifier (1,000-fold) → Bluetooth transmission		Sampling A/D (1,024 Hz) → Bandpass filter (10-500 Hz) → Normalized & Partitioned sEMG → Feature extraction (MAV and RMS)			

Figure 4

ROM calculation process in: (a) the isotonic exercise monitoring device and (b) the computer vision method.
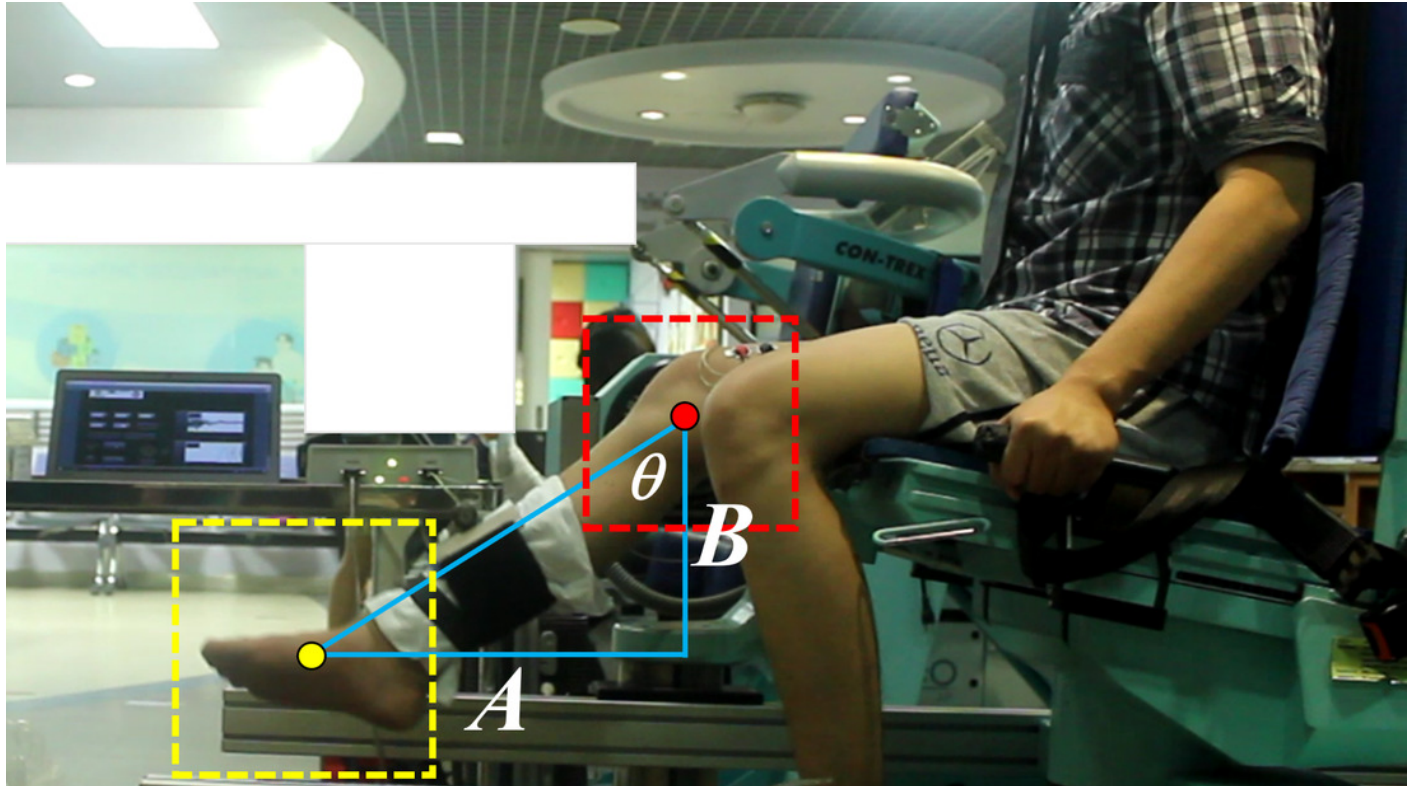
a. Monitoring isotonic exercise device

Hardware **Software**

Knee exercise → Triaxial accelerometer (±2 g range) → Sampling A/D (100 Hz) → Angle calculation → ROM calculation

$$\phi_a = \arctan(a_y/a_z)$$

$$\theta_a = \arctan\left(\frac{-a_x}{a_y \sin\phi + a_z \cos\phi}\right)$$

b. Computer vision method

Hardware

Knee exercise → Video record

Time synchronization by Con-Trex

Software

Sliding windows

↓

CNNs model

Input image → Convolution layers → Pooling layers → Fully connected layers → Foot / Non-foot

↓

ROI of foot image detection

↓

Non-maxima suppression

↓

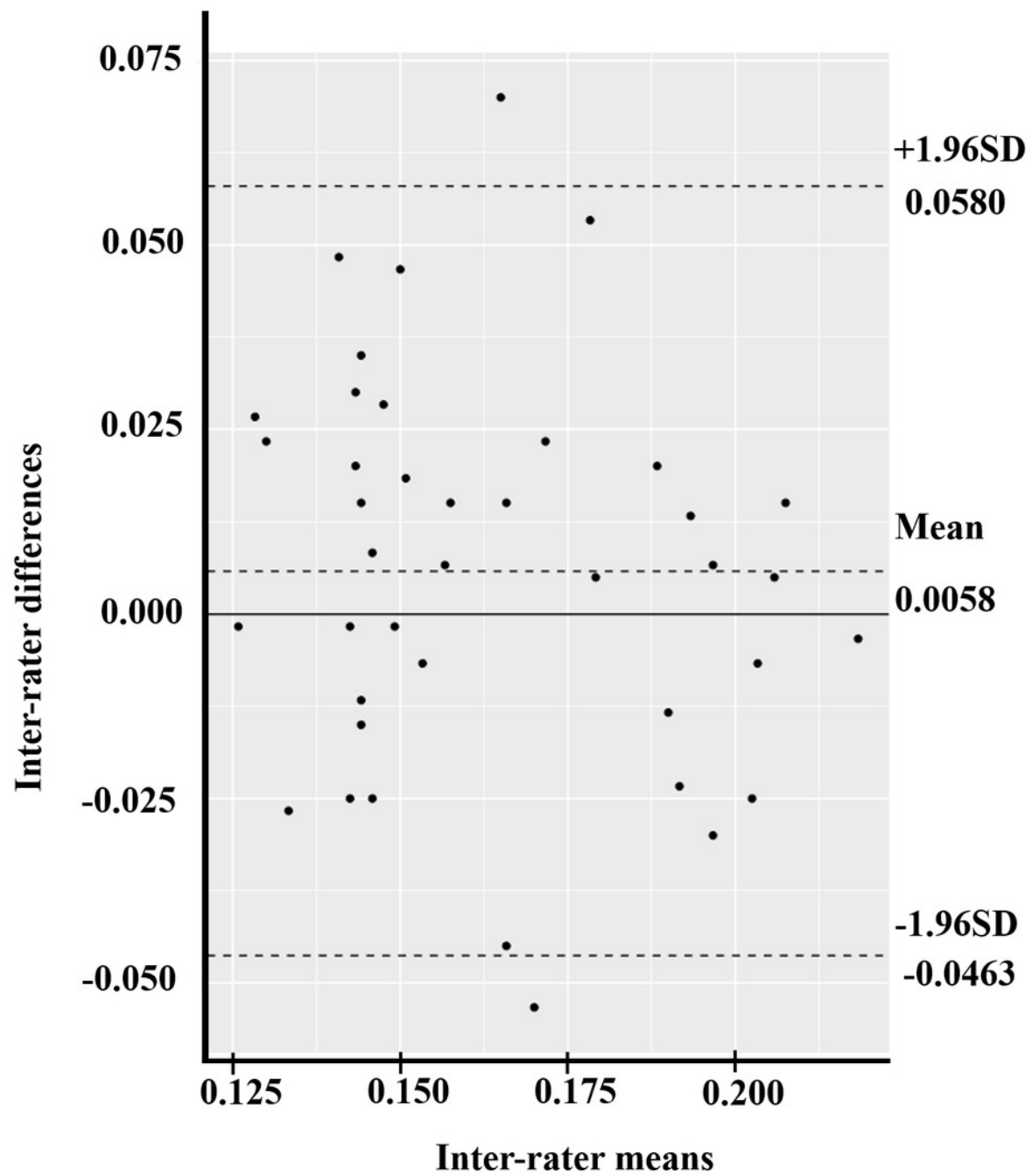Angle calculation

$$\theta = \arctan(A/B)$$

↓

ROM calculation

Figure 5

Example of knee joint angle calculation using the trigonometry rules in Equations 5 where θ is the angle of the knee joint.
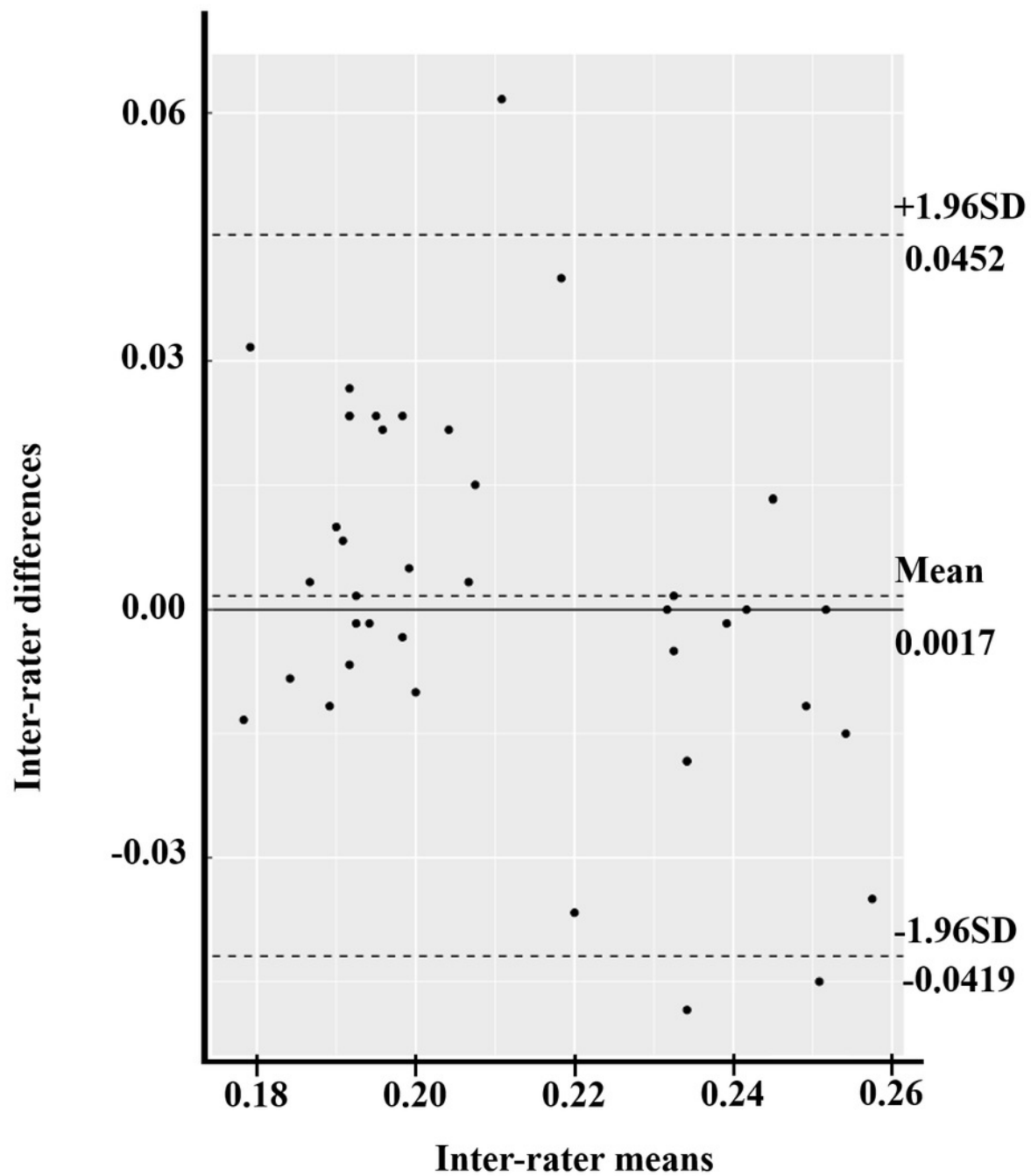
Figure 6

The Bland–Altman plot of the inter-rater agreement of MAV between the isotonic exercise monitoring device and the Mobi6-6b (n = 40).

Figure 7

The Bland–Altman plot of inter-rater agreement of RMS values between the isotonic exercise monitoring device and the Mobi6-6b (n = 40).

Figure 8

The Bland–Altman plot of inter-rater agreement of ROM values between the isotonic exercise monitoring device and the computer vision method (n = 40).