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Correlation of force sense error test measured by a pressure biofeedback unit and EMG activity of quadriceps femoris in healthy individuals

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ABSTRACT

Background: Our study developed a force sense error test (FSET) method for use on the quadriceps muscle, which could be employed in clinical practice to correlate the results of quadriceps muscle activity levels determined by surface electromyography (sEMG).

Methods: Twenty-four healthy individuals were included in the study. A pressure biofeedback unit (PBU) placed under the knee joint, was used for force sense error test (FSET) evaluation. First, a maximum contraction value was determined with the PBU. Next, 50% and 65% of the maximum contraction value were used for the analysis. Concurrently, norm values for the quadriceps muscle activity levels were determined by sEMG. Simultaneously, quadriceps muscle activity levels were recorded while testing the FSET using the PBU. Each measurement was repeated in triplicate, and the average constant errors observed by the PBU were recorded in mmHg.

Results: The FSET for both 50% and 65% of the normal mmHg value determined using the PBU positively correlated with activity change levels in the quadriceps muscle determined by sEMG ($p < 0.05$).

Conclusions: The relationship between the FSET measured using PBU and changes in the level of activity in the quadriceps muscle showed that a PBU can be used in clinical practice for proprioceptive evaluation of the knee region.

1. Introduction

The term proprioception is defined as the combination of joint position sense (JPS), kinesthesia (the perception of active and passive motion), and a sense of tension or force sense (FS) (Jones, 1994; Riemann and Lephart, 2002; Sherrington, 1907). The majority of studies investigating proprioception have mainly focused on JPS or kinesthesia, while research on FS is limited. FS is defined as a component of proprioception mainly related to the sense of tension, which is derived from muscle spindles and Golgi tendon organs (Kaynak et al., 2019) (Proske et al., 2004). Kim et al. (2014) described FS as "the ability to accurately reproduce a given force." However, the mechanism underpinning FS is not yet fully understood (Scotland et al., 2014).

In previous studies, two basic approaches have been used to measure FS; namely, the ipsilateral remembered (IR) method and the contralateral method (Kim et al., 2014; Zavieh et al., 2016). Researchers have preferred the IR method for evaluating the FS (Amirshakeri et al., 2019; Scotland et al., 2014; Zavieh et al., 2016). In the IR method, the target force is produced at a defined level of maximum voluntary isometric contraction by using visual feedback from the screen of the equipment. After an interval, the same target force is again reproduced on the same side without any visual feedback. The difference between the target force and the reproduced force is called FS error (Shakeri et al., 2019). FS error is considered one of the indicators of proprioceptive loss (Proske and Gandevia, 2012).

Isokinetic devices are widely used for FS evaluations (Dover and Powers, 2003; Li et al., 2016; Wang et al., 2016). Due to the fact that not every clinic has isokinetic devices, a more practical device for use in clinical practice is required to assess FS during both the acute and chronic stages following injury. Until now, existing literature has shown that the pressure biofeedback unit (PBU) is a useful training device for the FS of the cervical spine (Clark et al., 2015) and knee joint (Horstmann et al., 2017) in order to improve proprioceptive ability. Although the PBU is a practical device for use in the clinic, no study had used this device as an assessment tool for the FS measurement of the quadriceps femoris.

Recently, it has been speculated that FS plays an important role in maintaining functional joint stability since the inability to produce an appropriate force may increase the risk of injury (Allison et al., 2016). Studies have also shown that there is a relationship between FS error and functional ankle instability (Arnold and Docherty, 2006; Docherty et al., 2006). Although, the knee joint is the most studied joint for

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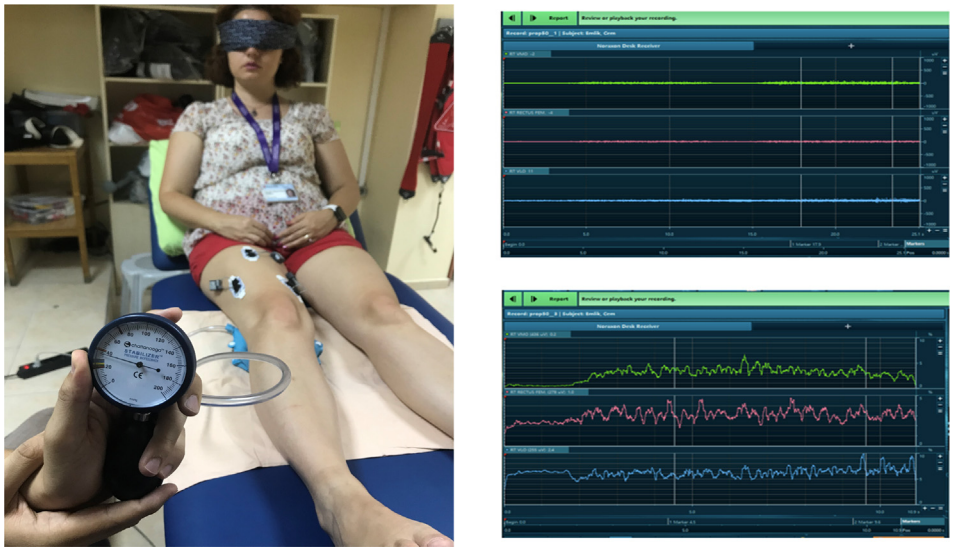

Fig. 1. The PBU value observed during the **FSET** 50% of the maximum quadriceps muscle contraction.

understanding proprioceptive deficits, FS error has not been investigated (Lephart et al., 1997). In addition, based on previous publications (da Costa et al., 2019; Tofari et al., 2016), surface electromyography (sEMG) was used as the gold standard in studies of the function of the quadriceps femoris muscle. To the best of our knowledge, no previous study has comprehensively investigated the relationship between sEMG activation and FS values for the quadriceps femoris muscle. Therefore, the aim of this study was to assess the possibility to use the PBU biofeedback unit for measuring the force sense. It was hypothesized that the FS error of the quadriceps femoris muscle determined using a PBU would correlate with sEMG activation.

2. Methods

2.1. Participants

Twenty-four healthy participants (15 males, 9 females; Age: 24.3 ± 3.5 years; BMI: 24.0 ± 3.5) were included in the study. Healthy participants were excluded if they had a previous history of lower extremity surgery, a lower extremity injury in the past year, and/or displayed neurological and systemic problems. This study was approved by the university's institutional review board, and all participants gave informed consent (GO 18/932).

2.2. Procedures

The Force Sense Error Test (FSET) protocol is based on the most preferred FS error protocol, the Ipsilateral Remembered Method (Amirshakeri et al., 2019; Scotland et al., 2014; Zavieh et al., 2016). Measurements were performed similar to predefined FSET procedures (Chen and Treleaven, 2013; Dover and Powers, 2003; Roren et al., 2009). The FSET of the quadriceps femoris muscle was measured with a PBU (Stabilizer ™, Chattanooga Group Inc., Chattanooga, TN), which is a device similar to a sphygmomanometer. In addition, quadriceps femoris muscle activity was simultaneously measured by sEMG.

2.2.1. EMG measurement

The sEMG device (Noraxon USA, Inc., Scottsdale, AZ) was used to measure the activation levels of the vastus medialis obliquus (VMO), vastus lateralis (VL), and rectus femoris (RF) muscles. The common-mode rejection ratio was greater than 80 dB, and the input impedance was greater than 10 MΩ. The sampling rate for the EMG data was 1000 Hz. Bipolar Ag/AgCl surface electrodes were placed at an interelectrode distance (center to center) of 2 cm. The electrode width was 1 cm.

The electrode sites on the body were prepared by shaving the hair, abrading the skin with fine sandpaper, and cleaning the surface with 70% isopropyl alcohol to minimize skin impedance. The electrode placement was determined according to the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) criteria (Hermens et al., 1999). A licensed physical therapist who was trained and experienced placed the fine-wire sEMG electrodes according to a standardized protocol. First, the researcher measured from the upper pole of the patella to the ipsilateral anterior superior iliac spine and asked the patient to lay in a supine position and extend the knee. The researcher calculated 20% of this distance and placed the sEMG electrode on the lateral side of the thigh and the upper and lateral part of the patella to represent the lower part of the VL. For the VMO, the electrodes were placed distal to the Anterior Superior Iliac Spine (ASIS) at a mark equivalent to 80% of the distance along a line drawn between the ASIS and the medial joint line anterior to the border of the medial collateral ligament. The placement of the electrodes for the RF was at 50% of the ASIS-to-patellar distance in the center of the anterior thigh between the marks already made to denote the medial and lateral-most palpable margins of the RF. The researcher placed the electrodes at appropriate angles to the muscle fibers of the VMO, RF, and VL.

2.2.2. Force sense error test procedure

<u>*Step 1. and Step 2.*</u>

Calibration of the PBU before FSET and calculating normal mmHg values: Healthy participants in the study sat with their knees fully extended on the exercise bed (extended sitting) (Fig. 1). The first researcher placed the PBU device under the dominant limb knee joint and inflated the cuff to 20 mmHg of pressure without any muscle contraction (Horstmann et al., 2017). Before starting the measurement, participants were instructed to push their knee on the PBU while contracting their quadriceps femoris at maximum effort (Fig. 2). The maximum mmHg value that was held over 5 s by the participants was recorded. EMG signals were normalized before each assessment of the subject. The increasing value from 20 mmHg to the maximum mmHg value was calculated and recorded as the maximum increase in mmHg (Fig. 2).

The first researcher then calculated 50% and 65% of the maximum increase in mmHg values and referred to them as the 50% norm mmHg and 65% norm mmHg values for measuring the FSET of the quadriceps

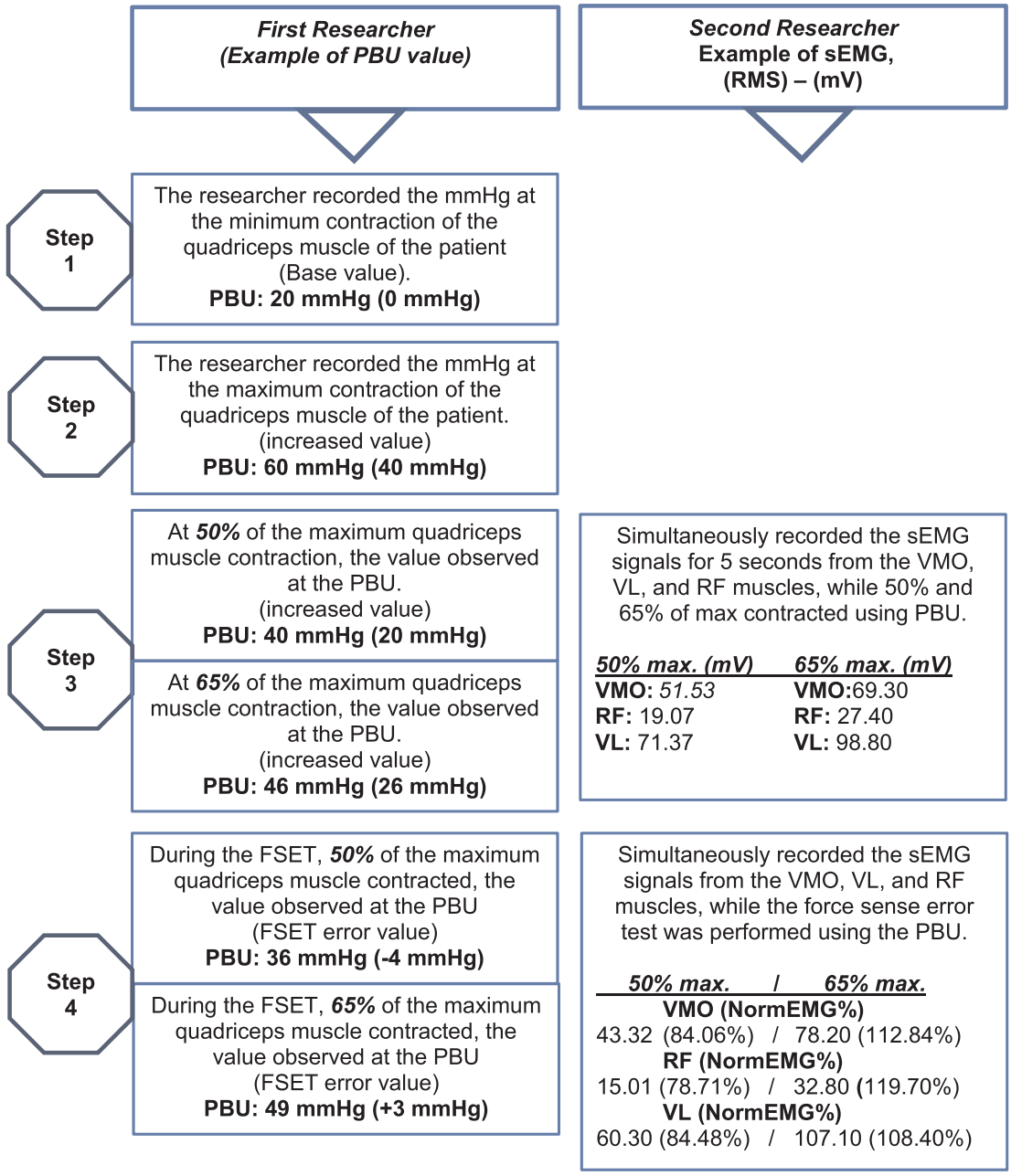

Fig. 2. Steps of the procedure for the force sense error test for 50% and 65% maximum mmHg values used by Pressure Biofeedback Unit.

Table 1
The PBU values (Mean ± SD) for each replicate. The intra-class correlation coefficient ($ICC_{3,1}$), 95% confidence intervals (95% CI), and standard error of measurement (SEM) indicate reliability.

PBU Values	Repeat 1	Repeat 2	Repeat 3	$ICC_{3,1}$ (95%CI)	SEM
	Mean ± SD	Mean ± SD	Mean ± SD		
FSET (mmHg) (50% max.)	43.37 ± 5.24	43.41 ± 5.80	43.50 ± 6.13	0.92 (0.85–0.96)	1.61
FSET (mmHg) (65% max.)	50.70 ± 7.02	50.54 ± 6.81	49.70 ± 7.53	0.96 (0.92–0.98)	1.42

Abbreviations: ICC, Intraclass Correlation Coefficient; CI: Confidence Interval SEM, Standard Error of Measurement, PBU: Pressure Biofeedback Unit, FSET: Force Sense Error Test.

Table 2
Descriptive statistics (mean ± SD, 95%CI) for the PBU values of the quadriceps, VMO, RF, and VL muscle activities.

50% of the maximum PBU value (n = 24)					
Norm value (mmHg)	FSET value (mmHg)	Muscles	sEMG-FSET RMS (mV)	sEMG-NV RMS (mV)	NormEMG (%)
QM 42.17 ± 4.44 (40.50–43.83)	1.34 ± 0.35 (0.69–2.08)	*VMO*	28.88 ± 18.75 (21.89–36.06)	25.57 ± 16.29 (19.09–31.91)	115.94% ± 20.96% (107.89%–124.93%)
		RF	12.12 ± 13.31 (7.64–18.12)	9.51 ± 8.76 (6.48–13.43)	113.70% ± 19.84% (105.75%–122.13%)
		VL	34.28 ± 19.83 (27.04–41.84)	29.60 ± 19.20 (22.15–36.97)	123.59% ± 30.92% (112.36%–136.57%)
65% of the maximum PBU value					
QM 49.50 ± 5.28 (47.27–51.73)	0.77 ± 0.67 (-0.57–2.11)	*VMO*	50.56 ± 41.61 (35.82–6.06)	49.00 ± 45.04 (33.34–68.02)	111.86% ± 125.27% (102.75%–121.56%)
		RF	19.69 ± 26.64 (11.65–32.32)	17.99 ± 27.77 (9.99–30.82)	113.60% ± 26.59% (103.88%–124.02%)
		VL	47.37 ± 23.76 (38.27–42.30)	46.02 ± 25.38 (36.23–55.98)	106.78% ± 20.04% (99.27%–114.48%)

Abbreviations: FSET:Force Sense Error Test, sEMG-FSET:sEMG Activity of Force Sense Error Test, sEMG-NV: sEMG Activity of Norm Value, PBU:Pressure Biofeedback Unit QM:Quadriceps Muscle, VMO:Vastus Medialis Obliquus, RF:Rectus Femoris, VL:Vastus Lateralis, RMS:Root Mean Square.

Table 3
Correlation between the force sense error test and **NormEMG%** for the VMO, RF, and VL muscles.

n = 24	FS "constant error" of PBU value	
Norm EMG% (50% max.)	*r*	***p****
VMO	0.495	**0.014**
RF	0.689	< **0.001**
VL	0.448	**0.028**
Norm EMG% (65% max.)	*r*	***p****
VMO	0.717	< **0.001**
RF	0.665	< **0.001**
VL	0.656	< **0.001**

* Pearson Correlation Analysis, $p < 0.05$, Abbreviations: sEMG-FSET: Surface Electromyography Activity of Force Sense Error Test sEMG-NV: Surface Electromyography Activity of Norm Value, PBU: Pressure Biofeedback Unit, FS: Force Sense, VMO: Vastus Medialis Obliquus, RF: Rectus Femoris, VL: Vastus Lateralis.

femoris muscle (Chen and Treleaven, 2013; Dover and Powers, 2003; Horstmann et al., 2017; Roren et al., 2009) (Table 1).

Step 3. Calculating the norm sEMG value: First, the first researcher informed the participants about the maximum increase in their mmHg values by using the PBU screen. Using this visual feedback, the participants were instructed to contract their quadriceps femoris to achieve 50% norm mmHg value and hold this position for 5 s during the isometric contraction of the quadriceps femoris muscle until they reached the 50% norm mmHg value. Simultaneously, the second researcher recorded the sEMG signal from the VMO, VL, and RF muscles. Five seconds of sEMG data were referred to as the norm sEMG value. The measurements were repeated three times. The same procedures were repeated for the 65% norm sEMG value.

Step 4. *FSET of the quadriceps femoris muscle for the 50% and 65% norm mmHg value:* In this step, participants were instructed to contract the quadriceps femoris in order to reach the previously described 50% and 65% mmHg norm values with their eyes closed by using only verbal feedback from the first researcher. After three practice sessions, the participants were instructed to find the same norm value without visual or verbal feedback for each of the norm values. When the participants were sure they had achieved the norm value, they alerted the first researcher. They were then instructed to hold that position for 5 s. Meanwhile, the second researcher simultaneously measured sEMG signals from the quadriceps femoris during the 5 s of the FSET (Fig. 1). The difference between the norm mmHg values and the value the participants achieved was calculated according to the constant error (CE) method (Röijezon et al., 2015), and the result was referred to as the mmHg FS error value (Fig. 2). CE is the deviation from the target where each value is described by a positive (overshoot) or negative (undershoot) number. CE gives an indication of accuracy as an average magnitude of the movements, and an indication of any systematic error, i.e., whether the person is generall overshooting or undershooting the target (Röijezon et al., 2015). All measurements were performed three times, and the average of the mmHg FS error values were used for statistical analysis.

EMG Signal Processing

Noraxon MyoResearch XP Master Edition software (Noraxon, Scottsdale, USA) was used for the sEMG data processing. The EMG signals were band-pass filtered (20–450 Hz) and smoothened using the root-mean-square with a 20-millisecond time window. The mean sEMG activity was measured during the 5 s of both the norm mmHg and FS error mmHg tests.

For normalization, the mean sEMG activity during the FSET was divided by the mean sEMG activity during the measurement of the norm value expressed as "NormEMG%." Next, the consistency between

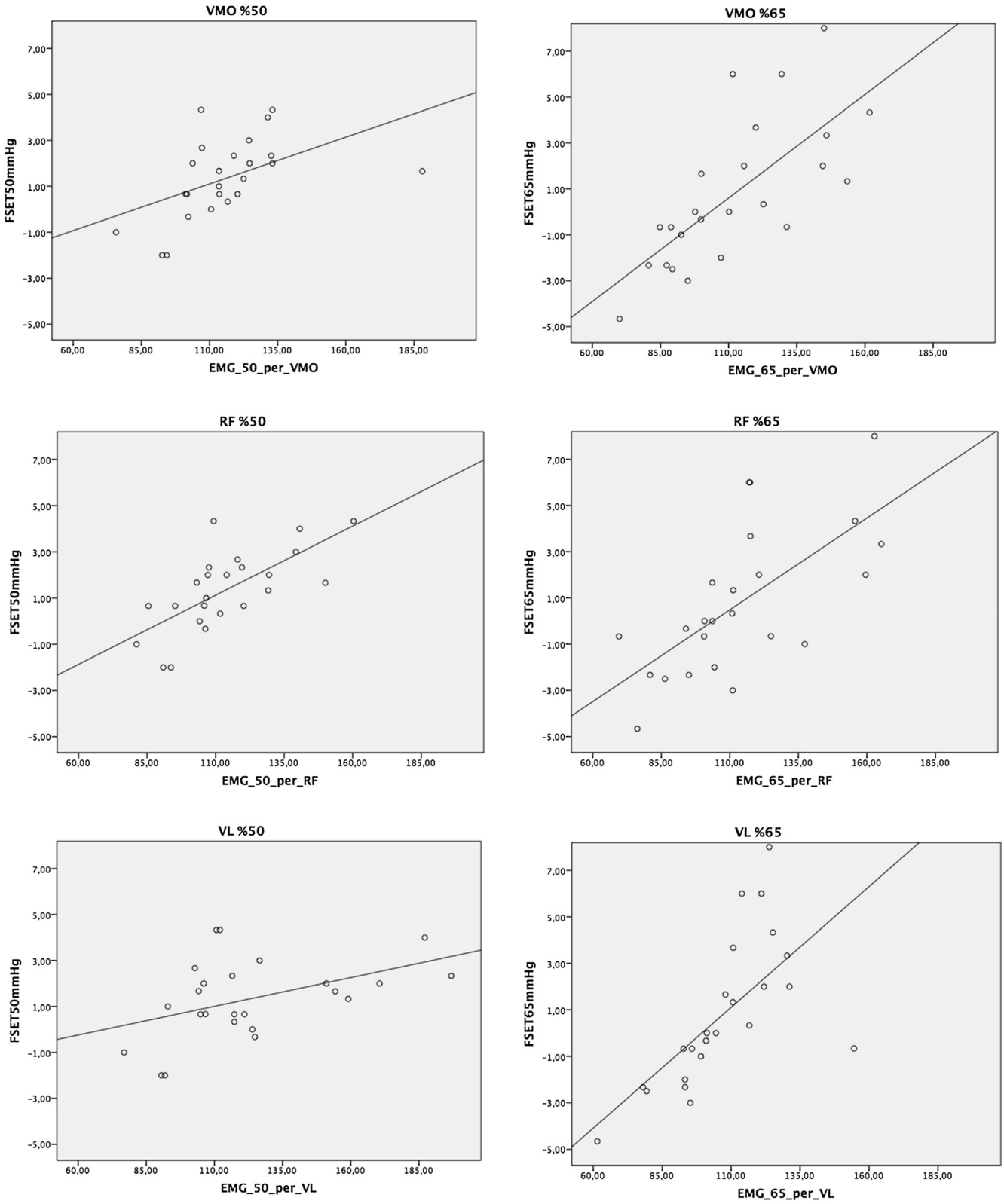

Fig. 3. Scatter plots and correlation lines, for the six different muscle sEMG activation percentage (Norm EMG%) obtained during the Force sense error test.

the values determined using the sEMG signals and the error values determined using the PBU were analyzed by statistical methods.

Statistical Analysis

Statistical analysis was performed by using IBM SPSS Statistics v.24 (IBM, USA). All data were expressed as means and standard deviations for descriptive data. The intraclass correlation coefficients ($ICC_{3,1}$) and standard errors of measurement for the mmHg FS error value for the three replicates were used to determine the consistency between trials.

ICCs were classified as poor (< 0.50), moderate (0.50–0.75), good (0.75–0.90) and excellent (≥0.90) (Lahey et al., 1983). The standard

error of measurement (SEM) was calculated using the SEM formula (Weir, 2005). The Pearson correlation coefficient test was used to determine the correlation between the mmHg FS error values and "NormEMG%". The level of statistical significance was set at $p < 0.05$. Correlation coefficients were classified as poor (0.10–0.30), moderate (0.30–0.70), or strong (0.70–0.100) (Ratner, 2009).

3. Results

3.1. Internal consistency

Reliability ($ICC_{3,1}$) values ranged from 0.85 to 0.98 with an SEM of 1.42 mmHg to 1.61 mmHg (Table 1). The muscle activity percentages (NormEMG%) based on the 50% and 65% of max mmHg values are presented in Table 2. The $ICC_{3,1}$ was considered "excellent" for all FSET parameters measured using the PBU.

3.2. Validity

There was a significant correlation between the FSET and NormEMG% for each muscle (Table 3, Fig. 3).

4. Discussion

The present study investigated the relationship between FSET measured using a PBU and the sEMG of the quadriceps femoris muscle activity and assessed whether FS was a reliable and valid method in clinical practice. The internal consistency of the FSET was high ($ICC_{3,1}$: 0.85 to 0.98). Additionally, the validity of the FS test demonstrated moderate to strong correlations for the quadriceps femoris sEMG muscle activity levels in healthy individuals (NormEMG%: 0.448 to 0.717).

The low-cost system for measuring FS described in the present study demonstrates reliability with high ICC values. Furthermore, our study is the first to demonstrate a moderate to strong correlation between the FSET measured using the PBU and sEMG activity for the quadriceps femoris muscle in healthy subjects. A greater correlation revealed the validity of this FS measurement method since the sEMG is accepted as the gold standard for measuring muscle activity. This feasible and simple methodology was found to be valid in only healthy subjects in the present study. It should be noted that in order to use this method in clinical practice to identify proprioceptive deficits associated with various diseases, a validation study should be performed.

Deficits in proprioception can cause a recurrence of injuries following surgery or tissue damage (Suner-Keklik et al., 2017). The identification of these deficits shortly after sustaining an injury would provide insights that reduce the risk of future injuries. Evaluation of proprioception is also important for documenting the effectiveness of rehabilitation programs (Hewett et al., 2012). Most of the studies are focused on the evaluation of knee proprioception (especially that of the quadriceps femoris muscle) in order to determine how individuals are affected by an injury or surgery. However, these assessments are mostly performed during the subacute or chronic phase following surgery or injury (Barrett, 1991; Kaya et al., 2018). It is well-known that the physical and functional status of the patients are limited during the acute phase following lower extremity surgeries or injuries. Evaluations, such as the open kinetic chain patterns, are contraindicated. Therefore, practical equipment that can be used in the clinical setting during each phase of recovery following injury and surgery is needed in order to accurately identify knee proprioception deficits.

The main receptors deriving proprioceptive input from joints are the Golgi tendon organs (GTO) and muscle spindles (Proske, 2006). Inputs from these two receptors arise from the stretching sensation and are mostly activated during isometric muscle contractions. In addition, the receptors from ligaments, the joint capsule, and tendons also provide proprioceptive information that allow the proper positioning of joints in space. In contrast to the muscle receptors (GTO and muscle spindles), these receptors provide information during midrange joint movements (Macefield et al., 1990). In the current literature, the most common assessments for knee proprioception include joint position sense detection or the threshold for the perception of passive movement (TPPM) (Costello and Donnelly, 2010; Ribeiro and Oliveira, 2010; Riemann and Lephart, 2002). Both methods include passive open kinetic chain patterns and midrange joint movements (Burke et al., 1988). Joint position sense evaluation can also include active movements. However, in this case, the individuals need sufficient muscle strength to offset the effects of gravity (Li et al., 2016). Therefore, force sense evaluation is a promising method for detecting proprioceptive deficits due to the nature of isometric muscle contractions and particularly the muscle receptors.

The present study showed that the FSET measured using the PBU was a practical method for evaluating knee proprioception. There is no gold standard and globally accepted measurement method for analyzing the validity of knee proprioception. Thus, in the current study, we used sEMG during isometric knee contractions to determine the validity of the PBU measurement. The results showed that 50% of the maximum PBU value resulted in moderate validity, and 65% of the maximum PBU value had good validity. These results indicated that PBU is valid and easy to use in a clinical setting. Considering that most proprioception evaluation equipment, such as isokinetic dynamometers, is expensive and should be used in a laboratory environment, PBU is light, easy to carry, and an inexpensive device.

The most important limitation of the current study is that only healthy young adults were included. Although strict inclusion criteria and a narrow age range were selected, the study subjects included both male and female students with a variety of potentially uncontrollable confounding factors, such as the degree of physical activity, gender differences, and differences in the level of kinematics of the lower extremity.

5. Conclusion

It is essential to establish practical evaluation approaches that are appropriate for measuring knee proprioception. Our study demonstrated a positive correlation between FSET measured using the PBU and sEMG activity from the quadriceps femoris muscle in healthy individuals. In the future, this test method could be used in geriatric or athletic individuals after knee surgery. Health professionals working in this area might be able to plan appropriate exercise regimens or daily-living activities with the help of the data obtained from the PBU-derived FSET measurements.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelekin.2019.102366.

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