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Research Article

A prototype for dynamic knee extension: construction, force characterization and electromyographic responses

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HIGHLIGHTS
- Description of the ergometer for dynamic knee extension (DKE), which enables its construction by other centers of research.
- .Characterization of the force signal during the DKE.
- The prototype built was effective for isolating anterior thigh muscles, which was evident by the higher activations of the *Vastus lateralis* in relation to the responses of the *Biceps Femoris.*

ABBREVIATIONS

DKE	dynamic knee extension
MIC	maximal isometric contraction
PF	peak force
PT	Potentiated twitch
RMS	root mean square
TI	Twitch interpolation
TC	
TS	Superimposed twitch
VA	voluntary activation level
W	Watts

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BACKGROUND: In the dynamic knee extension (DKE), a metal bar is positioned parallel to the bicycle frame, replacing the pedal and allowing consecutive extensions instead of a pedaling movement. In this exercise model, the knee joint returns to its initial position passively, allowing studies about the role of anterior thigh muscles during locomotion or balance. However, the DKE ergometer is not commercially available.
AIM: To describe the construction, responses, and applicability of a prototype ergometer for DKE.
METHOD: In the first experiment, six participants underwent a progressive effort to volitional exhaustion. The electromyography signals of the *Vastus Lateralis* and *Biceps Femoris* were monitored. In the second experiment, the twitch interpolation technique was used to test the fatigue status of seven participants after a high-intensity exercise.
RESULTS: The force signal has three phases: I: knee extension moment; II: crank draws the metal rod back; III: rapid compression of the load cell by the leg. In addition, *Vastus Lateralis* activation was higher than *Biceps Femoris* in all stages ($p<0.02$). The TI was sensitive to assess the peripheral characteristics of the high-intensity effort.
CONCLUSION: The construction of a DKE ergometer is plausible, increasing the possibilities of research into motor behavior.

KEYWORDS: Sports Science | Motor behavior | Exercise physiology | Electromyography signal | Force

INTRODUCTION

The first article that standardized the ergometer for dynamic knee extension (DKE) was published in 1985 by researchers of the August Krogh institute.[1] The main objective of the DKE ergometer is to promote an exercise model in which the main motor agent during the effort is the *Quadriceps Femoris*.[1] For this, a metal bar replaces the pedal of a cycle ergometer and the subject is positioned in front it, seated with the hip and ankle articulations firmly fixed on a bench and in specific boots, respectively. Using this experimental apparatus, Andersen et al.[1] observed higher activations of the *Quadriceps Femoris*, while the hamstrings and other muscles demonstrated only small participation or were inactivated during a progressive effort. Thus, the significant increases in the oxygen consumption and blood lactate can mainly be explained by activation of the anterior thigh muscles.[1] In addition, the subject's torso and high do not present any dislocation during exercise, which allows both quick access to the main blood vessels of the lower limbs and rapid extraction of muscle tissues using the muscle biopsy technique. Considering these characteristics, the use of the DKE ergometer is recognized as an important advance for exercise physiology approaches.[2,3] However, it can also be used in other experimental approaches, such as motor behavior approaches.

Although less explored, some characteristics allow the use of the DKE ergometer to investigate motor behavior aspects, such as fatigue effects on motor behavior, asymmetry, and force parameter studies. In this context, it is possible to change the dynamic extensions to dynamic flexions and the hamstrings become the motor agents.[1] Although this adaptation presents limitations for exercise physiology approaches (e.g., uncomfortable for prolonged exercises), inducing fatigue in the hamstrings is appropriate to investigate their role during several motor tasks. In addition, asymmetry patterns during different motor tasks can be investigated by simple changes in the effort demand, using one or two-legged exercise, which is also useful to induce muscle fatigue. Finally, through a simple system, the crank of the ergometer can be quickly stopped, changing the dynamic consecutive extensions to an isometric contraction unit, which makes possible assessments of maximal isometric force and rate of force development. Together with these isometric force parameters, the use of the DKE ergometer enables the application of the Twitch Interpolation (TI) technique, which allows estimation of the origin of fatigue (i.e., central, peripheral, or both).[4,5] In other words, the TI applied after different efforts indicates whether the exercise decreases the muscle activation due to the central nervous system (i.e., central fatigue), due to impaired capacity of muscle contraction (i.e., peripheral fatigue), or both factors acting in consonance. Thus, the use of DKE is also useful to investigate how central and peripheral mechanisms of fatigue are related to performance during different motor tasks.

However, the required ergometer is not commercially available. Thus, to study different mechanisms using DKE as an exercise model, researchers need to build the required ergometer. Although Andersen et al.[1] provided some information about the function and physiological responses of the ergometer, the construction steps were not their objective and they omitted crucial characteristics (e.g., ergometer dimensions). Therefore, the main objective of the present study is to describe an ergometer prototype construction for DKE, investigating the force signal during different efforts. In addition, considering that the main characteristic of this ergometer is isolation of anterior muscles, we also compared the electromyographic signals of the *Vastus lateralis* and *Biceps Femoris*. Finally, the effectiveness of the constructed ergometer to assess the fatigue characteristic was evaluated through the TI technique.

METHODS

Description and construction of the DKE ergometer

To make DKE possible, a metal bar, 87cm long, is used to replace the pedal of a mechanical braking cycle ergometer (Monark 828; Monark Exercise AB, Vansbro, Sweden). The subject is positioned with their back to the cycle ergometer, sitting in a specific chair with their knees at a 90º angle (initial position). The ankles are allocated and fixed in metal boots (Figure 1), connected to the metal bar through load cells, positioned in a semicircle with a diameter of 30 cm. The semicircle is easily changed to prolongation of the metal bar, also connected to the boots with load cells, allowing the execution of one-legged exercise. The opposite extremity of the metal bar is connected to an apparatus that replaces the pedal, with an axis connected to the crank. Two bearings guarantee the articulation of this apparatus, allowing smooth movement during each extension (Figure 2).

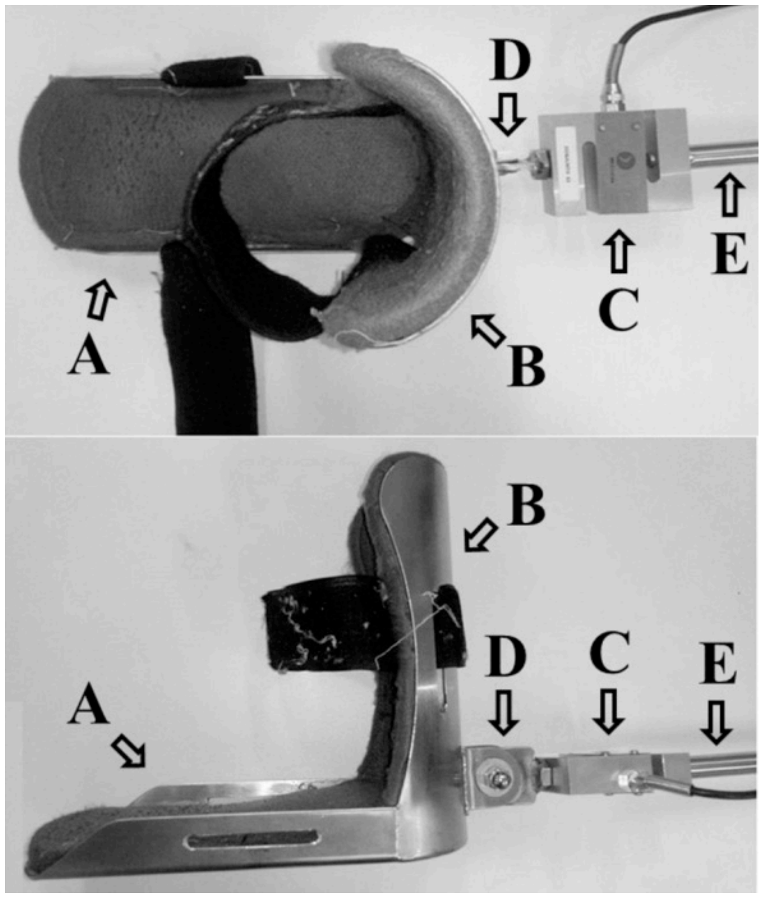

Figure 1. Superior and lateral views of the metal boots, load cells, and connections to the metal bar. The boot and metal bar are made of stainless steel. The bottom side of the boot (A) is a flat structure 27 cm long and 11.5 cm wide. On both sides of the bottom, 3cm high structures are positioned to allow fixation of the participant's foot, using holes 7 cm long. The posterior bottom (B) is a curved structure 23 cm high and 12 cm wide. Similar holes are made in this part of the boot, allowing fixation of the participant's leg. The boot is connected to the metal bar through a load cell (C) and a specific joint (D), which enables up and down movements of the boot.

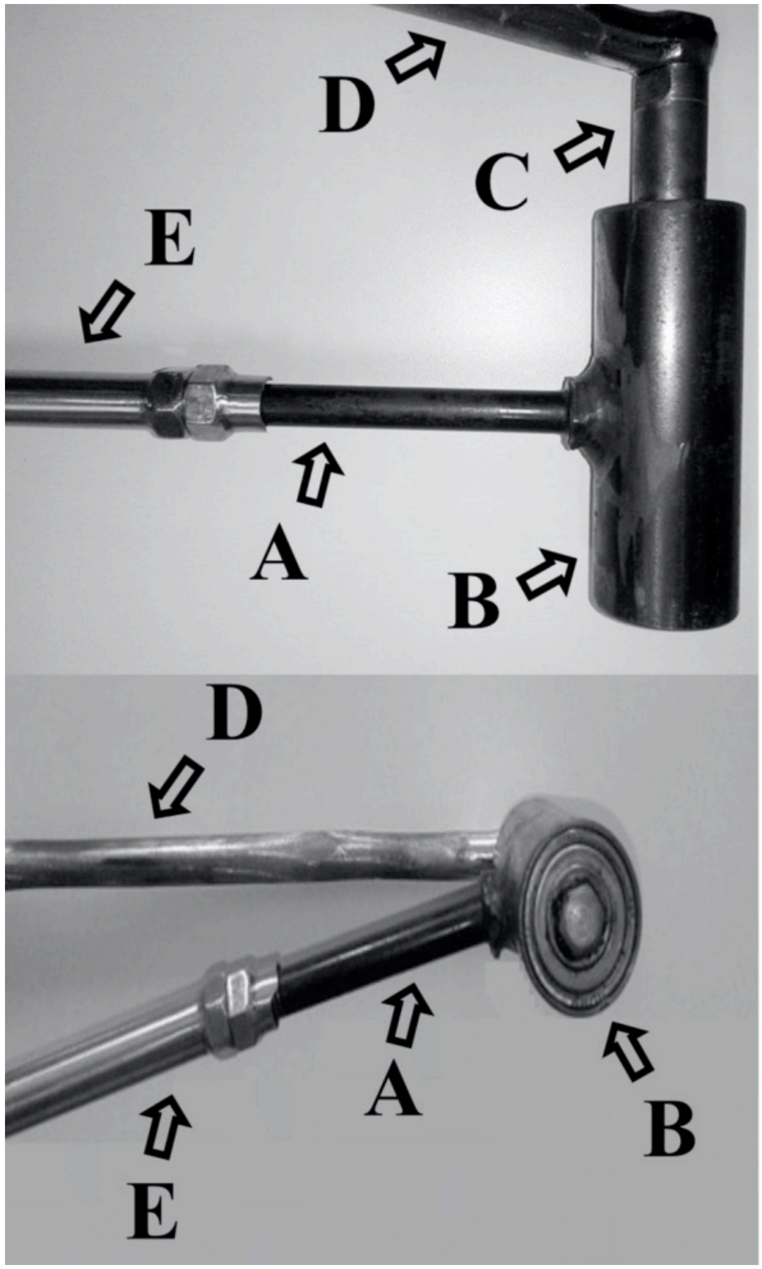

Figure 2. Apparatus built to connect the metal bar to the crank of the cycle ergometer. This apparatus is made up of a screw 14 cm long (4 cm thread and 1 cm thickness) (A) and a main part (B) 12 cm in diameter, where two bearings are positioned on an axis 14 cm long. The axis is fixed to the bicycle crank (D), allowing smooth movement of the metal bar (E) during the extensions.

During each extension, the cycle ergometer crank completes a quarter turn, moving the knee joint from a 90º angle to approximately 170º. Considering that the cycle ergometer has a fixed ratchet, the system remains in motion after the extension (inertia) and, thus, the knee joint returns to the 90º angle passively (i.e., without the contraction of the posterior thigh muscles). In this context, the anterior thigh muscles are the main motor agent during exercise.[1] The adjustments in the exercise intensity are performed exactly as in a conventional cycle ergometer, implementing kilogram-force (Kgf) by means of a friction tape, which allows the determination of the power values (i.e., Watts).

Although Andersen et al.[1] described in detail the ergometer for DKE, some changes were necessary to adapt the original design of the ergometer to our financial reality. For example, in the original design, square aluminum bars were used, with sides measuring 5 cm. This material reduces the total weight of the ergometer, but increases its total construction cost. Thus, we opted for simple metal bars, with sides measuring 3 cm, handled in conventional blacksmiths. To alleviate the weight problem, the ergometer was divided into two parts (i.e., a block where the seat is fixed and a support base for the cycle ergometer), facilitating its transport, when necessary. As the different parts of the ergometer can be firmly connected, stability is not decreased during assessments. The block where the bench was fixed can be described as a perfect cube with sides measuring 80 cm. The evaluated individual is positioned on an automobile seat, and secured during the efforts using a competition belt (4-point belt; Amicintos, São Paulo, Brazil). The bench is connected to the ergometer by means of an adjustable base both laterally and in the anteroposterior direction, according to the dimensions of the subject and the effort model (e.g., unilateral or bilateral).The support base for the cycle ergometer is a rectangle 80 cm high with a 120 cm base. The metal bar and boots are made of stainless steel, giving these structures resistance and low weight. Figure 3 demonstrates an overall illustration of the completed ergometer.

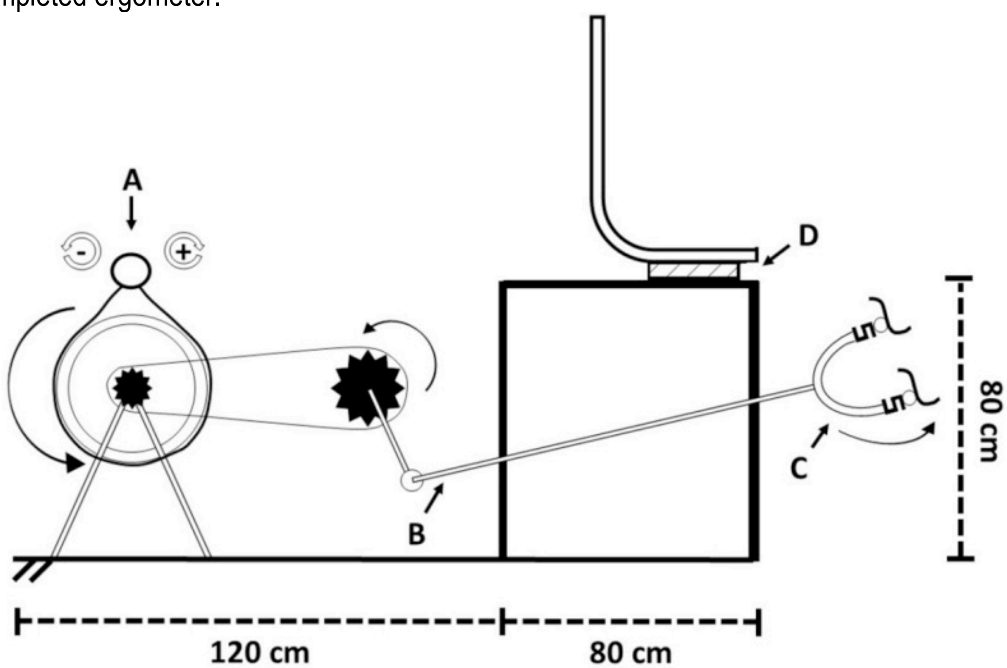

Figure 3. Illustration of the main components of the dynamic knee extension ergometer, built by our research group. Adjustments in intensity are made through a mechanical braking system, increasing or decreasing the tension applied by using a tape that surrounds the wheel of a conventional cycle ergometer (A). The pedal of the cycle ergometer was replaced by a metal bar with an extension of 87 cm, allowing extensions to be performed (B). At the end of the metal bar a semicircle with a diameter of 30 cm is positioned, which fixes two load cells that connect the boots, where the ankles of the subject are positioned (C). The subject is positioned with their back to the cycle ergometer, on a fixed bench, on a platform that can be adjusted both laterally and in the anteroposterior direction, allowing exercise with one or two legs. (D).The arrows indicate the direction in which the systems are moved for each extension.

The power output generated in a conventional cycle ergometer is the product between the load applied by the mechanical braking system (i.e., force; Kgf), the distance traveled by the wheel after a turn of the crank (i.e., displacement; $m.rev^{-1}$), and the cadence (i.e., number of turns per unit of time; $rev.min^{-1}$) [6]. The ergometer cycle wheel used by our research group is 51.4 cm in diameter. Considering that at each turn of the crank, 3.3 turns are made on the cycle ergometer wheel, at each complete cycle of pedaling 5.30 m are covered. Thus, the power output can be determined using the following equation:

$$\textbf{Power output } (Kg \bullet m \bullet min^{-1}) = \textbf{Force} \bullet \Delta D \bullet \textbf{Cadence} \qquad \textbf{Equation 1}$$

Where: Force is the load imposed by the mechanical braking system (Kg), ΔD is the distance traveled by the wheel at each crank revolution (5.30 $m.rev^{-1}$), and Cadence is the number of crank revolutions per minute ($rev.min^{-1}$). To express power output in Watts, the result is multiplied by the constant 0.16344416.

First experiment: Force signal and electromyographic activity

The main advantage of using DKE is to isolate the muscle of interest during activity. To ensure the presence of this advantage during exercise, six men (age: 28 ± 5 years; height: 1.81 ± 0.08 m; body mass: 92.0 ± 13.7 kg) underwent an incremental effort, where the force generated during each extension and the electromyographic activity of the muscles of interest were monitored. All participants were familiarized with the ergometer and the DKE by performing various efforts with different durations (i.e., 2 - 15 min) and intensities (i.e., 13 - 100 W). The interval between the familiarization session and the experiment was at least 24 h. The research ethics committee of the Ribeirão Preto School of Physical Education and Sports (n º 60156116.2.0000.5659) approved all procedures. All participants agreed to participate in the experiments and signed a free and informed consent form.

Prior to the incremental effort, the participants performed a warm-up with a load of 12 W and duration of 7 min. The intensity of the first stage was 25 W, with increments of 25 W every 2 min. The cadence was maintained at 60 rpm throughout the experiment. The increments were applied until exhaustion, which was characterized by the participant's inability to maintain the cadence for more than 10 s. If exhaustion occurred during the stage, the data were neglected, and the final complete stage was analyzed. The voltage values obtained by the load cells (250 kg capacity; CSR-1T, MK Controle, São Paulo - Brazil) were acquired through a system consisting of a signal acquisition board (NI-USB 6009, National Instruments®) and a signal amplifier (Output 0 to 10 VDC; CSR-1T, MK Controle, São Paulo - Brazil), using a frequency of 1000 Hz. Daily calibrations were performed through an overlapping known weight (e.g. 0 - 10.2 kg; with increments ranging from 0.101 to 4.146 kg). All procedures for signal acquisition, calibration, and analysis were performed in a Matlab® environment. The force observed during the efforts was smoothed in a digital Butterworth third-order filter, with a band pass cut-off frequency of 0.3 and 5 Hz, obtained through the analysis of residues.[7]

During the efforts, the electromyographic activity of the *Vastus lateralis* and *Biceps femoris* muscles of the right leg was determined (Miotool 400; Miotec®; Brazil). The Ag/AgCl electrodes with a 1cm uptake area (3M®, São José do Rio Preto - Brazil) were positioned according to SENIAM guidelines. Prior to the electrode connection, the anatomical points were trichotomized and cleaned with 70% alcohol. In all cases, the electromyographic signal was acquired with a frequency of 2000 Hz and a gain of 1000 times (Miograph; Miotec®; Brazil), which was later filtered through a bandpass filter of 20-500 Hz. The mean of the final ten contractions (i.e., ~ 10 s of exercise) was used to determine the root mean square (RMS), which was assumed to be a muscle activation index.

Second experiment: Sensitivity of the twitch interpolation technique

To test the application of the TI through the DKE ergometer, seven men (26.8 ± 2 years, 173.5 ± 6.3 cm height, and body weight of 90.8 ± 7.0 Kg) underwent an incremental effort and, after 48h of recovery, a high-intensity intermittent effort (5 x 1 min at 110% of the maximal power attained during the incremental effort, separated by 3 min of passive recovery). All participants were familiarized with the ergometer and the DKE using the same strategy described in the first experiment. These procedures were approved in the same ethical process as the first experiment.

The force parameters were obtained through the same procedures described in the first experiment. Before and immediately after the final effort, the TI was applied through two 5-s maximal isometric contractions (MIC), separated by 30 s of passive recovery. Electrical stimulations were delivered during the MIC, on approximately the third second of contraction, and after 5 s of recovery. For this, Square-wave 100 Hz doublet electrical pulses with a 10 ms interval between them were delivered (Carbon-rubber; 6 × 5 cm) at the femoral triangle (cathode) and the gluteal fold (anode) (Bioestimulador; Insight, Ribeirão Preto, São Paulo, Brazil). The stimulus intensity was 150 mA.

The peak force (PF) was assumed as the maximal values observed during the MIC without electrical stimulation. Differently, the superimposed twitch (ST) was determined by the force evoked amplitude through the doublet during the MIC (i.e., difference between PF and force evoked). The force evoked with the muscle relaxed was assumed as the potentiated twitch (PT). Finally, these variables were used to determine voluntary activation level (VA = [1 - (ST × (force level at stimulation/PF)/TC)] × 100.[5,8] Decreases in these variables indicate that fatigue occurs through peripheral factors (i.e., ST or PT, or central factors (VA).[4,5,9]

Statistical Analysis

The normality was confirmed through the Shapiro-Wilk test, which enabled data description using mean ± standard deviation. However, to avoid the non-uniformity error, the possible differences were tested through the Wilcoxon's test. Specifically, the *Vastus lateralis* and *Biceps femoris* activations were compared in the first experiment and the possible alterations after high-intensity effort were tested in the second experiment. These analyses were performed using SPSS 17.0 software (SPSS Inc, Chicago, Illinois), with the significance level set at p-value < 0.05.

RESULTS

Force signal characterization

Figure 4 demonstrates the typical behavior of force during DKE. The highest peak of force observed (I) corresponds to the moment of knee extension. The second peak of force (II) is evident when the crank pulls the metal bars backwards; now the leg is positioned for the next extension. Before the next extension, negative values of force are observed (III), which can be attributed to rapid compression of the load cell by the leg.

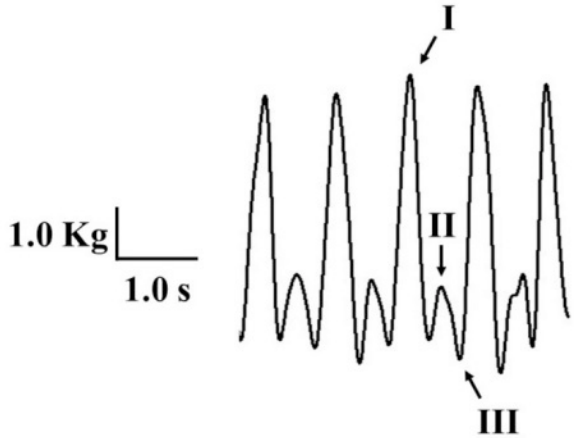

Figure 4. Force signal observed in five consecutive extensions performed on the ergometer. These signals were obtained during an effort at 36 W, performed by a participant with previous experience with the ergometer. I, II, and III, represent the distinct phases of the extension, which are described in the text.

Electromyographic signal during efforts

Figure 5 demonstrates the muscular activity responses of a participant who demonstrated exhaustion in the fourth effort. Figure 6 shows the mean behaviors of the RMS in the final ten extensions over the efforts. For all participants, the RMS of the *Vastus lateralis* muscle was higher than the value observed in the *Biceps femoris*, regardless of the stage performed. Considering that all participants performed at least three stages, all statistical analysis used these stages and the values observed at exhaustion (77.2 ± 21.7 W). These analyses demonstrated the higher activation of the *Vastus lateralis* compared to values observed for the *Biceps femoris*, in all analyzed stages ($p < 0.02$) (Figure 6).

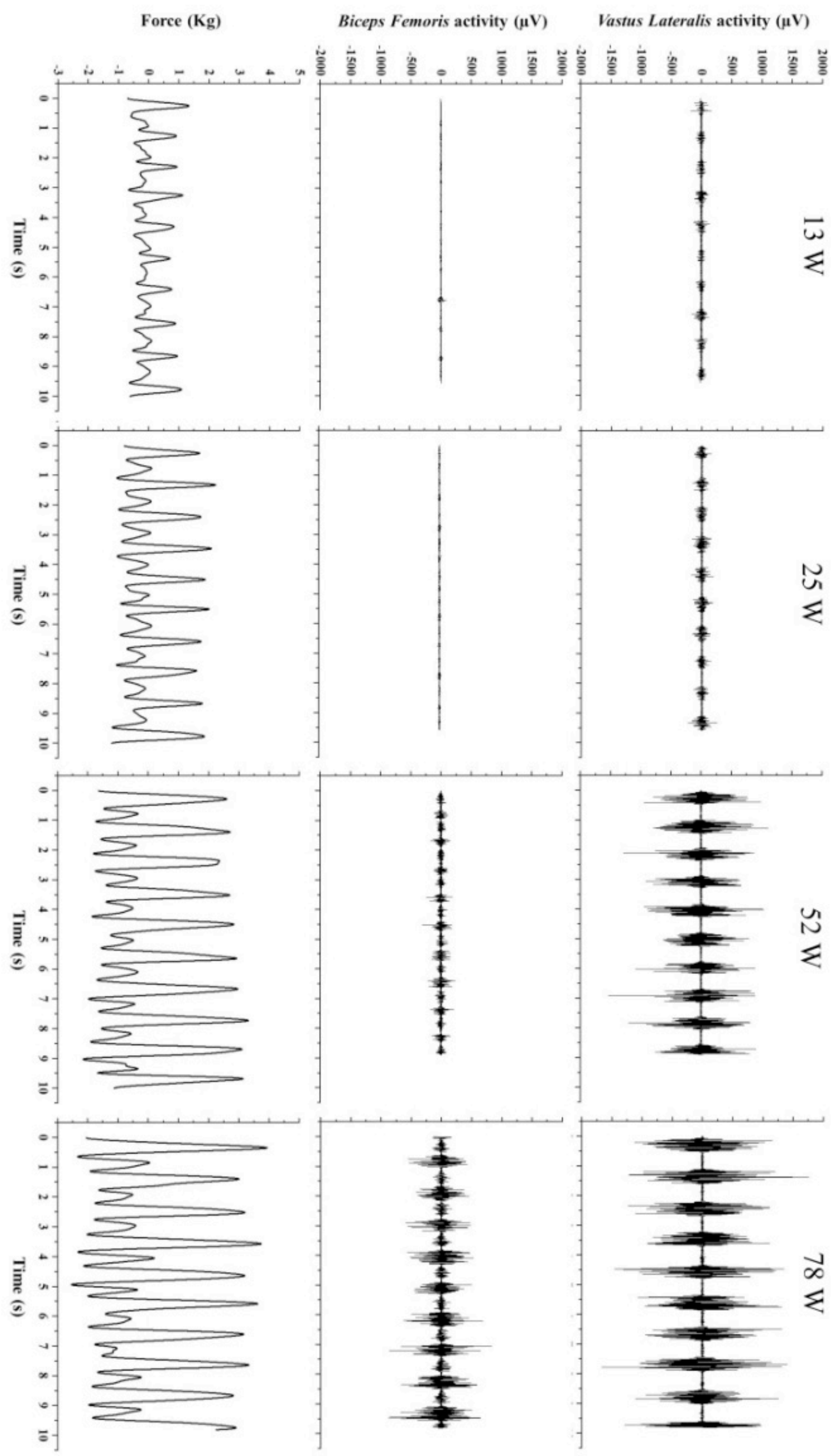

Figure 5. Individual behavior of electromyographic responses observed during four progressive efforts in the Vastus lateralis muscles (first panels), Biceps femoris (second panels), and the force signal (third panels).

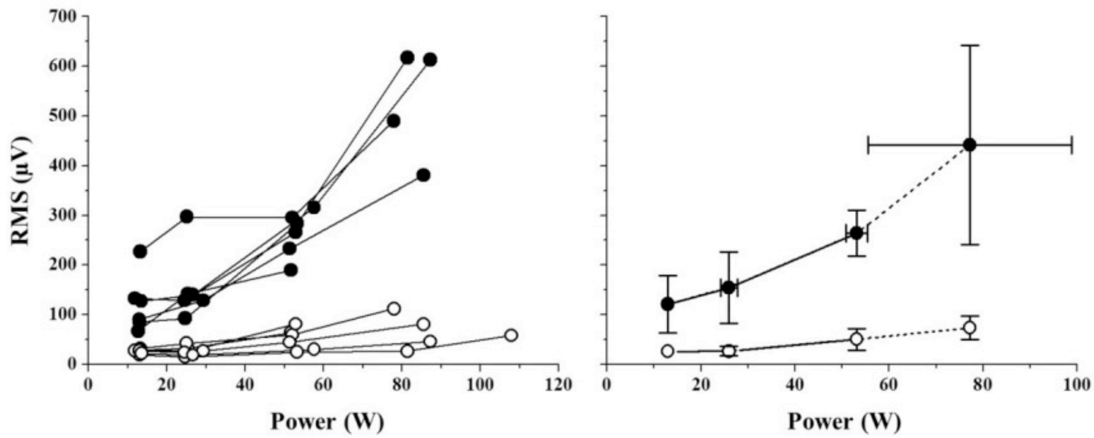

Figure 6. Root mean square (RMS) values observed in the progressive effort. A: behavior of individual values; B: behavior in the final three stages and at exhaustion (after dashed line); Full symbols: *Vastus lateralis* muscle; Empty symbols: *Biceps femoris* muscle; * Significant difference between muscles (p <0.05).

Sensitivity of the twitch interpolation technique

The maximal power output achieved during the incremental test was 95.8 ± 9.6 W. All participants completed the 5 X 1-min efforts. Overall, the mean values of cadence and power output were 61.0 ± 3.9 rpm and 97.59 ± 20.5 W, respectively. The time expended between the final effort and the first MIC was 8.0 ± 2.0 s. Table 1 demonstrates the performance during the intermittent efforts and the TI variables. Although no differences were observed for cadence values, the power output decreased significantly during the intermittent effort. The TI parameter demonstrated significant decreases in the PF, ST, and PT. The VA was not modified after the high-intensity effort.

Table 1 – Performance and variables obtained through the twitch interpolation technique (TI), before and after the high-intensity effort.

	Before	After	p-value
Performance			
Cadence (rpm)	62.7 ± 5.7	60.1 ± 3.7	0.07
Power output (W)	106.8 ± 22.6	92.7 ± 22.4	0.03
Power output (%)	110.7 ± 16.4	95.9 ± 16.0	0.03
TI			
PF (Kg)	43.5 ± 5.0	25.7 ± 2.8	0.02
ST (Kg)	1.1 ± 0.6	0.3 ± 0.4	0.02
PT (Kg)	10.2 ± 6.8	2.0 ± 1.3	0.02
VA (%)	99.1 ± 1.21	98.8 ± 2.8	0.74

Performance effects were tested between the responses during the first and fifth efforts. Power output values are expressed in absolute terms and relative to maximum achieved during the incremental test (%). PF: Peak force; ST: superimposed twitch; PT: potentiated twitch; VA: voluntary activation.

DISCUSSION

The aim of the present study was to describe the construction of an ergometer for DKE and investigate its responses (i.e., force signal and electromyography pattern) and applicability (i.e., sensitivity of the TI). The main results showed that it is possible to build an ergometer similar to that used in other research centers but with a reduced cost. In addition, the electromyographic responses indicate that this prototype induced greater activation of the *Vastus lateralis* compared to *Biceps femoris* responses. In addition, the parameters obtained through the TI technique changed after the exercise, demonstrating that the DKE ergometer can be used to investigate fatigue mechanisms.

The first work standardizing an ergometer prototype for the DKE was published by Andersen et al.[1] In that work, the authors describe in detail the construction, functioning, and responses, both mechanical (e.g., strength signal) and physiological (e.g., cardiorespiratory and blood lactate concentrations), observed in progressive efforts using DKE.

The behavior of the force observed at each knee extension demonstrated three well-defined phases. Although this force behavior is very similar to that characterized by Andersen et al.[5], these authors observed stabilization of the force values before the next contraction (i.e., between moment III and the next moment I). In our experiments, these stable values were not observed, probably due to the length of the crank (i.e., 18 cm), which is slightly smaller than found in other DKE ergometers. This characteristic reduces the angular speed of the crank, making the movement more dynamic, without major changes in the proposed exercise.

Previous results showed high activations of the anterior thigh muscles (e.g., *Vastus lateralis*, *Vastus medialis,* and *Rectus femoris*) without significant changes in other muscles of both the lower limbs (e.g., *Tibialis anterior*, *Biceps femoris*, *Gluteus medius,* and *Gastrocnemius*) and those responsible for trunk stabilization (e.g., *Rectus abdominis* and *Erector spinae*).[1] Thus, although the *Vastus lateralis* presented slightly greater activation, the authors confirmed that all portions of the *Quadriceps* were used during the dynamic extensions and are the major muscles responsible for the movement.[1] The results of the present study demonstrated that the prototype built by our study group was effective for inducing higher activations of the *Vastus lateralis* in relation to the responses of the *Biceps Femoris*. However, we did not measure the activation of other portions of the quadriceps. In fact, as shown in Figure 5, some activation of the *Biceps femoris* occurs, mainly in the stages close to exhaustion. Similar results were also observed by Andersen et al.[1] in the final stages of progressive efforts and during a maximum isometric contraction. Thus, our results demonstrate that the use of the *Biceps femoris* appears to be an attempt to maintain cadence, which presented a progressive pattern with the increases in intensity.

Our results also demonstrated that the use of a built ergometer enables the application of the TI technique, which was effective to quantify the effects of peripheral fatigue. The results demonstrated that the DKE ergometer was an interesting tool to change the dynamic kicks to isometric efforts and, consequently, allow the application of the TI in the first 15 s of recovery. In addition, the PF, ST, and PT responses demonstrated the sensitivity of the TI to evaluate the peripheral fatigue effects,[5] as demonstrated previously in high-intensity exercises.[10] Differently, no differences in the VA indicated maintenance of the central nervous system after the proposed exercise.[5] Thus, our results indicated that the constructed DKE ergometer represents an alternative to study fatigue mechanisms, which expands the research possibilities in exercise physiology and motor behavior.

Although the construction of the DKE ergometer seems to be effective and promising, the present study has some limitations. First, although similar activations are expected in the other anterior thigh muscles, only the *Vastus lateralis* activity was assessed, which limits our interpretations about other muscles of the Quadriceps. In addition, although the *Biceps femoris* presented high representability for the knee flexion, its biarticular characteristics can influence comparisons with *Vastus lateralis* activity, a monoarticular muscle. However, although merely speculative, considering that the hip and ankle articulations are firmly fixed, there are no reasons to believe there are high activations of other muscles (e.g., those responsible for trunk stabilization) or inhibition in the other Quadriceps muscles during the DKE. Finally, despite the sensitivity of the TI, future experiments should evaluate the test-retest reliability using the DKE ergometer.

CONCLUSION

The results of the present study demonstrate that the construction of a DKE ergometer is possible, using simple technology and with low cost. These results expand the possibilities of research into motor behavior, mainly to investigate the effects of muscle fatigue on different motor tasks. In this context, the use of dynamic contractions to induce fatigue is a breakthrough in the knowledge about its effects on gait or balance, mainly through different intensities and, consequently, origins of fatigue. In addition, the use of TI through the DKE ergometer can be explored to assess peripheral, central, or both mechanisms after a fatigue inducing protocol, which were not explored in previous studies.[11,12]. Finally, the anterior thigh muscles are large enough for physiological alterations to occur throughout the body, such as increases in oxygen consumption and blood lactate concentrations, further increasing the possibilities for investigating the physiology of exercise.[1-3,6,13,14]. Thus, future research centers can use the present study to build a DKE ergometer and investigate motor behavior or physiological aspects related to exercise.

REFERENCES

1. Andersen P, Adams RP, Sjogaard G, Thorboe A, Saltin B. Dynamic knee extension as model for study of isolated exercising muscle in humans. *J Appl Physiol*. 1985;59(5):1647-1653. DOI: 10.1152/jappl.1985.59.5.1647
2. Bangsbo J, Kjær M, Hellsten Y. Bengt Saltin (1935–2014). *J Physiol*. 2014;592(23):5149-5151. DOI: 10.1113/jphysiol.2014.285411
3. Booth F. Muscle adaptation to exercise: New Saltin's paradigms. *Scand J Med Sci Sports*. 2015;25(S4):49-52. DOI: 10.1111/sms.12595
4. Martin V, Kerhervé H, Messonnier LA, et al. Central and peripheral contributions to neuromuscular fatigue induced by a 24-h treadmill run. *J Appl Physiol*.2010;108(5):1224-1233. DOI: 10.1152/japplphysiol.01202.2009

5. Neyroud D, Vallotton A, Millet GY, Kayser B, Place N. The effect of muscle fatigue on stimulus intensity requirements for central and peripheral fatigue quantification. *Eur J Appl Physiol*.2014;114(1):205-215. DOI: 10.1007/s00421-013-2760-2
6. Brown SP, Miller WC, Eason JM. Exercise physiology: basis of human movement in health and disease. Lippincott Williams & Wilkins; 2006.
7. Winter DA. Biomechanics and motor control of human movement. John Wiley & Sons; 2009.
8. Strojnik V, Komi PV. Neuromuscular fatigue after maximal stretch-shortening cycle exercise. *J Appl Physiol*. 1998;84(1):344-350. DOI: 10.1152/jappl.1998.84.1.344
9. Girard O, Bishop DJ, Racinais S. Neuromuscular adjustments of the quadriceps muscle after repeated cycling sprints.*PLoSOne.* 2013;8(5): e61793. DOI: 10.1371/journal.pone.0061793
10. Marshall PW, Rasmussen SB, Krogh M, Halley S, Siegler JC. Changes in the quadriceps spinal reflex pathway after repeated sprint cycling are not influenced by ischemic preconditioning.*Eur J Appl Physiol*.2020;120:1189-1202. DOI: 10.1007/s00421-020-04359-9
11. Barbieri F, Gobbi L, Lee Y, Pijnappels M, van Dieën J. Effect of triceps surae and quadriceps muscle fatigue on the mechanics of landing in stepping down in ongoing gait. *Ergonomics*. 2014;57(6):934-942. DOI: 10.1080/00140139.2014.903302
12. Barbieri FA, Beretta SS, Pereira VA, et al. Recovery of gait after quadriceps muscle fatigue. *J Gait Posture*. 2016;43:270-274. DOI: 10.1016/j.gaitpost.2015.10.015
13. Osada T, Saltin B, Rådegran G. Assessment of voluntary rhythmic muscle contraction-induced exercising blood flow variability measured by Doppler ultrasound. *Open J Mol Integr Physiol*. 2013;3(04):158. DOI: 10.4236/ojmip.2013.34021
14. Greenhaff PL. Milestones in human physiology: muscle energy metabolism and blood flow during contraction. *J Physiol*. 2003;551(2):397-399. DOI: 10.1113/jphysiol.2003.044412

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