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Wootaek Lim, PhD[1,2]

SEX DIFFERENCE IN ABSOLUTE AND NORMALIZED FORCE AT FOUR DIFFERENT ISOMETRIC CONTRACTION INTENSITIES: A CROSS-SECTIONAL STUDY

ORIGINAL ARTICLE

ABSTRACT

Purpose: When measuring isometric contractions, providing real-time visual feedback differs from the practices in general clinical environment. In addition, even though men and women have clear physical and physiological differences, most of the existing studies analyzed absolute muscle contractions with no distinction between men and women. The aim of this study was to investigate whether there are differences in absolute and normalized hip extension forces measured without visual feedback between men and women.

Methods: Twenty-eight healthy adults participated (13 men and 15 women; age=- 22.00±11.44 years; height=165.86±18.30 cm; and weight=61.91±12.34 kg) in the study. Maximum (MVC) and submaximal voluntary contraction forces (75%, 50%, and 25% of MVC, in a random order) of hip extension were measured using a wireless strain gauge and with no visual feedback.

Results: Absolute contraction forces measured at four target intensities were significantly greater in men ($p<0.001$). Intra-trial reliability of contraction forces across 3 trials was very high in both men and women. There was a significant difference in normalized forces at 75% ($p=0.024$), 50% ($p=0.033$), and 25% ($p=0.004$) of MVC between the sexes.

Conclusion: Normalized force close to the target intensity was measured at high-intensity for men and low-intensity for women. In submaximal intensities, a decrease in normalized force smaller than the assigned target intensity occurred in both men and women as the target intensity decreased, with men showing a smaller decrease proportionally.

Key Words: Dynamometer, Hamstring Muscles, Isometric Contraction, Muscle Strength, Sex Difference

DÖRT FARKLI İZOMETRİK KASILMA YOĞUNLUĞUNDA MUTLAK VE NORMALLEŞTİRİLMİŞ KUVVETTE CİNSİYET FARKI: KESİTSEL BİR ÇALIŞMA

ARAŞTIRMA MAKALESİ

ÖZ

Amaç: İzometrik kasılmaları ölçerken gerçek zamanlı görsel geribildirim sağlamak genel klinik ortamdaki uygulamalardan farklıdır. Bununla birlikte, erkek ve kadınların belirgin fiziksel ve fizyolojik farklılıkları olmasına rağmen mevcut çalışmaların çoğunda mutlak kas kontraksiyonları cinsiyet ayrımı yapılmadan analiz edilmiştir. Bu çalışmanın amacı, erkekler ve kadınlar arasında görsel geribildirim olmaksızın ölçülen mutlak ve normalize edilmiş kalça ekstansiyon kuvvetlerinde farklılık olup olmadığını araştırmaktır.

Yöntem: Çalışmaya 28 sağlıklı yetişkin katıldı (13 erkek ve 15 kadın; yaş=22,00±11,44 yıl; boy=165,86±18,30 cm; ve vücut ağırlığı=61,91±12,34 kg). Kalça ekstansiyonunun maksimum (MVC) ve submaksimal istemli kasılma kuvvetleri ((MVC'nin %75, %50 ve %25'i, rastgele sırayla) kablosuz bir gerinim ölçer kullanılarak ve görsel geri bildirim olmaksızın ölçüldü.

Sonuçlar: Erkeklerde dört hedef yoğunlukta ölçülen mutlak kasılma kuvvetleri önemli ölçüde daha yüksekti ($p<0,001$). Tekrarlı ölçüm tutarlılığı üç deneme boyunca hem erkeklerde hem de kadınlarda çok yüksekti. MVC'nin %75'inde ($p=0,024$), %50'sinde ($p=0,033$) ve %25'inde ($p=0,004$) cinsiyetler arasında anlamlı fark vardı.

Tartışma: Hedef yoğunluğa yakın normalleştirilmiş kuvvet erkeklerde yüksek yoğunlukta, kadınlarda düşük yoğunlukta ölçüldü. Submaksimal yoğunluklarda, hedef yoğunluk azaldıkça, erkeklerde orantılı olarak daha küçük olmak üzere hem erkeklerde hem de kadınlarda belirlenmiş olan hedef yoğunluktan daha küçük bir normalleştirilmiş kuvvet azalması gözlendi.

Anahtar Kelimeler: Dinamometre, Hamstring Kasları, İzometrik Kasılma, Kas Kuvveti, Cinsiyet Farkı

1 Department of PhysicalTherapy, College of Health and Welfare, Woosong University, Daejeon, Republic of Korea.
2 Department of Digital Bio-Health Convergence, College of Health and Welfare, Woosong University, Daejeon, Republic of Korea.

Correspondence (İletişim):

Department of PhysicalTherapy, College of Health and Welfare, Woosong University, 171 Dongdaejeon-ro, Dong-gu, Daejeon, 34606, Republic of Korea.
E-mail: wootaeklimpt@wsu.ac.kr
ORCID: 0000-0002-5523-6294

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INTRODUCTION

In clinical practice, maximal or submaximal voluntary isometric contractions are performed according to the patient's condition or treatment purpose (such as proprioceptive neuromuscular facilitation stretching), and muscle contraction intensity should be recorded quantitatively and/or qualitatively. In the past, manual muscle testing (MMT) was primarily utilized to measure voluntary isometric contractions. However, in MMT, subjective judgment factors of the measurer may affect the results. In addition, it has the disadvantage that quantified values in the ratio or interval scale cannot be presented, and those above normal cannot be classified in detail (1). The rating of perceived exertion (RPE), which is based on an individual's subjective judgment rather than the measurer, is also often used to measure intensity (2,3). However, it is important for physical therapists to aware that RPE can be significantly affected by psychological factors. The primary drawback of these measurement methods is the inability to quantitatively determine the absolute force produced by muscle contractions. To compensate for this, a variety of measurement equipment is currently utilized by physical therapists, ranging from specialized equipment such as isokinetic dynamometers to portable devices such as portable dynamometers and strain gauges (4,5).

However, most of the existing studies provide measured values as real-time visual feedback, helping performers to clearly distinguish each target intensity (6,7). This does not reflect the general clinical environment in which the patient cannot know his/her voluntary muscle contraction force. It is necessary to check whether the performer can produce the correct amount of muscle force based on his/her own judgment without visual feedback. In one of the previous studies, 100%, 50%, and 20% of maximum voluntary contraction (MVC) were separately performed, but the subject was a field sport athlete with better muscle performance than the general public (8). In addition, while men and women should be divided into separate groups because of their clearly different physical characteristics, analyses were conducted using overall means without grouping them by sex (9,10). A study on reliability between repetitions, not just absolute contraction force, is also needed. Research on existing reliability is mainly focused on intra-rater reliability at different time points rather than reproducibility at the same time point (11). In the case of some studies in which repetitions were performed at the same time, there is a problem in that the number of repetitions was too small to 2, or only specific trials were selectively presented in spite of performing 3 or more repetitions (12). If only the largest value is selectively presented, the variation in individual iterations is unknown, and the baseline can be set too high.

This study aimed to identify differences in absolute and normalized hip extension forces and differences in intra-trial reliability between men and women at four different target intensities (100%, 75%, 50%, and 25% of MVC).

METHODS

Study Design

This study designed as a cross sectional study. The experiment was conducted on January 29, 2020 at the College of Health and Welfare, OOOOOOO University. The study was approved by the Institutional Review Board of OOOOOOO University (Number: 1041549-191011-SB-81) and informed consent was obtained from participants prior to any study-related procedures. The research related to human use has been complied with all the relevant institutional policies and has been conducted in accordance with the tenets of the Helsinki Declaration.

Subjects

Twenty-eight healthy adults participated. Subjects were those who had no musculoskeletal or nervous system problems, and had not experienced any pain in the hip, knee, or ankle joint for the past 6 months. The sample size was calculated with the G*Power version 3.1.9.7 software (Heinrich-Heine Universität Düsseldorf, Düsseldorf, Germany), with the alpha probability of 0.05 and a power of 0.8.

Procedures

The subject lies down on the treatment table in the supine position. Pelvis and non-measured legs were fixed to the treatment table using straps. The straight leg was slowly raised by a sling (Marpe,

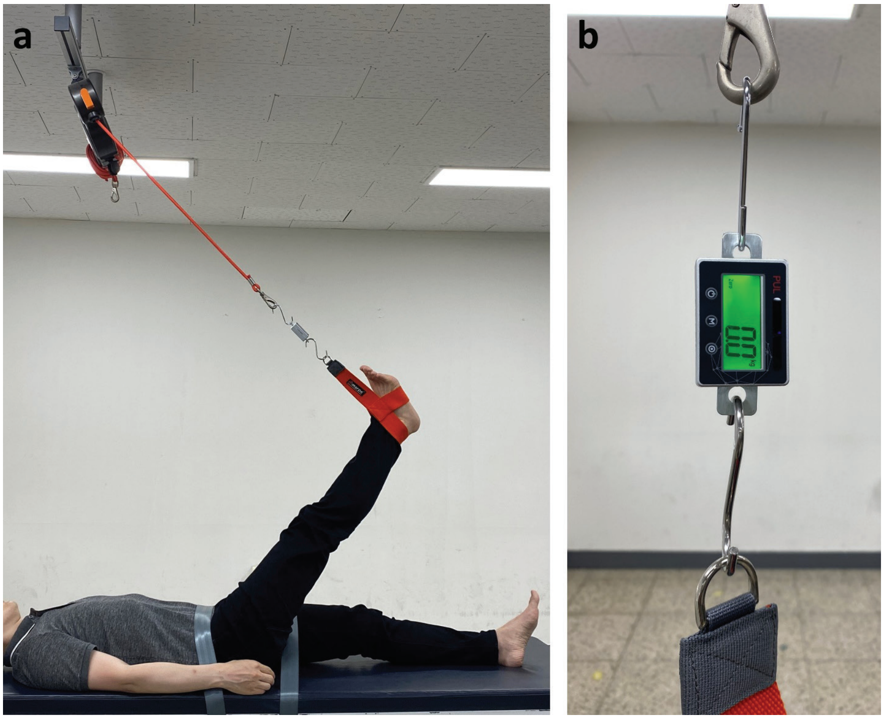

Figure 1: (a) Starting Position to Measure Absolute Force during Hip Extension (b) with Strain Gauge.

Jeonju, South Korea) until the point of discomfort. One end of the sling wire was fixed to the ceiling and the other end was connected to the ankle using an ankle strap (Figure 1a). The angle between the lower extremity and the sling wire was maintained at 90 degrees. A wireless strain gauge (Re-live, Kimhae, South Korea) was connected in the middle of the sling wire, and absolute force was recorded 4 times per second (Figure 1b) (4,7,13,14). The term "absolute force" refers to the direct force measurements obtained using the strain gauge. It provides a quantitative measurement of the actual force magnitude exerted by the subjects during hip extension. To minimize the effect of leg weight due to gravity, the strain gauge was calibrated (i.e., set to zero) before measurement. There was no visual feedback during hip extension. For MVC, total 3 trials (5 sec/trial, 10 sec rest between trials) were performed, and the middle 3 seconds were used excluding 1 second from the front and back out of 5 seconds. After MVC, 3 trials (5 sec/trial, 10 sec rest between trials) were performed in 75%, 50%, and 25% of MVC. The three submaximal target intensities were provided in random order, and sufficient rest was provided between submaximal target intensities. To calculate the normalized force, the following formula was used: Normalized Force = (Absolute Force / MVC) * 100%.

Statistical Analysis

Shapiro-Wilk was performed to test the normality of data. Based on the result of Shapiro-Wilk test, the Mann-Whitney U test was used to compare age (years) between sexes and the Independent Samples T-test was used to compare other variables such as height (cm), weight (kg), absolute contraction force (N), normalized force (%), and difference between normalized force and target intensity (Δforce, %) between sexes. Intraclass correlation coefficient (ICC; 3,1, Consistency) was used to analyze intra-trial reliability. Additionally, coefficient of variation (CV) was calculated as follows: $CV = 100 \times (2 \times (SDd / \sqrt{2})/(X1 + X2))$, where SDd is the standard deviation of the differences between two trials, and X1 and X2 represents the mean of each trial (15,16). All statistical analyses were performed using IBM SPSS 27 for Windows (IBM Corp., Armonk, NY, USA) and Microsoft Excel 2019 for Windows (Microsoft Inc., Redmond, WA, USA). The significance level was set at $p<0.05$. All values were reported as mean ± standard deviation.

Table 1. Characteristics of the Subjects.

	Men (n=13)	Women (n=15)	*p*
Age (year)	22.54±1.90	21.53±0.64	0.294
Height (cm)	173.46±3.55	159.27±4.67	< 0.001
Weight (kg)	70.69±10.42	54.30±8.18	< 0.001

Table 2. Absolute Contraction Force and Intra-trial Reliability across Three Trials at Four Different Target Intensities.

Target intensity	Sex	Absolute force	Trials	ICC	CV
100%*	Men	85.11±21.97 N	1st-2nd	0.82	11.60
			2nd-3rd	0.93	6.98
			3rd-1st	0.74	14.13
	Women	53.84±16.52 N	1st-2nd	0.80	15.37
			2nd-3rd	0.90	9.51
			3rd-1st	0.85	13.09
75%*	Men	66.19±24.66 N	1st-2nd	0.98	5.02
			2nd-3rd	0.94	9.54
			3rd-1st	0.95	8.64
	Women	32.43±14.44 N	1st-2nd	0.93	11.85
			2nd-3rd	0.98	7.02
			3rd-1st	0.91	13.37
50%*	Men	47.42±19.84 N	1st-2nd	0.93	10.90
			2nd-3rd	0.97	7.96
			3rd-1st	0.92	12.32
	Women	22.70±10.16 N	1st-2nd	0.96	9.44
			2nd-3rd	0.91	13.77
			3rd-1st	0.91	13.55
25%*	Men	28.32±13.64 N	1st-2nd	0.95	12.00
			2nd-3rd	0.94	10.85
			3rd-1st	0.85	20.00
	Women	11.38±6.21 N	1st-2nd	0.89	18.35
			2nd-3rd	0.96	11.82
			3rd-1st	0.91	16.49

*P<0.001, significantly different between men and women, ICC: intraclass correlation coefficient, CV: coefficient of variation

RESULTS

There was no significant difference in age between men and women (p=0.294) but was significant difference in height and weight (p<0.001) (Table 1). The average hip flexion angle was 63.8°. Absolute contraction forces measured at each target intensity were significantly different between men and women (Table 2). Intra-trial reliability of contraction forces across 3 trials was very high at all target intensities in both men and women. Δforces in men were 0.8±14.7%, 5.0±15.1%, and 7.9±11.5% at 75%, 50%, and 25% of MVC, respectively (Figure 2).

Δforces in women were -14.9±19.1%, -7.6±14.4%, and -4.0±8.3% at 75%, 50%, and 25% of MVC, respectively. There was significant difference in normalized forces between sexes at 75% (p=0.024),

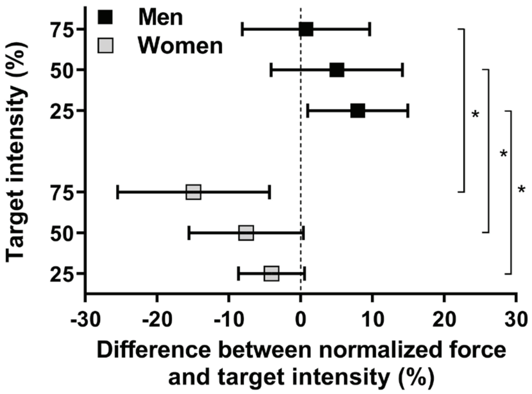

Figure 2: Difference between Normalized Force (%) and Target Intensity (% of MVC) in Men and Women.

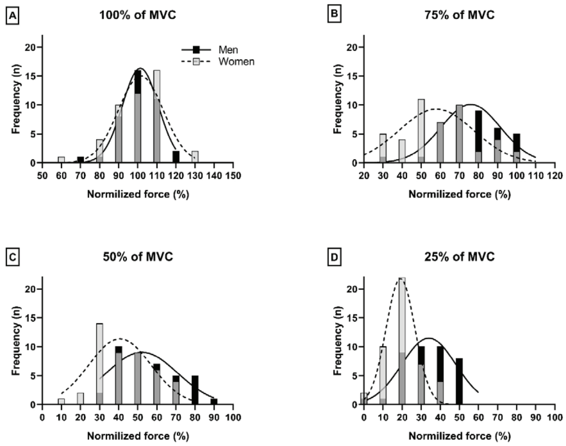

Figure 3: Frequency Distribution of Normalized Force (%) in Men and Women at Four Different Target Intensities.

50% (p=0.033), and 25% of MVC (p=0.004). The difference in frequency distribution of normalized forces between men and women was most mismatched at 25% of MVC (Figure 3).

DISCUSSION

The absolute contraction forces of men measured at four different target intensities were significantly higher than those of women. One interesting thing is that the ratio of women contraction force to men contraction force decreased gradually with decreasing target intensity. In detail, women showed 63.2%, 48.9%, 47.9%, and 40.3% of the contraction force of men at 100%, 75%, 50%, and 25% of MVC, respectively. It is already widely known that the maximal contraction force of women is lower than that of men because of the physical characteristics between men and women (17). However, if the decrease in contraction force at submaximal target intensity is relatively small compared to men, the ratio can be increased. In this study, women reduced the contraction force more than required, and it was confirmed that the ratio also decreased gradually when the target intensity decreased. Differences between men and women may be due to physical and physiological characteristics. Women has less CSA for type I, IIA, and IIB muscle fibers and less peak torque of hamstrings and quadriceps than men (18,19). The sexual dimorphism observed in muscle composition can be attributed, at least in part, to endocrine factors, specifically the influence of hormones like testosterone, which significantly modulate the process of protein synthesis (20,21). In addition to simple physical characteristics, differences between men and women are also observed in muscle extensibility and movement strategy (22,23). It is also known that women have slightly lower proprioception including threshold to detect passive motion in the lower extremities (24–26). In addition to the absolute contraction forces, the frequency distribution of normalized force also showed differences between men and women. In particular, in the case of women, a high frequency was observed in 25% of MVC. This may be because the mean of normalized force at 25% of MVC was lower than that of men, closer to 0%, which is the left end of the range, and consequently the range from min to max became narrower than that of men. In one of the existing studies, there was a difference between men and women in frequency distribution at 100% of MVC – this is probably because, in that study, the number of repetitions was 5 times and the maximum value out of the 5 trials was set to 100% of MVC, but the average of 3 times was set as 100% of MVC in the present study (27).

Since the baseline value of contraction force between men and women is significantly different, it is necessary to analyse using muscle force normalized to 100% of MVC, which is a relative value rather than an absolute value, which is contraction force (28,29). Normalized muscle forces in men were 75.8±14.6, 55.0±15.1, and 32.9±11.5 at 75%, 50%, and 25% of MVC, respectively. Normalized muscle forces in women were 60.1±19.1, 42.4±14.4, and 21.0±8.3 at 75%, 50%, and 25% of MVC, respectively. In the values of Δforce, similarities and differences between men and women are observed, respectively. First, the difference is that, in 75% of MVC, the normalized force to the assigned target intensity was the closest for men, but the most distant for women. What they have in common is that when the target intensity is lowered from 75% to 25% of MVC, Δforce increases gradually. As Δforce gradually increases as it goes to low-intensity, unlike high-intensity, it was the closest for women at 25%, while it was the most distant for men. In previous studies that did not separate men and women, under-production at high-intensity (30), and over-production at low-intensity were often observed (8). Under-production at high-intensity has been viewed as a protective mechanism to reduce the risk of injury caused by intense muscle contraction (30). If this study also performed statistical analysis with a single group without grouping by sex, contraction force would be 67.4% in 75% of MVC (under-production) and 26.5% in 25% of MVC (over-production). That is, there is a clear difference according to the characteristics of men and women, but when averaged, the difference between men and women is offset and can be interpreted differently.

If the amount of force produced by muscle during a single contraction shows a quantitative ability of muscle performance, the same amount of force produced during repeated contractions will show a qualitative ability (31). Intra-trail reliability confirmed through ICC and CV was found to be very high in both men and women except for 100% of MVC. The difference between the trials was more pronounced than the difference between men and women. When comparing the ICC measured at each target intensity, the 2-3rd trials had the highest total of 5 times, and the 3rd-1st trials had the lowest number of just once. If wishing to use consistent data in an experimental study, it is most recommended to use the average of the 2nd and 3rd trials. Unlike absolute contraction force, there was no significant difference between men and women in reproducibility. In order to maintain the same muscle contraction strength, the body provides real-time information that occurs during muscle contraction to the central nervous system via afferent pathways (32–34). This feedback mechanism is implemented by proprioceptors such as muscle spindles and golgi tendon organs (35). During muscle contraction, motor unit recruitment and rate coding are constantly adjusted to the situation, helping the muscle to maintain a constant contractile strength (36–38). Changes in neuromuscular activation can be confirmed by electromyography, and increased EMG is observed in actual sustained contraction (39). Since the feedback mechanism only provides information that occurs during movement, feedforward control of movement in the pre-contraction phase is required to generate the same amount of muscle force during repetitive contractions (40,41). Feedforward sends anticipatory input to the sensory area before movement occurs. The internal copy of the motor signal is then compared with the reafferent signals from the sensory system to determine sensory discrepancy (42). Integrated information in the feedforward and feedback mechanism will help the contraction force approximate the target intensity (43).

In a previous study conducted on lower extremity muscles, it was found that the maximum muscle contraction occurred most frequently between 3-5 repetitions (12). Three repeated measurements of each target intensity may not have been sufficient to elucidate differences between men and women. In addition, in this study, electromyography activity was not measured, so there was a limitation in interpretation.

In this study, the absolute contraction force during hip extension was measured three times at four different target intensities, and differences in absolute and normalized force with its reproducibility between sexes were confirmed. The results showed that the normalized force close to the target intensity was produced at high-intensity for men and at low-intensity for women. Also, when both men and women reduced the target intensity from high-to low-intensity, it was confirmed that the normalized force did not decrease as much as the decrease of the target intensity, and the decrease was smaller in men. In addition, there was no significant difference in reproducibility between men and women, and reliability was generally higher in 2nd-3rd trials. In clinical practice, physical therapists should be aware that absolute and normalized muscle force may manifest in different patterns at maximal and/or submaximal intensities between sexes.

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Ethical Approval: The institutional review board of Woosong University approved this study (Number: 1041549-191011-SB-81).

Informed Consent: A written informed consent form was obtained from all participants.

Author Contributions: Concept, Design, Supervision, Resources and Financial Support, Materials, Data Collection and/or Processing, Analysis and/or Interpretation, Literature Research, Writing Manuscript, Critical Review – W.L.

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