Analysis of torque, power, work, and quadriceps muscle activities according to self-selected velocity for knee extension movement

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무릎 폄 동작에 대한 자가 선택 속도에 따른 토크, 힘, 일, 대퇴사두근 근활성도 분석

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Abstract

The purpose of this study is to investigate changes in biomechanical parameters and quadriceps muscle activity according to different demands for movement speed. Additionally, a correlation was established between speed and acquired data. Participants were 38 healthy adults. The self-selection speed required slow, moderate, and fast motions for knee extension movement. Biomechanical parameters (peak torque; PT, average torque; AT, total work; TW, average power; AP, peak power; PP) during knee extension were measured to evaluate knee extensor function. Muscle activities were acquired for the vastus medialis (VM), vastus lateralis (VL), and rectus femoris (RF) muscles during knee extension with three self-selective angular velocities using electromyography. The biomechanical parameters showed significant differences among angular velocities ($P < 0.001$). According to the results of Mann-Whitney post hoc tests, PT, AT, TW, AP, and PP values at fast were significantly greater than at other angular velocities ($P < 0.001$). It was also significantly higher at moderate than at slow velocities ($P < 0.001$). The self-selective angular velocity has a very strong positive correlation with PT, TW, AP, and PP ($P < 0.001$) and a strong positive correlation with AT ($P < 0.001$). As speed increased, biomechanical factors and muscle activity increased. The rate of increase in speed and the muscle activity and AT were similar. However, the TW, AP showed a larger increase than the rate at which the speed was increased. This study demonstrated that high speed increases the efficiency of exercise.

1. Introduction

Definition of muscular strength is the ability to exert a force on an external object or resistance [1]. Higher levels of muscular strength can increase functional performance and reduce the risk of injury. Injuries occurred when performance demands exceed an individual`s capacity (i.e., ability, awareness, and understanding) [2]. The cause of the problem is not the task (e.g., isotonic) itself, but the demand (e.g., choice of load, number of repetitions, speed, etc.), which involves the various parameters of movement. Resistance training (RT) is most commonly used to increase muscular strength [3]. Taking the most commonly used isotonic exercise as an example, an increase in load leads to an increase in the exercise demand for the subject [4]. In isokinetic exercise, the subject required the best effort in an entire range of motion while the selected maximum velocity was limited by the exoskeletal device [5]. Previous studies on the velocity component compared the fast maximum constant velocity (e.g., 300 ~200 degree/sec) and the slow velocity (e.g., 60 ~120 degree/sec) [6-12]. It can be considered that there are similar performance demands because subjects required maximum effort for both velocities.

Therefore, in order to know the effect of velocity, it is necessary to investigate different demands on speed rather than specifically constrained velocity. This study aims to compare the change in the biomechanical parameters (peak torque; PT, average torque; AT, total work; TW, average power; AP, peak power; PP), and quadriceps muscle activity according to different demands for movement speed and the correlation between velocity and acquired data.

2. Method

2.1 Participants

A total of 38 healthy young adults (19 males, 19 females, mean ± standard deviation; age = 23.21 ± 2.13 years, height = 166.84

± 8.58 cm, weight = 62.95 ± 13.82 kg, body mass index = 22.37 ± 3.35 kg/m2) volunteered to participate in this study. Participants had no previous lower limb injury, neurological disorder, or cardiovascular disease; and they weren't involved in any other exercise program. The University Institutional Review Board approved this study (SM-201910-059-1), which was performed in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from each participant after explaining the experimental purpose and protocol of the study. Participants were aware of their right to withdraw from this study.

2.2 Knee extensor muscle function at the self-selective angular velocity

Prior to the measurement, participants conducted a 5-minute warm-up at their own preferred pace using a cycle ergometer. Three minutes following this warm-up, participants were asked to sit in a dynamometer chair. The axis of the dynamometer was aligned with the lateral epicondyle of the knee, and the force pad was placed approximately 3 cm above the medial malleolus. The trunk and thigh were secured using straps. Participants performed concentric knee extensions at self-selective angular velocities of slow, moderate, and fast subjectively determined using the isotonic mode of a dynamometer. The range of motion of the knee joint was set from 90° flexion to maximal voluntary knee extension (0°). The order of the knee extension test at three self-selective angular velocities was randomly assigned to each participant and separated by a 5 min rest interval to minimize muscle fatigue. Three trials were performed at each angular velocity and a 30-second rest was allowed between each trial.

The angular velocity values (degrees per second) used in the analysis were average values within the range of motion (90° flexion to 0°) during knee extension at a self-selective velocity. Biomechanical parameters (PT, AT, TW, AP, PP) during knee extension were measured to evaluate knee extensor function. Knee extension angular velocity and biomechanical parameters of the knee extensor were calculated as mean values of three trials [18]. To compensate for individual differences related to body weight (BW), the measured values of PT (Nm/kg), AT (Nm/kg), and TW (J/kg) were normalized to each individual's BW [19].

2.3 Electromyography

The EMG measurements and analysis were collected using the wireless surface EMG system (Zerowire EMG, Aurion, Italy) and MyoRESEARCH software (XP Master, version 1.07.1, Noraxon, Scottsdale, AZ, USA). EMG data were acquired for the vastus medialis (VM), vastus lateralis (VL), and rectus femoris (RF) muscles during knee extension with three self-selective angular velocities. The electrode sites were shaved, and the skin cleaned with rubbing alcohol. The attachment placement of the Ag-AgCl electrode was determined according to the Surface Electromyography for the Non-Invasive Assessment of Muscles guidelines [20, 21] .

The EMG signals were sampled at 1000 Hz and synchronized with isokinetic dynamometer data. The signal was filtered using a bandpass filter (20–450 Hz). The filtered signals were full wave rectified and smoothed using the RMS with a 10 ms window. For normalizing the EMG data, participants completed a maximal voluntary isometric contraction (MVIC) test for the knee extensor using an isokinetic dynamometer. The knee and hip joints of the examined limb were maintained at 60° and 90° flexions, respectively [22-24] . Three 5 s trials were recorded with 2 min of rest in between. The first and last seconds are discarded and the root mean square (RMS) value for the middle 3 seconds was calculated and the highest value of the three consecutive tests was used for analysis [25] . EMG signals obtained during the knee extension were normalized to the MVIC (MVIC %).

2.4 Statistical analysis

The Shapiro-Wilk test was used for the normality test of all data. Kruskal–Wallis one-way ANOVA (two-tailed, significance level $\alpha = 0.05$) was used for comparison of knee extensors biomechanical parameters and muscle activity at three self-selective angular velocities. A Mann-Whitney U test was used for post hoc analysis and Bonferroni correction (0.05/3) was applied (two-tailed, significance level $\alpha = 0.0167$). Spearman Rank-order correlation was used to analyze the correlation between biomechanical parameters and muscle activity in all trials (n=114) performed at self-selective slow, moderate, and fast angular velocities (0.0 - 0.1: zero; 0.1 - 0.4: weak correlation; 0.4 - 0.6: moderate correlation; 0.6 - 0.8: strong correlation; >0.8: very strong correlation) [26] . All acquired data were analyzed using SPSS software (SPSS 22.0, SPSS Inc., Chicago, IL, USA). $P < 0.05$ was considered statistically significant.

3. Results

The measured self-selective slow, moderate, and fast angular velocities (°/s) of the knee extension were 27.82 ± 18.65, 80.06 ± 19.66, and 122.6 ± 23.31, respectively. Table 1 shows the differences in biomechanical parameters (PT, AT, TW, AP, PP) and muscle activity (VMO, VL, RF) of the knee extensors during concentric contraction according to the three self-selective angular velocities. The biomechanical parameters showed significant differences among angular velocities ($P < 0.001$). According to the results of Mann-Whitney post hoc tests, PT, AT, TW, AP, and PP values at fast were significantly greater than at other angular velocities ($P < 0.001$). It was also significantly higher at moderate than at slow velocities ($P < 0.001$). In addition, significant differences were found in the muscle activity according to the angular velocity. As a result of the post hoc tests, VMO, VL, and RF muscle activity at fast were significantly higher than at other angular velocities ($P < 0.001$), and at moderate than at slow angular velocities (VMO; $P < 0.001$, VL; $P = 0.005$, RF; $P = 0.015$), respectively.

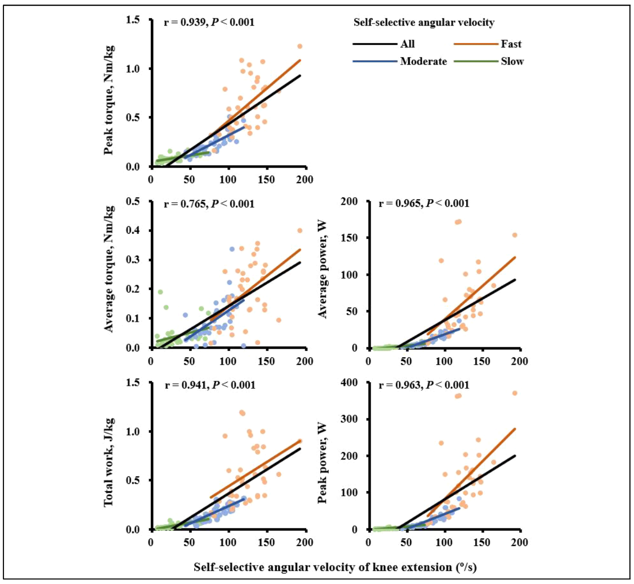
[Table 1] . Comparison of biomechanical parameters and muscle activity of knee extensors according to self-selective angular velocities using the Kruskal Wallis test (N=38).

Variables	Slow	Moderate	Fast
Biomechanical parameters			
Peak torque, Nm/kg	0.08 (0.03)	0.24 (0.10)	0.62 (0.26)
Average torque, Nm/kg	0.04 (0.04)	0.09 (0.07)	0.19 (0.10)
Total work, J/kg	0.04 (0.03)	0.17 (0.09)	0.55 (0.29)
Peak power, W	3.18 (3.65)	25.16 (18.29)	130.76 (90.80)
Average power, W	1.24 (2.16)	11.66 (8.32)	60.37 (42.48)
Muscle activity			
VMO, %MVIC	13.95 (7.7)	22.63 (13.49)	67.06 (38.21)
VL, %MVIC	16.77 (7.94)	24.89 (16.37)	68.01 (43.29)
RF, %MVIC	19.06 (9.66)	25.18 (11.44)	57.68 (25.61)

The correlation between the self-selective angular velocity of knee extension and biomechanical parameters is presented in figure 1. The self-selective angular velocity has a very strong positive correlation with PT, TW, AP, and PP ($P < 0.001$) and a strong positive correlation with AT ($P < 0.001$). Figure 2 shows the correlation between self-selective angular velocity and muscle activity in knee extensors. The angular velocity has a strong positive correlation with each muscle activity corresponding to VMO, VL, and RF ($P < 0.001$).

4. Discussion

This study investigated the changes in biomechanical parameters and quadriceps muscle activity according to the increased demand for movement speed. The self-selective fast and moderate angular velocity was 122.6°/s, 80.06°/s, which was 4.4 times and 2.9 times faster than the slow velocity, respectively. Muscle activities and AT of the fast speed demand group were increased by 3 to 4.8 times compared to the slow speed. Interestingly, TW and AP in the fast speed condition were more affected by the speed increase, increasing by 13.8 times and 41.1 times, respectively.



[Fig. 1] Self-selective angular velocity of knee extension

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