CHARACTERISTICS OF STRENGTH AND POWER FOR THE RATE OF FORCE DEVELOPMENT DURING LEG EXTENSION

Kodayu Zushi[1], Yasushi Kariyama[2], Amane Zushi[1], Takuya Yoshida[3], Kazutaka Takahashi[1], Kiyonobu Kigoshi[3], Mitsugi Ogata[3]

Graduate School of Comprehensive Human Sciences, University of Tsukuba, Tsukuba, Japan[1]
Faculty of Sport Science, Yamanashi Gakuin University, Kofu, Japan[2]
Faculty of Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan[3]

A multi-strength tester (MST) was developed to assess the rate of force development (RFD) during isometric leg extensions. This study aimed to examine the relationship between RFD measured by MST and strength and power performance. Participants performed isometric leg presses with MST, countermovement jumps, squat jumps (SJ), and concentric squat of 70% of 1 repetition maximum (sq70). Significant correlations were found between the early phases of RFD measured by MST and countermovement jump. There were no significant correlations found in SJ. The late phase of RFD measured by MST significantly correlated with sq70. The present results suggest that the early phases of RFD with MST relate with countermovement during jump performance. The late phase of RFD with MST relate with the ability of generating force under heavy resistance.

KEYWORDS: assessment, multi-strength tester, countermovement jump, squat

INTRODUCTION: The ability to generate large forces in the lower limbs as quickly as possible is essential for sports performance and for assessing the rate of force development (RFD). RFD can be obtained from the rising force-time curve and is related to power; jump height of countermovement jump (Nuzzo et al., 2008), sprint start; and maximal sprint velocity (Young, McLean, Ardagna, 1995). RFD has a neural factor that is different from maximum force that takes over 300 ms to reach (Thorstensson et al., 1976). Measuring RFD to assess training adaptations and conditions is necessary for distinguishing it from maximum force for athletes. For strength training and conditioning, it important to conduct measurements and assessments in real time. Therefore, we have developed a multi-strength tester (MST; jointly developed with Takei Scientific instruments Co., Ltd.) to measure and gain feedback from the RFD in real-time (Fig. 1). The MST was used to measure the force during isometric single leg press with the foot plate to display the force-time curve and RFD variables.
This study proposes that RFD measured during MST can be used to evaluate the basic force-generating ability. Hence, the purpose of this study was to examine the relationships between RFD as measured by MST, jump, and squat exercise performance.

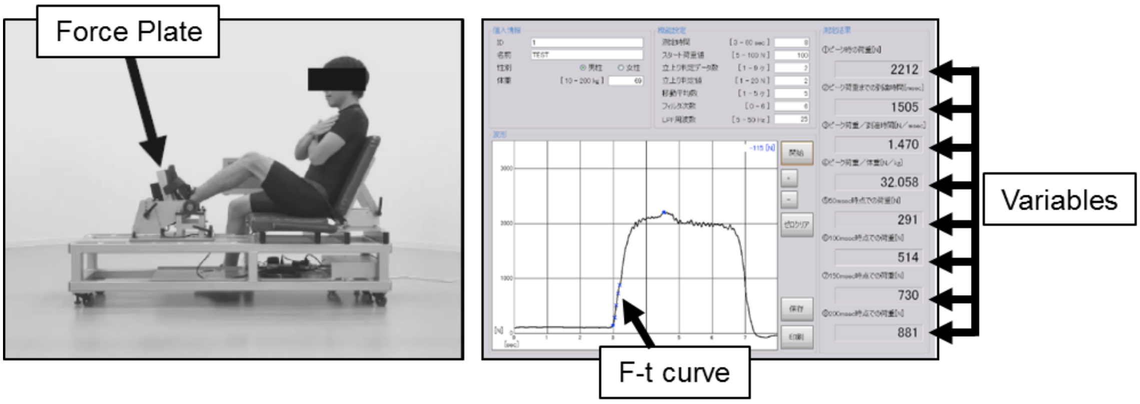

Figure 1 Measuring equipment: the multi strength tester and posture of a participant during measurement (left) and the display that shows the measurement results (right)

METHOD: Seventeen male track-and-field athletes, jumpers and decathletes (mean ± SD of age, 21.9 ± 1.9 years; mass, 66.0 ± 4.9 kg; height, 175.1 ± 7.7 cm) volunteered to participate in this study. Prior to conducting the experiments, all subjects were informed all subjects about the purpose of the study, the study methods, the risks, and the safety precautions accompanying the experiment. The study was approved by the University`s Ethics Committee.

The RFD, measured by MST and three tests of performance of strength and power were conducted. Each experimental trial was conducted as follows.

RFD measured using MST: The RFD during isometric single leg press was measured. Participants were accommodated on the MST at the long seat position with a knee angle of 115°. Leg extensions that were standardized to 100 N of active pre-tension to reduce compliance between the foot and footplate, or/and between muscle, tendons, and joints. This setup also prevented the participants from undertaking countermovement. Leg extension commenced the participants at their own timing, and they were asked to perform for 3 seconds. Two types of RFD were calculated. F_{time} was measured at 9 time points (25 ms interval from 25 ms to 300 ms) from onset of force exertion (defined as F_{25}, F_{50}, F_{75}, etc.; (Folland, Buckthorpe, Hannah, 2014). The 0 ms time point was not included and ⊿RFD was obtained by increasing the force across 25 ms in the interval from 0 ms to 300 ms (0-25, 25-50, …275-300) (Fig. 2).

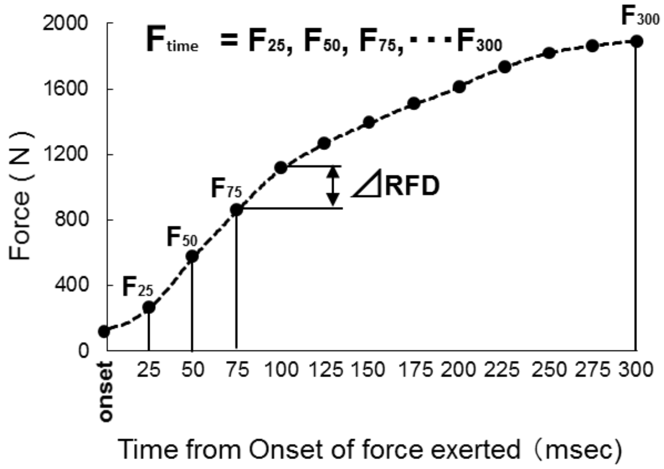

Figure 2: Calculation of the RFDs during leg extension. F_{time}: The force at the specific time points (defined as F_{25}, F_{50}, F_{75}, etc.).⊿RFD: The force development in 25 ms (0-25, 25-50, ・・・275-300).

Concentric squat (squat): Squats were performed so that the depth corresponded to a 115 ± 5° knee angle, which is the same range as that observed during the MST, using 70% 1RM (70% of 1 repetition maximum). 1RM, which is a back squat RM, was measured during advanced examinations using the same protocol. In order to unify the protocols at the start of the trial, the ground contact position of the foot part was uniform in all trials and the knee joint angle was monitored using a goniometer (DKH Inc., SG150). Participants were instructed to perform the squat “as fast as possible.” Maximum ground reaction force was recorded as a measure of performance.

Vertical Jump: Participants performed squat jumps (SJs) and countermovement jumps (CMJs) without arm swings. SJs were performed without countermovement so that the depth corresponded to a 115 ± 5° knee angle, reflecting the MST trial. CMJs were performed by jumping from a standing position using countermovement. The jump heights of SJ and CMJ were calculated from the impulse during the trial. Participants were instructed to jump “as high as possible.

Squat and jump performances were measured using a force platform (Kistler, 9287C). The analog signal was sampled at 1000 Hz and stored in an external computer. MST force was measured via a strain gauge load using cells built in the foot plate. The force signal was sampled at 1000 Hz. The force curve was filtered using a sixth-order zero-lag Butterworth filter with a cut-off frequency of 25 Hz.

Pearson’s correlation coefficients were used to describe the relationships between the other tasks and each variable in the RFD as measured by MST at each time point/period. Statistical significance was set at $p < 0.05$ and Strong correlation was set at $p < 0.01$.

A

	F_{time}											
	F_{25}	F_{50}	F_{75}	F_{100}	F_{125}	F_{150}	F_{175}	F_{200}	F_{225}	F_{250}	F_{275}	F_{300}
○	.625**	.734**	.767**	.756**	.689**	.618*	.600*	.568*	.525*	.489*	.472	.473
◇	.209	.112	.133	.143	.116	.091	.065	.049	.048	.023	.008	-.018
△	-.019	.054	.140	.236	.338	.392	.413	.432	.457	.481*	.477	.486*

B

	⊿RFD											
	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300
●	.625*	.756**	.733**	.483*	-.022	-.168	.160	.029	-.104	-.163	-.212	.197
◆	.209	.075	.147	.128	-.071	-.110	-.162	-.106	.018	-.272	-.479	-.148
▲	-.019	.079	.241	.462	.597*	.473*	.351	.382	.480	.508*	-.004	.322

*; $p < 0.05$ **; $p < 0.01$

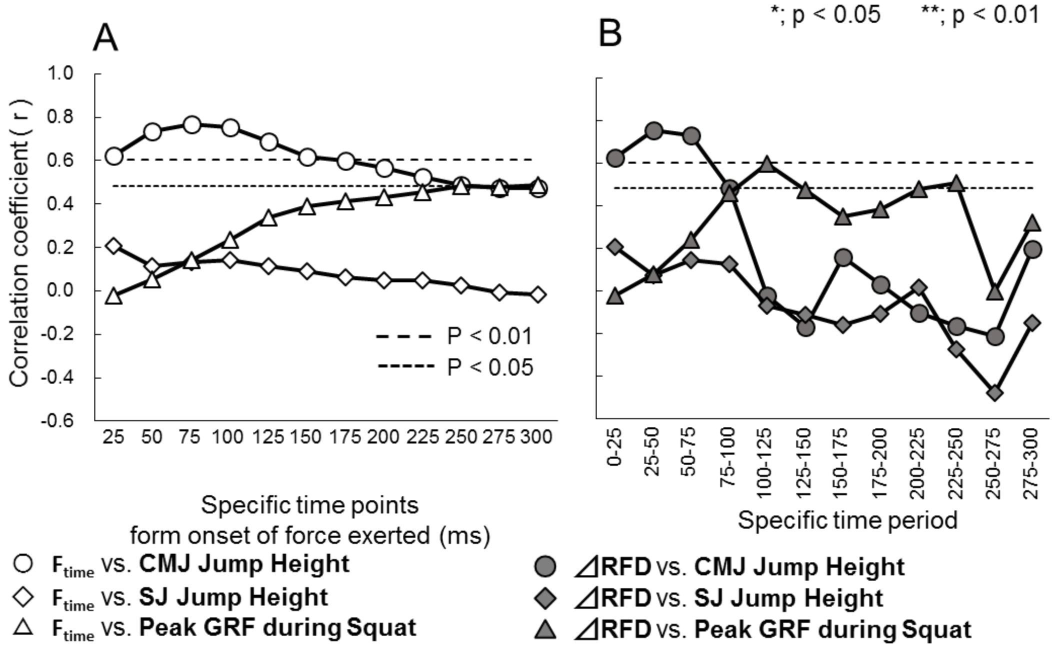

Table 1 & Figure 3: Correlation coefficients between F_{time} and performance of strength and power (A), and between ⊿RFD and performance of strength and power (B).

RESULTS: Figure. 3A shows the correlation coefficients for F_{time} in MST and other strength and power performances for leg extension. Significant correlations were found between maximal ground reaction force of squats and F_{time} after 250 ms (Fig. 3 A; △). Significant correlations were found between the CMJs jump height and F_{time} at all time points. In addition, a strong correlation was found with F_{time} before 150 ms (Fig. 3A; ○). No significant correlation was found between jump height of SJs and F_{time} at each time point (Fig. 3A; ◇). Correlation coefficient of the maximum ground reaction force of squats and F_{time} ascended (Fig. 3A; △). Correlation coefficient of the CMJs jump height and F_{time} ascended until F_{75} and, Correlation coefficient descended since F_{75} (Fig. 3A; ○).

Fig. 3B represents the relationships in ⊿RFD measured by MST and strength and power performance for leg extensions. Significant correlation was found between maximum ground reaction force of squats and ⊿RFD for 100-125 ms, 225-250 ms (Fig. 3B; ▲). Significant correlations were found between the jump height of CMJs and ⊿RFD for 0-100 ms (Fig. 3A; ●). No significant correlation was found between the jump height of SJs and ⊿RFD at each time period (Fig. 3A; ◆).

DISCUSSION: In the results, F_{time} and ⊿RFD for early phases (~150 ms) were shown to have a strong and significant correlation with the CMJ jump height (Fig. 3A; ○ and ◇, Fig. 3B; ●and ◆). However, no significant correlation was found between RFD and SJ jump height. Only concentric phases comprise the SJ. Therefore, performing SJ requires the generation of force under high-speed muscle contraction (Fukashiro & Komi, 1987).

CMJ is characterized by a countermovement phase and the rate of force development during this phase necessitates high CMJ performance (Laffaye & Wagner, 2013). In addition, force was generated under lower muscle contraction speed during this phase (Fukashiro & Komi, 1987). It is suggested that the early phase of RFD in MST is similar to the speed of muscle contraction and duration of exerted force during countermovement (Figure 4). This may explain the differences in correlation coefficients between RFD measured by MST and CMJ jump height and SJ jump height.

Significant correlations were found between maximum ground reaction force of squats and F_{time} after 250 ms (Figure 3A; △). Squats tended to require more than 250 ms to reach maximum ground reaction force. It is suggested that the late phase of RFD as measured by MST is similar to the duration of force exerted during squats. Previous studies reported that MVC (measured under isometric contraction) is a factor for determining RFD after 125 ms from the onset of contraction (Folland, Buckthorpe, Hannah, 2014). These may be the cause of significant correlations between maximum ground reaction force of squats and RFD measured by MST.

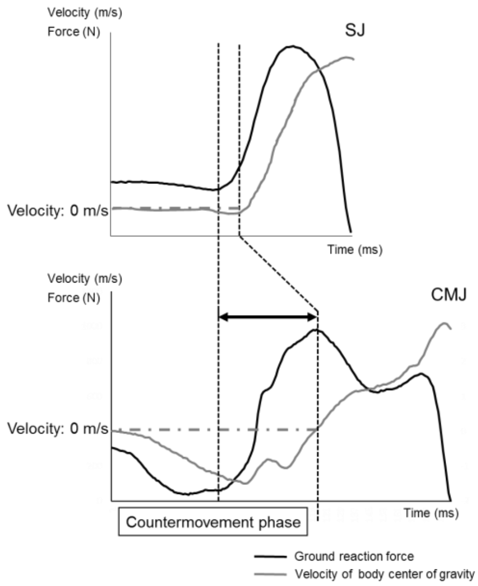

Figure 4: A Force-time curve (black line) and a velocity-time curve (gray line) during vertical jump

CONCLUSION: The purpose of this study was to examine the relationship between RFD calculated using novel custom equipment (MST), and standard strength and power measures of performance during leg extension tasks Relationships between RFD measured by MST and the assessed variables varied were different according to the time point/period from when the starting force was exerted. The early phase of RFD measured using MST is related to strength and power for jumps performed a using countermovement. Additionally, the late phase of RFD in MST is related to the performance of strength and power in similar exercises with a similar duration of exerted force. This study suggests that there are benefits of measuring RFD with MST. The measurement shows the strength and power associated with exercise. In addition, it is important to consider the duration from onset of exerted force by measuring RFD with MST.

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