STUDY OF THE MECHANISM OF EXPLOSIVE FORCE PRODUCTION ON QUICK LIFT MOTION BY ANALYSIS OF EMG AND MOTION

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The aim of this study is to investigate how explosive force exerts during power clean (PC) motion. The subjects are ten skilleds and ten unskilleds. The joint trajectory and EMG during PC are recorded. The joint torque and its rate of torque development (RTD) are calculated from the obtained data. The joint stiffness is estimated from *joint stiffness index* (JSI) calculated from EMG of agonist and antagonist muscle pair. Experimental results indicated that the skilleds showed the *double knee bent* that is typically seen in a stretch-shortening cycle (SSC). Skilleds exerted large values of RTD and JSI just after a period of exerting their small values during SSC. It indicates that a much amount of elastic energy stored in a low stiffness state is instantly transferred to the upper segments in the successive high stiffness state by “tenodesis action” of muscles. This is why large RTD generates in the skilled.

KEY WORDS: power clean, rate of torque development, stiffness and stretch-shortening cycle.

INTRODUCTION: Various quick lift trainings are widely practiced into strength training programs. Quick lift training and its variants are generally recognized as an effective resistance-training method for explosive force production development and athletic performance enhancement. It has been well documented that the explosive force production is quantitatively evaluated by the rate of force development and is known to be largely dependent on the highest possible force and the timing to emerge (Stone 1993). There are many experimental reports related to the explosive force production in athletic motion. Bojsen et al. (2005) made it clear that resistance training with ballistic motion improved the rate of torque development (RTD). However, the RTD during the quick lift training has not been fully discussed despite the quick lift training is recognized as one for improving the explosive force production. Most of researches about the quick lift training have just focused on the load that provides the greatest peak power or force output (Comfort et al. 2011). So, the purpose of this study is to clarify how explosive force is produced during power clean (PC) motion that is a widely practiced quick lift training by featuring differences between skilled group and unskilled group in kinetic and kinesiologic point of views.

Table 1
Subject characteristics

Variable	All	Group	
	(n = 20)	Skilled (n = 10)	Non-Skilled (n = 10)
Age [yr]	20.30 (1.49)	21.40 (2.01)	20.30 (0.95)
Height [m]	1.72 (0.05)	1.70 (0.06)	1.73 (0.04)
Body Weight [kg]	67.29 (5.45)	67.00 (6.06)	68.10 (5.99)
Fat [%]	12.95 (2.71)	13.04 (2.50)	12.86 (3.03)
LBM [kg]	58.27 (4.41)	58.17 (4.38)	59.26 (4.60)
BMI [kg/m^2]	23.06 (1.90)	23.32 (2.15)	22.80 (1.68)
PCmax [kg]	67.25 (9.69)	80.00 (6.87)	54.50 (6.85)**
%PCmax [kg/BW]	1.00 (0.23)	1.20 (0.10)	0.81 (0.12)**

** Represents statistically significant difference between the groups ($p < 0.01$) Mean (S.D.)

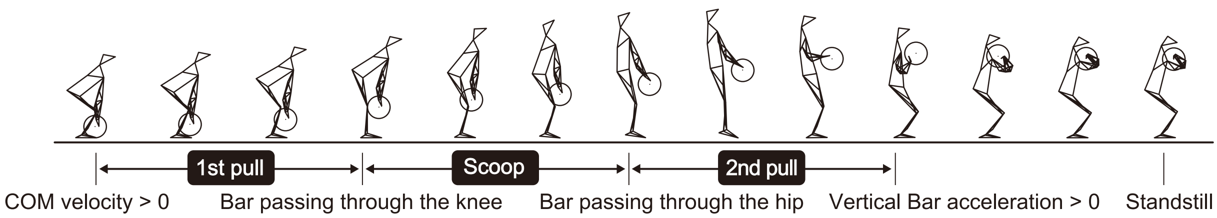

Figure 1: Definition of phases of PC motion

METHODS: Twenty healthy men who are familiar with the resistance training volunteered to be subjects for the present study. They are classified into two categories: the skilled and the unskilled classified by a typical criteria as "PC 100% one repetition maximum/body weight (BW)" exceeding 1.0 or not. Table 1 shows the subjects' data. Prior to participating in this investigation, all subjects read and signed the informed consent. Subjects performed PC of which intensity was set at 70% of individual PC max. The trajectories of markers attached on the subjects' body, ground reaction force and center of pressure during PC were recorded by the motion capture system (Cortex3, Motion Analysis, Sampling Frq.: 250 Hz, shutter speed: 1/500 sec). For recording muscle surface electromyography (EMG), active electrode (S&ME, DL-141) with a inter-electrode distance of 12 mm were placed on the Gluteus Maximus (GM), Rectus Femoris (RF), Biceps Femoris (BF), Vastus Medialis (VM), Gastrocnemius (GC) and Tibialis Anterior (TA) muscle of right leg with a sampling frequency of 1000 Hz. EMG data was recorded in synchronized with motion capture system. In addition, the maximum voluntary contraction (MVC) of each muscle was recorded after the measurement of PC motion by manual resistance. Analytic period of PC motion is from onset of lifting the bar placed on the ground to standstill; the whole period of PC motion was divided into three phases (Figure1). The time-trajectory data of joint angle and segments coordinate were obtained by using the motion capture system (Mac3D system, Motion Analysis). Center of the mass (COM) and moment of inertia of each body-segment are derived from the body segment inertia parameters. The joint torque of hip, knee and ankle are calculated according to the dynamic equations. Furthermore, we calculated the time differentiation of the joint torque as a RTD of each joint. The %RMS of EMG was calculated for evaluating the muscle activity levels, which is the root mean square of EMG normalized by MVC.

We newly establish the *Joint stiffness index* (JSI, 0 < JSI <100), as a numerical index to evaluate joint stiffness that is calculated from EMG as follows;

$$\mathrm{JSI} = 2(\%RMS_{\mathrm{flx}} \times \%RMS_{\mathrm{ext}})/(\%RMS_{\mathrm{flx}} + \%RMS_{\mathrm{ext}}) \quad (1)$$

In Eq.1, $\%RMS_{flx}$ and $\%RMS_{ext}$ represent the %RMS of flexor and extensor muscle respectively. As Figure 2 imaginarily showing, when $\%RMS_{flx}$ and $\%RMS_{ext}$ take equally large values, JSI takes large value. So large JSI indicates that the joint is in high stiffness that is obtained by co-contraction of agonist and antagonist muscles. In contrast, some studies have estimated stiffness from the co-contraction index (CI) (Falconer et al. 1985). CI is the value based on summation of agonist and antagonist muscles activity. Therefore, CI takes large value, even if antagonist and agonist take equally small values as shown in Figure 2. So, CI does not accurately represents strength of joint stiffness. This is why we employed JSI to estimate joint stiffness. The couple of agonist and antagonist muscles to calculate JSI are as follows; Hip: GM and RF, Knee: VR and BF, Ankle; TA and GC. We applied the independent t-test to assess difference of the groups. The alpha level for all statistical tests was set at 0.05.

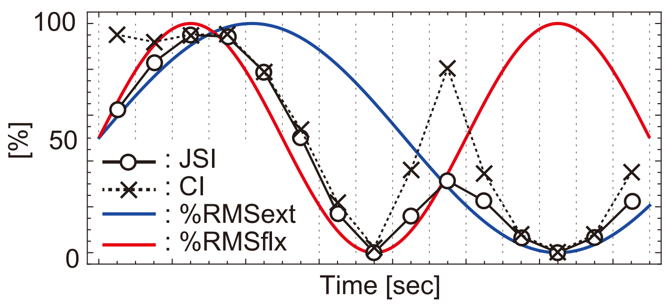

Figure 2: Comparison between JSI and CI with two imaginary antagonistic EMGs activity

RESULTS: Figure 3 shows mean value and standard deviation of ground reaction force of vertical component (Fz), angle of hip, knee and ankle and their angular velocity during PC motion of two groups (skilleds and non-skilleds). Knee flexion-extension occurs in the skilled group in scoop phase with Fz decreasing, which suggests that all skilleds have acquired a dexterous motion called "double knee bent (DKB, hereafter)" that is an unique technique in skilled weight lifters. This fact clearly suggests that the subjects were reasonably classified into two groups. Figure 4 shows mean value and standard deviation of joint torque and RTD and its peak value during PC motion of two groups. As shown RTD, that takes completely different patterns between the groups. Peak joint torque and RTD of hip and knee were significantly different between the groups (p<0.01). Figure 5A and 5B shows mean value and standard deviation of %RMS and JSI during PC motion of two groups. Figure 5C shows mean value of timing of peak value of RTD and JSI. Skilleds' peak value of ankle JSI appeared in common in early scoop phase, and peak value of knee and hip JSI appeared in common in the end of scoop phase, which were closely the same timing as those of the peak RTD. On the other hand, the timings of peak JSI and RTD of non-skilleds were largely deviated and seems to have no ordering and no relationship between them.

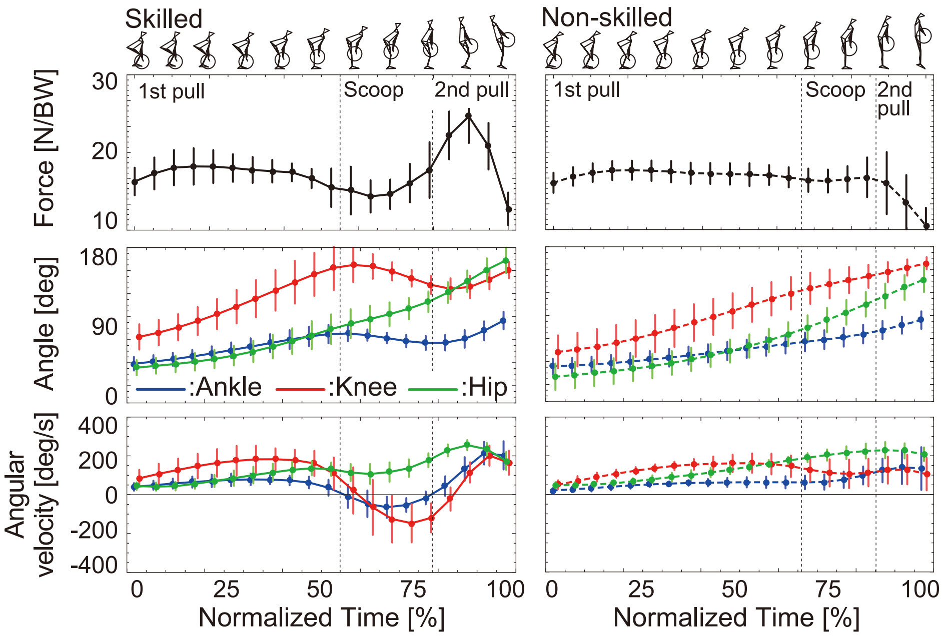

Figure 3: Time courses of ground reaction force, joint angle and angular velocity during PC

DISCUSSION: Skilleds showed the unique technique DKB in scoop phase accompanied by a little decrease of Fz, which means DKB is a kind of counter movement induced in a stretch-shortening cycle (SSC). The skilleds showed large ankle JSI from the end of 1st pull phase

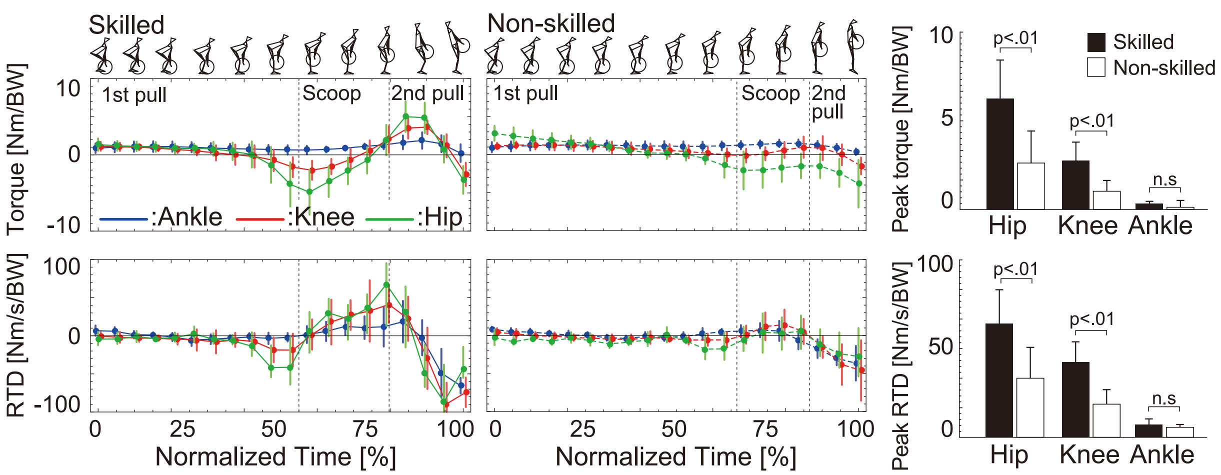

Figure 4: Time courses and peak value of joint torque and RTD during PC

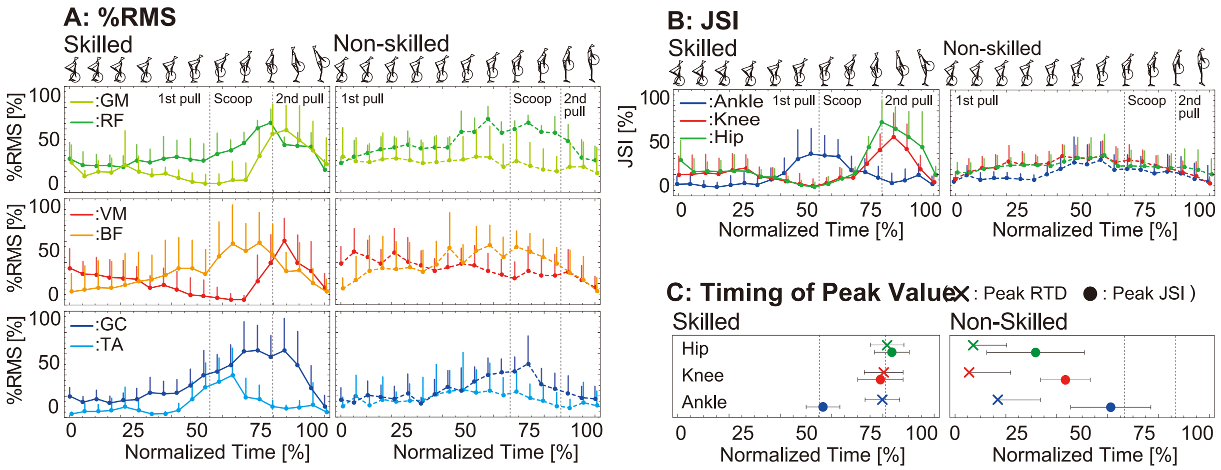

Figure 5 A: Time courses of %RMS during PC motion. B: Time courses of JSI during PC motion. C: Timing of peak value of RTD and JSI in normalized time.

to early scoop phase, which was the same period of Fz decreasing. This motion is interpreted as a pre-activation phase of SSC. In this phase, skilleds' GC shows approximately 50% %RMS in dorsiflexing. Thus GC acts as a stiff spring to absorb load and store potential energy. On the other hand skilleds' knee and hip joints show small JSI and the torques of these joint takes the opposite sign of the angular velocity at the onset of scoop. It means these joints have done negative work while reserving some elastic energy in muscles around hip and knee joints. From the end of scoop phase to early 2nd pull phase, knee and hip JSI and RTD took large value. They are completely different feature from Non-skilleds. Bojsen et al. (2005) indicated that there is positive correlation between vastus lateralis muscle stiffness and RTD, and concluded that high muscle stiffness arrows to transfer energy with high efficiency. Thus, JSI plays an important role in the PC motion to exert large RTD. Taken together, PC with DKB induces SSC, and high stiffness arrow to transfer energy that came from muscle viscoelasticity with high efficiency and large RTD. It means that muscles take *tenodesis action* (Prilutsky et al. 1994) to transfer energy in PC motion. This is an explanation why large RTD, that is high explosive force production, generates in the skilled during PC.

CONCLUSION: We have considered about muscle activity and estimated joint stiffness during PC motion to elucidate the mechanism of explosive force production. The study suggested that low stiffness state of joint at the onset of double knee bent allows to stored elastic energy that is effectively transferred by promptly changing the joint stiffness into high state, that is, *tenodesis action* of lower limb muscles.

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