ABSENT MUSCLE COORDINATION PATTERNS AND REDUCED FORCE EXERTION IN THE NOVICE OF CLEAN EXERCISE

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The clarification of the problems to perform the clean in novice obtains several suggestions for technical guidance. We aimed to identify the control of muscle coordination patterns and related kinetic problems during the clean. Five experienced participants (EXP) and five novices (NOV) performed the clean. The synchronous activation patterns among several muscles were extracted using a decomposition technique. The median number of patterns in NOV (2) was smaller than that of EXP (4). We specified the absent pattern, which was related to the activation of lower limb extensors at the termination of the scoop phase. This might lead to insufficient ankle plantarflexion torque or backward ground reaction forces for pulling the barbell. A practical implication is that a novice needs to pay attention to learning the appropriate activation timing of lower limb extensors for sufficient force exertion.

KEYWORDS: muscle synergies, joint torque, resistance training, barbell.

INTRODUCTION: The clean exercise is a common resistance training method to improve the power exertion abilities of the leg extensors. A novice can improve the power during the clean by learning techniques (Sakadjian et al., 2014), which suggests that learning techniques is required to maximize the training effect. Thus, understanding the muscular control difficulties of the novice while performing the clean is practically valuable for an effective training process. The clean exercise consists of several subtasks such as the double knee bend during the pull phase and triple extension just before turnover of the barbell; the importance of the learning subtasks for the novice is recognized (United States Weightlifting Association, 2015; Kipp et al., 2012). Regarding motor control, less variety of muscle coordination patterns was observed when the untrained person performed the challenging beam-walking task (Sawers et al., 2015). After adaptation to a pedal force exertion task, novel muscle coordination patterns were extracted (De Marchis et al., 2013). To sum up with these evidences, it is expected that the variety of muscle coordination patterns in the novice are insufficient. A previous research showed that the novice could not exert sufficient power during the clean (Sakadjian et al., 2014). The lesser variety of muscle coordination patterns in the novice might relate to smaller exertion during the clean. However, the muscle coordination patterns during the clean exercise in the novice have not been revealed yet. This would clarify the problem points of controlling the muscle coordination patterns for the execution of subtasks in the novice.

The purpose of this study was to obtain suggestions for technical guidance in performing the clean. For this purpose, we aimed to clarify the control of muscle coordination and related problems of force exertion in the novice during the clean. We hypothesized that a part of the novice's muscle coordination pattern is not constructed.

METHODS: We recruited five male experienced participants (EXP; height: 1.74 ± 0.03 m, body mass: 66.2 ± 3.9 kg, 21.4 ± 0.5 years) and five male novices (NOV; height: 1.72 ± 0.07 m, body mass: 66.3 ± 8.7 kg, age: 22.0 ± 1.7 years). The experienced participants continued performing the clean as a training method at least for 1 year, and the novices had never performed the clean. Before the measurement, the participants warmed up with a squat exercise without the barbell. The participants performed the clean 12 times (6 trials × 2 sets). The height of the start position of the barbell was set below the knee. The weights were set as 40% of body mass (range: 20.0–30.0 kg; barbell weight, 20 kg) for the safety of the novices. This is the almost minimum relative weights, and the range of weights was similar to that reported in a previous study (Sakadjian et al., 2014).

We recorded the position values of the reflective markers with a three-dimensional motion capture system with 18 cameras operating at 100 Hz (Flex 3, NaturalPoint, Inc., Corvallis, USA). These reflective markers were attached to 30 anatomical landmarks in the whole body (Kibushi et al., 2018), the four corners of the force platform and four points of the barbell. The whole-body model was used for the analysis, including 15 rigid segments (head, torso, arms, forearms, hands, thighs, shanks, feet, and barbell) by 14 joints. One force platform (TF-4060-D, Tec Gihan Co. Ltd, Kyoto, Japan) was used to record the ground reaction force (GRF) at a sampling frequency of 1,000 Hz. We measured surface electromyography (EMG) from 18 muscles in the right lower limb, trunk, and upper limb during the clean (Figure 1). EMG signals were amplified (SX230-1000, Biometrics, Gwent, UK) and bandpass filtered between 20 and 450 Hz. All the EMG signals were recorded at a sampling frequency of 1,000 Hz.

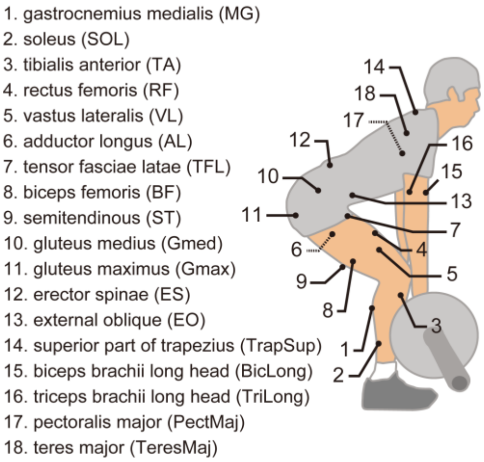

Figure 1: Measured muscles and their abbreviations.

We analyzed six trials of the sampled EMG signals, and kinematic and kinetic data from each participant. The lifting motion of the clean was divided into three phases according to barbell height. The first pull phase was defined as the start position up to a barbell height exceeding the knee joint. The scoop phase was defied as a duration until the barbell height exceeded the knee to hip joint. The second pull phase was defined as a duration until the barbell height exceeded the hip joint to half of the distance between the elbow and the hip joint.

The position coordinates of the markers were smoothed using a low-pass digital Butterworth filter with a cutoff frequency of 7–8 Hz based on the residual analysis (Winter, 2009). The joint torque was calculated using the inverse dynamics.

The EMG signals were high-pass filtered (40 Hz) with a zero lag fourth-order Butterworth filter to remove the noise. Thereafter, the EMG signals were demeaned, digitally rectified, and low-pass filtered at 10 Hz with a zero lag fourth-order Butterworth filter. The low-pass filtered EMG signals were time interpolated over one lifting motion to fit a normalized 200-point time base. The muscle synergies were extracted using a nonnegative matrix factorization (NMF) algorithm (Kibushi et al., 2018). The NMF approximately decomposes a matrix into two non-negative matrixes. The specific muscle activation pattern is represented by the following equation:

$$\boldsymbol{m}(t)\sum_{i=1}^{N}\boldsymbol{w}_i\, c_i(t)+\boldsymbol{\varepsilon}(t)$$

where $\boldsymbol{m}(t)$ is the EMG data at a time t, N is the number of synergies, $\boldsymbol{w}_i$ is the weighting of a muscle in a muscle synergy i. Each component of $\boldsymbol{w}_i$represents the contribution of one particular muscle to that muscle synergy, and an individual muscle may contribute to multiple muscle synergies. $c_i(t)$ represents the time series of activation level in the ith muscle synergy, and $\boldsymbol{\varepsilon}(t)$ is the residual. For functional sorting of the extracted synergies, we calculated the cosine similarities of the muscle synergies between all pairs of the synergies.

The effect size of Cohen's *d* was calculated to compare the following average values between the EXP and NOV: the GRF and ankle plantarflexion torque at the timing barbell height exceeded the hip joint and maximum positive power of ankle joint.

RESULTS AND DISCUSSION: We found different profiles in the vertical and horizontal GRFs between the EXP and NOV (Figure 2a, b). The vertical GRF in the EXP increased in the late-scoop phase, but not in the NOV (10.70 ± 0.78 N/kg in the EXP and 8.00 ± 1.72 N/kg in the NOV; Figure 2b: *d* = 2.08) at the termination of the scoop phase. This suggests that the novices had several difficulties in performing the clean in the late-scoop phase. As in the exertion of the vertical GRF during the late-scoop phase, the novices seemed to have difficulties in the exertion of the horizontal GRF. The EXP exerted backward GRF, while the NOV exerted small forward GRF (−0.98 ± 0.46 N/kg for the EXP and 0.11 ± 0.33 N/kg for the NOV; Figure 2a: *d* = 2.72) at the termination of the scoop phase. The high backward velocity of the barbell during the second pull phase is one of the success factors for the clean (Kipp and Meinerz, 2017). The backward GRF might also be important for novices. Herein, we address the kinetic and neuromuscular mechanisms of difference in GRF between the EXP and NOV.

We observed the different characteristic profiles of the ankle torque and power between the EXP and NOV. The experienced participants exerted prominent peak ankle plantarflexion torque and positive power around the late scoop to the early second pull phase (torque: 1.11 ± 0.30 Nm/kg, positive power: 4.59 ± 1.43 W/kg), while the novices did not exert prominently (torque: 0.83 ± 0.22 Nm/kg, positive power: 2.00 ± 1.36 W/kg; Figure 2c, d: *d* = 1.06 and 1.86). The phases with differences in ankle kinetics were similar to those of the horizontal and vertical GRFs, which suggest that the smaller ankle joint kinetics led to the smaller vertical and horizontal GRFs in the novices.

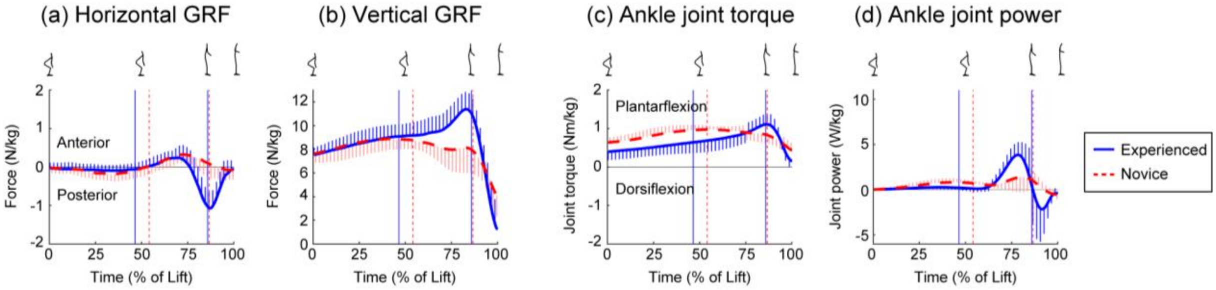

Figure 2: Ensemble average of the horizontal GRF, vertical GRF, ankle joint torque, and ankle joint power in EXP and NOV.

The number of extracted muscle synergies from EMG data in the NOV (2-4) was smaller than that in the EXP (3-5) (median number of synergies, EXP: 4, NOV: 2). This implies that the variety of muscle coordination patterns in the novices were insufficient. Our result is consistent with that of a previous study that presented that less variety of synergies was observed in untrained persons (Sawers et al., 2015). The functions of muscle synergies in the EXP are summarized in Table 1. We found that Synergy 3 was not extracted in the NOV (Figure 3: Synergy 3). Synergy 3 was mainly comprised of ankle plantarflexors (medial gastrocnemius and soleus), knee extensors (rectus femoris and vastus lateralis), hip abductor (gluteus medius), hip extensors (biceps femoris and gluteus maximus), trunk rotator (external oblique), scapular elevator (superior trapezius), shoulder extensor (triceps long head), and shoulder adductor (pectoralis major). The main activation timing of Synergy 3 was the late-scoop phase. Function of Synergy 3 was execution of the triple extension and shoulder shrugging at the termination of the scoop phase. Absence of Synergy 3 in the novices is the notable finding of this study. This suggests that novices cannot control their coordinated muscle activity to execute the triple extension and shoulder shrugging. The less ankle plantarflexion torque exertion or power in the novices might have been derived from the absence of Synergy 3. Grieve (1970) suggested the importance of controlling the force exertion timing for weightlifting. In addition, we mentioned in the previous section that backward GRF might be the success factor for the clean. The novice might need to learn the activation timing of the lower limb extensors for pulling the barbell.

Table 1: Function of muscle synergies.

	Activation phase	Function
Synergy 1	First pull & early scoop	Pull the barbell by lower limb, upper limb and trunk
Synergy 2	Scoop	Hip and knee extension and standing the upper body
Synergy 3	Late-scoop	Triple extension, shoulder shrugging
Synergy 4	Second pull	Lifting the barbell by upper limb muscles

This study has some limitations. First, we treated 40% of body mass as the barbell weights. The characteristics of muscle synergies might depend on the variety of barbell weights. Second, the number of participants was small. Lastly, we did not measure maximum voluntary contraction (MVC). Therefore, we could not compare with activation levels of the muscle synergies between the participants. The activation levels of some synergies have been indicated to highly correlate with the pedal force effectiveness in cycling (De Marchis et al., 2013). This suggests that analysis of the relationship between the activation levels of synergies and force exertion patterns is also important. Further experiments that include the MVC measurement is required to reveal the effect of the activation levels of synergies. This would help in acquiring another technical guidance except for a triple extension.

A practical implication for technical guidance to the novice during the clean is that the possible fatal problem points of executing a subtask might exist in the triple extension. In particular, the novice needs to learn the activation timing of the lower limb extensors at the triple extension to improve the pull.

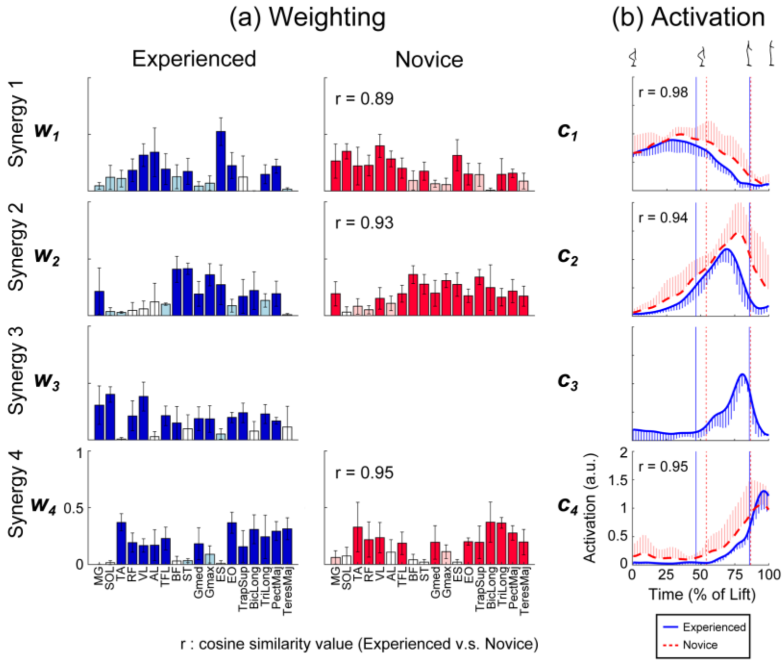

Figure 3: Average weighting and ensemble average of activations of synergies in EXP and NOV.

CONCLUSION:

We revealed that a muscle coordination pattern that relates to executing the triple extension is absent in the novices. This is the novel evidence about the technical guidance for performing the clean. Our findings suggest that the novice needs to learn the activation timing of the ankle plantarflexor muscles, knee and hip extensors at the triple extension for sufficient GRF or joint torque exertion. Therefore, technical guidance for the appropriate activation timing of the lower limb extensors at the triple extension would facilitate the maximization of the training effect of the clean. Further analysis of the activation levels of the existing muscle coordination patterns is required to acquire another technical guidance except for the triple extension.

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