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3-Dimensional Performance Optimization Model of Snatch Weightlifting

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ABSTRACT

Object : The goals of this research were to make Performance Enhanced Model(PE) taken the largest performance index (PI) through artificial variation of principle components calculated by principle component analysis for trial data, and to verify the effect through comparing kinematic factors between trial data (Raw) and PE.

Method : Ten subjects (5 men, 5 women) were recruited and 80% of their maximal record was considered. The PI is a regression equation. In order to develop PE, we extracted Principle components from trial position data (by Principle Components Analysis (PCA)). Before PCA, we made 17 position data to 3 row matrix according to components. We calculated 3 eigen value (principle components) through PCA. And except Y (medial-lateral direction) component (because motion of Y component is small), principle components of X (anterior-posterior direction) and Z (vertical direction) components were changed as following. Changed principle components = principle components + principle components × k. After changing the each principle component, we reconstructed position data using the changed principle components and calculated performance index (PI). A Paired t-test was used to compare Raw data and Performance Enhanced Model data. The level of statistical significance was set at $p \leq 0.05$.

Result : The PI was significantly increased about 12.9kg at PE (101.92±6.25) when compared to the Raw data (91.29±7.10). It means that performance can be increased by optimizing 3D positions. The difference of kinematic factors as follows : the movement distance of the bar from start to lock out was significantly larger (about 1cm) for PE, the width of anterior-posterior bar position in full phase was significantly wider (about 1.3cm) for PE and the horizontal displacement toward the weightlifter after beginning of descent from maximal height was significantly greater (about 0.4cm) for PE. Additionally, the minimum knee angle in the 2-pull phase was significantly smaller (approximately 2.7cm) for the PE compared to that of the Raw. PE was decided at proximal position from the Raw (origin point (0,0)) of PC variation).

Conclusion : PI was decided at proximal position from the Raw (origin point (0,0)) of PC variation). This means that Performance Enhanced Model was decided by similar motion to the Raw without a great change. Therefore, weightlifters could be accept Performance Enhanced Model easily, comfortably and without large stress. The Performance Enhance Model can provide training direction for athletes to improve their weightlifting records.

Keywords : Weightlifting, Optimization, Performance Enhanced Model, Performance Index, Principle Component Analysis

Ⅰ. Introduction

Despite its apparent simplicity, weightlifting is an event requiring both tremendous skill and great power. As a result, researchers and coaches alike have been studying effective weightlifting technique often with the help of motion analysis methodology since the early 1970s, and it appears that weightlifting technique is continuously changing. For example, Moon (2003) noted that the technique of Korean weightlifters has evolved from initially throwing the trunk backward through hip extension during the last pull, then to mainly using knee joint extension, to most recently using extension of the hip and knee joint at the same time. As the research for weightlifting technique, Garhammer (1980) used mechanical power to evaluate performance of weightlifters and this factor has been used in many subsequent studies (Akkus, 2012; Hadi et al., 2012; Harbili, 2012; Hoover et al., 2006) with bar trajectory being the principle factor. Garhammer (1985) noted three key bar positions within the bar’s trajectory. The first was

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the maximum anterior/posterior (AP) movement of the bar during the Snatch. The second was the maximum horizontal distance of the bar from the vertical reference line during the second pull. The third was horizontal distance of the bar from the vertical reference line just after it began to descend from maximum height. These factors have been used by many studies (Akkus, 2012; Harbili, 2012; Hoover et al., 2006). Other researchers have considered movement of the athlete and not just the bar. Akkus (2012) reported that joint angles were also key factors to evaluate a weightlifters performance and stated that “double knee bend” is an important technique for creating leverage and utilizing knee extensor muscles (Enoka, 1979). Moon (2008) emphasized that it was important to achieve a smaller minimum knee angle during the double knee bend in the second pull phase of the snatch. Also, Kipp et al. (2012) reported that it was important to employ knee extensor muscles during the second pull through control of trunk and hip motions during the first pull. When correlating biomechanical factors with weightlifting performance, Moon (2002) reported that knee joint range of motion in the second-last pull phase and AP displacement of bar from start to lock out position showed high correlations with weightlifting records. Kauhanen et al. (1984) reported that there was a high correlation between peak ground reaction force and performance during the first pull of the clean.

As mentioned above, previous research has studied performance in weightlifting. Most research aimed at providing suggestions for performance enhancement through comparing motions between highly skilled and less skilled athletes. This is generally an effective method, however, Kipp et al. (2012) reported that there are severe differences in barbell trajectories and kinematic or kinetic characteristics within lifters with similar experience or skill levels. Thus we need to be cautious and should consider if every highly skilled athlete utilizes optimal technique before using this information to make recommendations. To address this issue we need to determine what optimal technique is, which is difficult, but if identified, that would make the training goals clear and likely result in rapid performance enhancement.

Robotics research has sought optimal motion (Lee et al., 2005; Lim et al., 2005; Melchiorri & Vassura, 2001; Sanger, 2000), but investigation for human motion is very complicated and related to many kinematic and kinetic factors. In robotics, there are different optimization methods but most of them are related to efficiency. For example, some optimization models of robots use minimization of torque and torque variation during a simple lifting motion (Lee et al., 2005; Melchiorri & Vassura, 2001). Model development for enhancing sports performance by optimizing motion is more difficult. Research to enhance sports performance is connected with not only efficiency but also many factors such as maximal strength and power. Thus, torque minimization doesn’t satisfy the optimization criteria in sport performance research. Optimization research for weightlifting (M. Borysiewicz, 1981; Lee et al., 2005, Nejadian et al., 2008) has been confined to 2D analysis and used only 4 – 5 joint angles. For these reasons, it is considered that human motion consists of a lot of freedom and there is limitation of method to solve optimal solution by numbers of freedoms. But, despite these difficulties, it could be meaningful endeavor in order to seek performance enhanced model (PE) or optimal motion.

The goals of this research were to make PE taken the largest performance index (PI) (Moon, 2002) through artificial variation of principle components calculated by principle component analysis for trial data and to verify the effect through comparing kinematic factors between trial data (Raw) and PE.

II. Methods

1. Subjects

Ten subjects (5 men(S6-S10), 5 women(S1-S5, gold medalist 1, silver medalist 1 in Beijing Olympic)) were recruited for this study (Table 1). These subjects all participated in the Guangzhou Asian Game in 2010 as members of the Korean national team.

2. Procedure

1) Data Collection

Before the experiment, athletes had a sufficient warm-up progressing from just the bar to 80% of their maximal record. Subjects performed 3-5 repetitions of snatch motion and the single best trial (identified subjectively through discussion with the subject and coaches) was selected for analysis. 80% of their maximal record was considered for analysis in this study because the experiment was performed in the middle of

Table 1. The characteristics of the subjects

Subject	Weight Category (kg)	Age (y)	Height (cm)	Body Weight (kg)	Maximal Record (kg)	Trial Record (kg) <Record/weight>
S1	75+	27	170.50	114.0	140	95 <83.33>
S2	63	25	158.70	63.5	102	90 <141.73>
S3	58	20	156.30	60.9	90	85 <139.57>
S4	53	24	156.70	56.2	99	85 <151.24>
S5	69	23	163.70	70.7	102	85 <120.22>
S6	56	24	153.10	60.6	126	120 <198.01>
S7	69	24	163.00	73.8	136	120 <162.60>
S8	77	28	165.90	79.7	158	130 <163.11>
S9	105+	28	185.00	135.1	206	150 <111.02>
S10	85	24	169.50	90.1	167	130 <144.28>
Mean±SD		24.70±2.45	164.24±9.29	80.46±25.81	132.60±36.73	109.00 <141.51>±23.78 <31.58>

training preparation for the 2010 Guangzhou Asian Games and subjects were not at their peak condition. 12 infrared high speed cameras (Motion Analysis Co. system) captured 3D position data of 24 reflective markers attached to the body using the default marker setting offered Motion Analysis Co.. The sampling rate was 120 Hz.

2) Data Processing

The Raw position data were smoothed with a butterworth 4^{th} order lowpass filter at cutoff frequency of 6Hz. The snatch movement was divided into 4 phases: (a) first pull phase-from start to barbell knee position, (b) second pull phase-from barbell knee position to barbell hip position, (c) last pull phase-from barbell hip position to maximal heel lift, and (d) lock out phase-from maximal heel lift to lock out position.

3) Performance Enhanced Model(PE)

The optimization criteria of the 3D snatch motion model PE is maximization of a PI made by Moon (2002). The PI is a regression equation made through using 65 kinematic factors from 22 athletes to predict their record performances from Asian weightlifting competitions (from 2000 to 2001). R-square of this regression is 0.936. $PI = -42.229 + 2.032 \times A1 - 0.258 \times A2 + 2.094 \times A3 + 0.459 \times A4 - 1.424 \times A5$ ----- (1)

Note. A1 is an AP (anterior-posterior) displacements of shoulder joint from second pull to last pull. A2 is maximal bar velocity in first pull phase. A3 is AP displacements of hip joint from second pull to last pull. A4 is an angular displacements of hip joint from second pull phase to last pull phase. A5 is AP displacements of hip joint from first pull to lock out phase.

In order to develop PE, we extracted Principle components from trial position data (by Principle Components Analysis (PCA). Before PCA, we made 17 position data(wrist(2), elbow(2), shoulder(2), hip(2), knee(2), ankle(2), toe(2), head(1), barbell(2)) to 3 row matrix according to components. We calculated 3 eigen value (principle components) through PCA. And except Y (medial-lateral direction) component (because motion of Y component is small), principle components of X (anterior-posterior direction) and Z (vertical direction) components were changed as following.

Changed principle components = principle components + principle components × k. ---(2), k = [0.3, 0.28, ---, 0.2, 0, -0.2, -----, -0.28, -0.3]

After changing the each principle component, we reconstructed position data using the changed principle components and calculated A1, A2, A3, A4, A5, PI with satisfying constraint condition repeatedly. Constraint condition is satisfied if the difference between lengths of body segments for Raw data and those calculated from reconstructed position data was smaller than half of variation term of body segments length for Raw position data. The Performance Enhanced Model was calculated in Matlab 7.0. Specific Procedure was followed by figure 1.

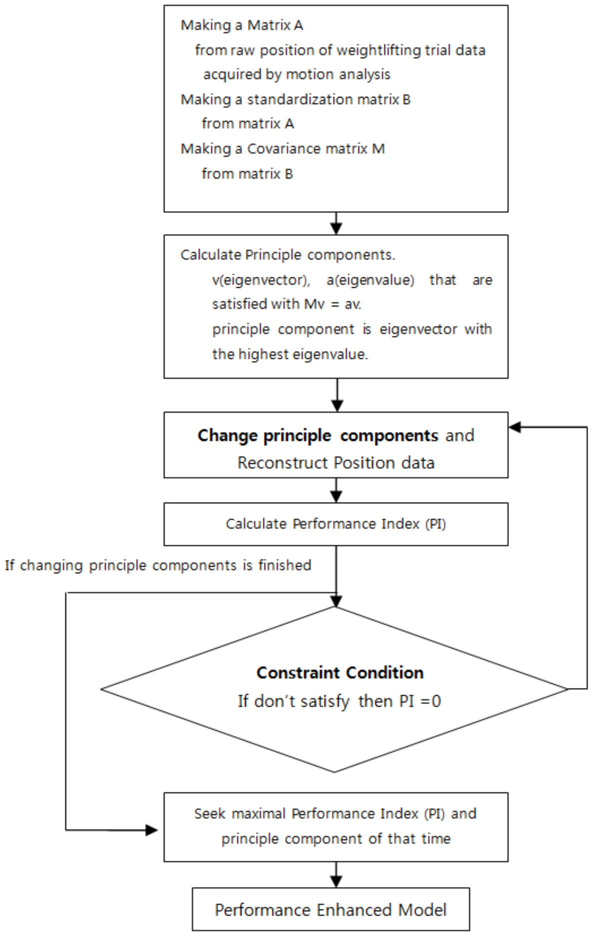

Figure 1. Procudure for calculation of Performance Enhnaced Model

4) Statistical Analysis

A Paired t-test was used to compare Raw data and Performance Enhanced Model data. The level of statistical significance was set at $p \leq 0.05$.

III. Results

The PI was significantly increased (Table 2) with the PE (101.92±6.25) when compared to the Raw data (91.29±7.10). Average PI increase of 10.3 corresponds to an increase in performance of about 12.9kg. The AP displacements of shoulder joint from second pull phase to last phase (A1) had a positive correlation with PI. A1 of PE was significantly larger (4.5cm) than that of the Raw.

The maximal velocity in the first pull phase (A2) had a negative correlation with PI; there were no significant differences in this variable between the PE and the Raw. The AP displacements of the hip joint from second pull phase to last pull phase (A3) had a positive correlation with PI. A3 of PE was significantly larger (2.5cm) than that of the Raw. Angular displacement of the hip joint from second pull phase to last pull phase (A4) had a positive correlation with PI; there were no significant differences in this variable between the PE and the Raw.

Table 2. PI and Regression Factors

Subject	PI		A1		A2		A3		A4		A5	
	Raw	PE	Raw	PE	Raw	PE	Raw	PE	Raw	PE	Raw	PE
Average	91.29	101.92	41.35	45.85	135.13	135.55	22.67	25.17	154.07	154.16	23.76	26.34
SD	±7.10	±6.25	±4.57	±4.09	±20.45	±20.13	±2.05	±2.52	±3.37	±3.53	±3.69	±3.82
P-value	.000		.000		.231		.000		.510		.000	

Table 3. Variation term of body segments length for raw position data

unit: cm

Subject	Left thigh	Left shank	Right thigh	Right thigh	Left upperarm	Left forearm	Left upperarm	Left forearm
Average	3.75	2.88	3.59	3.01	6.36	3.73	6.49	3.70
SD	±1.05	±0.82	±1.02	±0.73	±1.01	±1.05	±1.41	±0.86

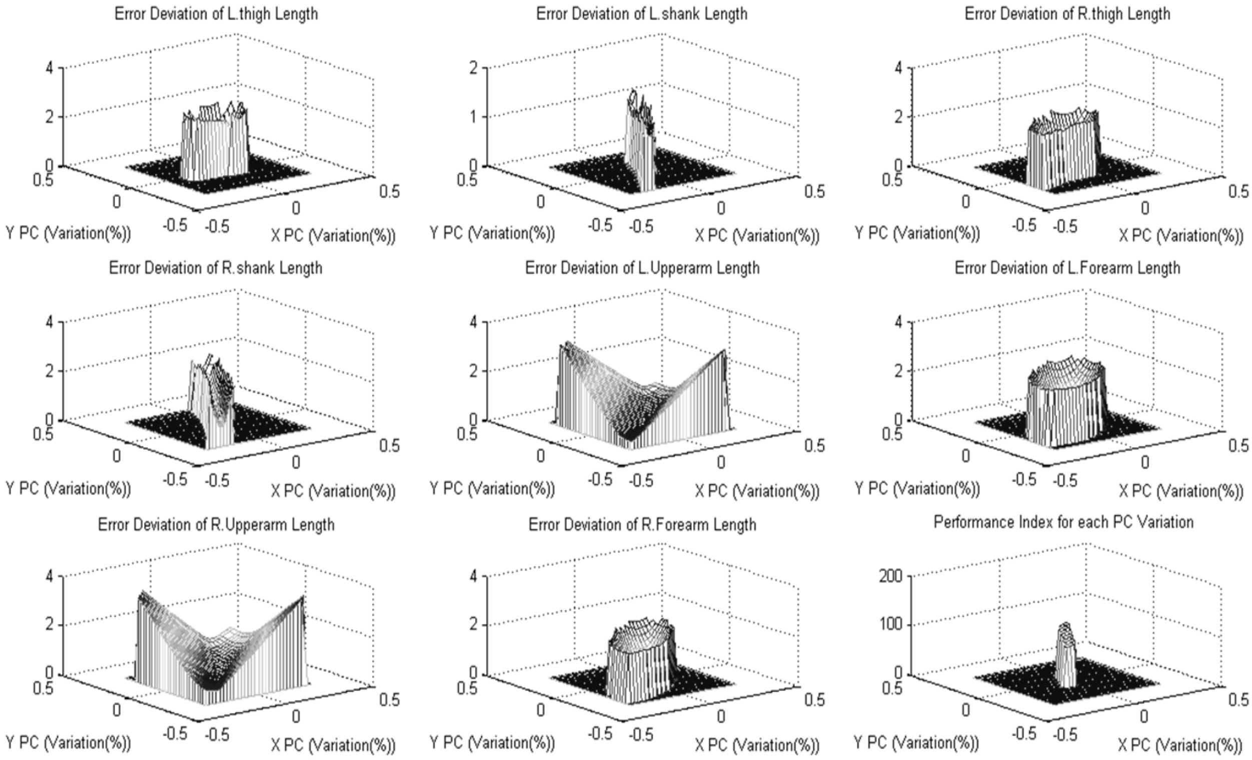

Figure 2. Variation terms of segments length(PC variation) and PI for changing principle components

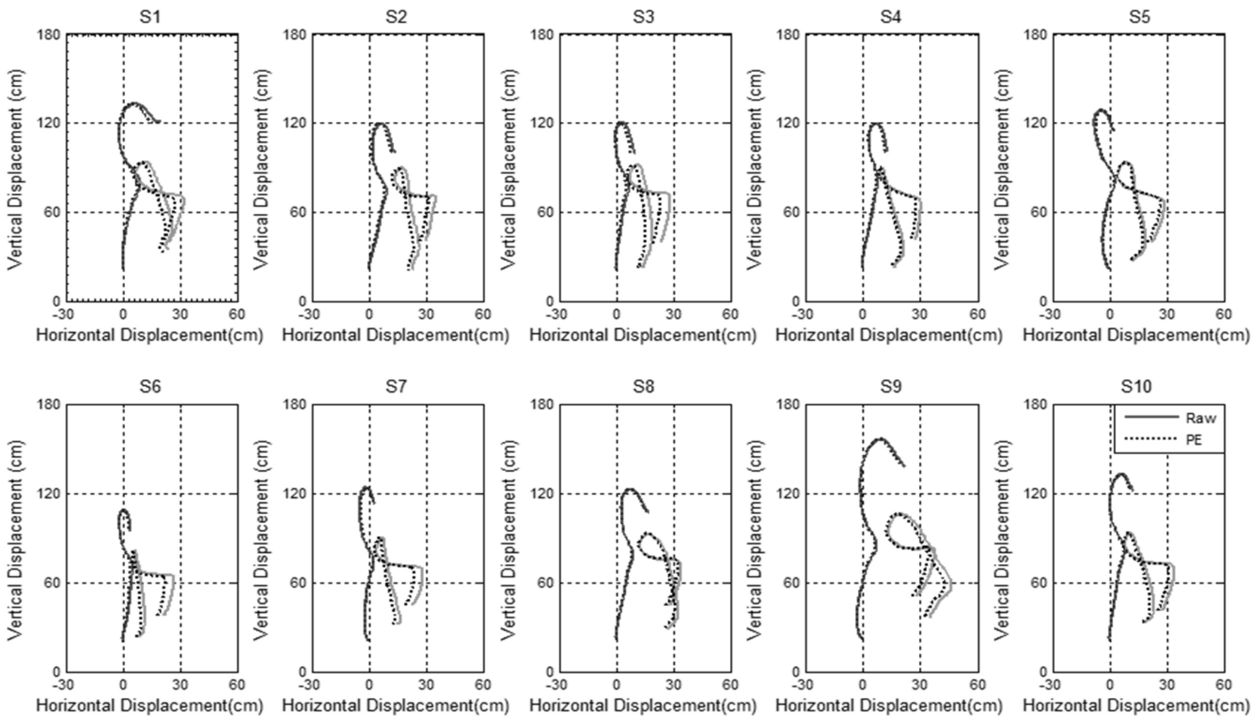

Figure 3. Trajectory for Barbell hip joint and shoulder joint

The displacement of the hip joint from pull phase to lock out phase (A5) had a negative correlation with PI. A5 of the PE was significantly larger (2.58cm) than that of the Raw. There was a variation term of body segments lengths from the Raw. Variation terms(VT) were about 3-6cm on average. Especially, VT was greater at left upper arm (6.369cm) and right upper arm (6.497cm) than other segments (Table 3). Figure 2 shows variation terms for 8 segments (left-right thigh, shank, upper arm, forearm) length and PI for changing principle components. If variation terms of 8 segments satisfy constraint condition, value was kept. But if not, it fell down 0. Dark color for bottom of figure 2 means down to 0. PE was decided as most PI value in intercept conditions of PI satisfying constraint condition for each variation terms of segment length(PC variation). That is, PE is position data reconstructed from most PI value through principle components.

There were some significant differences in bar movement for the PE compared to the actual trials (Table 4): the movement distance of the bar from start to lock out was significantly larger (about 1cm) for PE, the width of anterior-posterior bar position in full phase was significantly wider (about 1.3cm) for PE and the horizontal displacement toward the weightlifter after beginning of descent from maximal height was significantly greater (about 0.4cm) for PE. Additionally, the minimum knee angle in the 2-pull phase was significantly smaller (approximately 2.7cm) for the PE compared to that of the Raw.

Ⅳ. Discussion

The significant difference in the PI between the PE and the Raw means that performance can be increased (on average 13kg per subject) by optimizing 3D positions. Weightlifters usually endeavor to improve their Snatch records by about 10kg per year, but this is not easy. Through this research, the PE can provide important feedback to weightlifters allowing them to see their individual movement modifications required to improve their records, and they can have an exact training goal.

AP displacements of the shoulder joint from the second pull phase to the last pull phase (parameter A1 in the model) are related to hip joint extension. Moon (2008) reported that it is necessary to focus on knee joint extension in the first pull phase to ensure the trunk does not erect vertically too fast as this compromises the long, powerful pull required in the last pull phase achieved through strong hip joint extension with a large range of motion. Therefore, increasing the AP displacement of the shoulder joint from the second pull phase to the last pull phase as proposed by the PE would be considered positive aspects in making a strong pull motion in the last pull phase. Parameter A2 in the model is the maximal bar velocity in the first pull phase. Moon (2002) reported that vertical bar velocity in the first pull phase is negatively correlated with performance. The reason is that the higher the bar velocity in the first pull phase, the more quickly the trunk leans back because hip joint extension occurs quickly. Thus, controlled trunk and hip motion during the first pull is important for the Snatch to ensure lifting force is delivered effectively to the bar in last pull phase. It is important to keep the trunk leaned forward as much as possible and to perform mostly knee extension in first pull phase. As Akkus (2012) reported, knee extension velocity during the first pull was greater than that of the hip, and knee angular velocity was greatest during the first pull. In the model, parameter A3 is the AP displacements of the hip joint from the second pull phase to the last pull phase. A3 is strongly related to parameter A5 the AP displacement of the hip joint from first pull to lock out phase. Even though A3 and A5 are both AP displacement of the hip joint, A3 was positively correlated and A5 was a negatively correlated with the PI due to a difference of analysis phases. There are many weightlifters who erect the trunk vertically at the start of the lift by extending the hip joint and then, the trunk leans forward again as the Hip joint moves backward because they can't control the heavy barbell weight. This is undesirable because these motions decrease barbell velocity, negatively impact rhythm, and result in a short pull up. Therefore, increased AP displacement of the hip joint throughout the entire lift (parameter A5) could be negatively correlated with performance. Conversely, increased AP displacement of the hip joint between the second pull and last pull phases (parameter A3) means the hip joint moves forward powerfully through large ankle plantar flexion and the use of large muscles like Latissimus dorsi and Trapezius muscles (Moon, 2008). Increased plantar flexion during the second pull generates larger ground reaction forces (Akkus, 2012) allowing a more powerful and longer last pull up.

Table 4. Compare of kinematic factors between the Raw and the PE

Factor	Raw Mean±SD	PE Mean±SD	*P*-value
Drop displacement	15.57±3.24	15.48±3.34	0.408
Movement distance of the bar from start to lock out	126.43±15.36	127.59±15.64	0.000
Width of anterior-posterior bar movement in full phase	13.53±6.17	14.89±6.17	0.000
Horizontal displacement toward weightlifter in the first pull (cm)	0.92±3.23	1.04±3.55	0.289
Horizontal displacement away from weightlifter in the second pull (cm)	-0.62±3.45	-0.64±3.72	0.864
Horizontal displacement toward weightlifter after beginning of descent from maximal height (cm)	3.22±4.78	3.61±5.11	0.042
Maximal vertical velocity of bar in the full phase	224.98±21.09	224.29±21.26	0.126
Minimum knee angle in the 2-pull phase	115.53±5.54	112.85±5.24	00.000

The PE average variation term of body segments lengths from the Raw was about 3-6cm (Table 3). These results are likely due to motion capture artifacts and errors in data processing such as smoothing and digital filtering. This was especially true for the variation terms of the forearm lengths because of the increased motion of the shoulder joints. Therefore constraint conditions were chosen in order to develop the model.

Figure 2 is a S1(Gold medalist in 2008 Beijing Olympic) data. According to exchanging Principle component in a range satisfying constraint condition, upper arm or forearm were wider than lower body (shank, thigh). It was considered that it was a result from fluidity of shoulder joint. Shank was especially small in a range satisfying constraint condition. Also, shapes for error variation of left-right joint components were similar.

In PI for each PC variation, PI was decided at proximal position from the Raw (origin point (0,0)) of PC variation). This means that Performance Enhanced Model was decided by similar motion to the Raw without a great change. Therefore, weightlifters could be accept Performance Enhanced Model easily, comfortably and without large stress.

Figure 3 is a graph of barbell, hip joint and shoulder joint trajectories. Most Korean national weightlifters did not have an optimal trajectory as reported by Garhammer (1985). After the start, most Korean weightlifters move backward overall, but the barbell of some weightlifters (S5, S7, S9) moves forward in the first pull phase. Hoover et al. (2006) reported that these findings may be due to differences in coaching and these factors could certainly affect the displacement patterns exhibited by the lifters. Thus, Korean weightlifters may require additional teaching methods for maximal skill development. The PE could aid the coaches because it is interesting to note that there is almost no difference in barbell trajectory between the Raw and the Performance Enhanced data, however, there are important differences in hip and shoulder joint trajectory.

Moon (2008) recommended to lean the trunk forward and position the hip joint higher than the knee joint thus ensuring the hip joint was more backward than low hip joint position at the start. From figure 3, it can be seen that forward hip joint movement from the second pull phase to the last pull phase is greater for all subjects in the PE than the Raw. For shoulder joint movement, the PE is similar to the Raw at the start but there is a difference during the last pull; the joint moves not only backward but also has a longer pull up motion than the Raw. These motions mean more powerful last pull up through active hip extension. Overall, if we compare the PE and the Raw trajectories, anterior hip joint movement is larger and the shoulder joint performs a longer pull up motion for last pull and lock out phase while the barbell moves more toward the lifter after it reaches maximal height. These differences provide us with important information to enhance weightlifting skills. Additionally, to perform a powerful pull up motion in the last pull phase, an important point to be considered is that the lock out motion should be late. Thus, flexibility training, strengthening of abdominal muscles and training for a fast lock out motion with just the bar are needed. Weightlifting research typically focuses only on barbell trajectory, providing valuable information. However, analyzing complex barbell and body movement simultaneously offers greater potential for skill evaluation of weightlifters.

In Table 4, Drop distance was used by many researches (Akkus, 2012; Hoover et al., 2006). Especially, Akkus (2012) reported that Drop distance is the most important indicator of an effective technique for a snatch and average vertical barbell drop displacement was 20.78 (±5.92) at 1999 USA Men's and Women's weightlifting championship. PE (15.48cm) is smaller than the Raw (15.57cm) in a shade difference and there in no significant difference. Drop distance (about 15.5cm) of our study is smaller than that of Akkus's study (2012). Our experiment was conducted about 80% of maximal record and was studied on the basis of the most stable lock out position after last pull. Therefore, drop distance of about 15.5cm proposed by our study could be meaningful to evaluate optimal drop distance because needless barbell height is inefficient as many coaches have advised lifters to minimize drop displacement from height to catch position (Isaka et al., 1996). But, optimal maximal barbell height is not clear yet. It should be considered in further researches. For Movement distance of bar from start to lock out, PE is longer total displacement of barbell movement than the Raw and there is a significant difference. It was prospected because PE (14.89±6.17cm) was larger width movement than the Raw (13.53±6.17cm) in width of anterior-posterior bar position in full phase. That is, it could be considered that horizontal variation is larger than vertical variation. For horizontal displacement toward weightlifter of bar after beginning of descent from maximal height as one of the horizontal displacement factors used by many studies (Akkus, 2012; Garhammer, 1985), PE showed significant larger than the Raw. Hoover et al. (2006) reported that larger negative displacement values after peak height usually require the lifter to jump forward to catch the bar and the large positive values at this time in the movement usually require the lifter to adjust back for the catch. Therefore, it is needed to minimize any adjustment while the bar is moving. Because every subject in this research performed lock out on the condition that hip and shoulder joint is being backward than barbell, it could be considered that PE makes motion attaching barbell to the body more closely. Usually, weightlifters have to move shoulder joint to forward before maximal barbell height to perform lock out, but in our study, larger horizontal displacement toward weightlifter of bar after beginning of descent from maximal height gives us a margin time and just need of small shoulder joint movement to adopt a lock out position. Therefore, it was considered that this result was meaningful as effective motion. For Maximal vertical velocity of bar in the full phase, There is no significant difference. If we considered that it was no significant difference for A2 factor in Table 2, it could be considered that PE was more related to trajectory of motion than velocity of motion. For Minimum knee angle in the 2-pull phase, PE is smaller knee angle than that of the Raw in a significant difference. Moon (2002) reported that more weightlifter is skillful, the smaller knee angle they have in the process performing 'double knee bend' proposed by Enoka (1979) in the 2-pull phase. And highly skilled weightlifters showed smaller knee angle than that of skilled weightlifters studied by Burdett (1982). This counter movement like knee flexion during the transition phase and the second bending flexion of the knees during the snatch lift may be performed rapidly enough to store recoverable elastic energy (Akkus, 2012; Garhammer & Gregor, 1992). Judging from previous studies, it was considered that PE shows us a positive direction to enhance skill. That is, the greater range of motion of knee joint from minimum knee angle in the 2-pull phase was made, the larger knee extension torque and power might be produced.

V. Conclusion

The goals of this research were to make Performance Enhanced Model(PE) taken the largest performance index (PI) through artificial variation of principle components calculated by principle component analysis for trial data. And to verify the effect through comparing kinematic factors between trial data (Raw) and PE. Ten subjects (5 men(S6-S10), 5 women were recruited and 80% of their maximal record was considered. The cpnclusions were as follows. PI was decided at proximal position from the Raw (origin point (0,0)) of PC variation). This means that Performance Enhanced Model was decided by similar motion to the Raw without a great change. Therefore, weightlifters could be accept Performance Enhanced

Model easily, comfortably and without large stress. The Performance Enhance Model can provide training direction for athletes to improve their weightlifting records.

Practical Applications

The Performance Enhance Model provides training direction for athletes to improve their weightlifting records. Firstly, the trunk should be lean forward to actively lift the hip until hip joint position is higher than knee joint at the start. Then, the first pull phase should be executed primarily with knee joint and minimal hip extension. From the second pull phase to the last pull phase, powerful hip joint extension through a large range of motion should be coupled with large ankle plantar flexion. This effectively directs the applied forces to vertical movement of the barbell. Also, it is recommended to perform a long pull up motion during the last pull and to train to be able to make a fast lock out motion.

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