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Effects of Isokinetic versus Isotonic Training of Shoulder Joint on 2D Kinematics and Barbell Velocity during Power Clean and Power Snatch of Advanced Level of Adolescents Weightlifters

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Abstract The shoulder joint is the weakest link in the kinetic chain of weightlifting. The purpose of this study was to compare the effects of additional isokinetic versus isotonic training of shoulder joint and its cessation on two dimensional kinematics and barbell velocity during one repetitive maximum of power clean and power snatch among advanced level of adolescent weightlifters. Nineteen weightlifters were divided into either isokinetic or isotonic group. All weightlifters were recruited from the same pool of advanced level of weightlifters who went through mandatory training provided by their coach. The training described in this study was an additional training to their mandatory training. The barbell velocities during second pull and turnover phases were compared before, after and one month after the cessation of additional training program. A trend of positive improvement of one repetitive maximum of power clean and power snatch were observed following both types of training programs. Both types of training showed a trend of increased barbell velocity during second pull phase in both one repetitive maximum power snatch and power clean. Both types training showed a trend of decreased barbell velocity during turnover phase in one repetitive maximum power snatch but not in one repetitive maximum power clean. Both types of training on shoulder joint may provide potential benefit to improve power clean and power snatch performance.

Keywords Biomechanics, Weightlifting, Rotator cuff, Strength

1. Introduction

Weightlifting is a sport that demands a dynamic strength and power which involves a multi-joint movement and whole body lifts. During the two competitive lifts which are snatch and clean and jerk, athletes need to generate an extremely high peak force and fast rate of force development which consequently exhibit high power output and impulse [1-5]. It requires a high level of dynamic force of both upper and lower body with the vertebrae musculature serve as both the stabilizers and primary movers throughout the different phases of lift [6]. Weightlifting involves torque generation and transmission from the ankle, knee, hip and shoulder joints. The common movements of these joints are flexion-extension of the ankle, knee and hip joints and abduction-adduction of the shoulder joint. Additionally, arm strength was required to maintain the heavy loads above the lifter's head for a few seconds during catch phase [7]. Therefore, strength of both upper and lower limbs is equally important to ensure a successful lift during competition.

It was reported that the glenohumeral joint assists the catch and pulls during snatch [8-10]. Ernst and Jensen observed that the rotator cuff muscle group is active at all phases of snatch [11]. In particular, supraspinatus and infraspinatus are reported to be most active during the turnover and catch phase while the teres minor is most active during first pull and transition phase. However, due to its depth, the activity of subscapularis muscle was not reported. Being technically demanding than clean and jerk, most electromyography studies in weightlifting emphasized on snatch event. Currently, studies regarding rotator cuff activation during clean and jerk are scarce.

Despite the less attention given with regards to the application of rotator cuff in competitive weightlifting, shoulder injury such as shoulder impingement and rotator cuff tendonitis are common among weightlifters. It was reported that more than 36% of weight-training related injuries and disorders occurred at the shoulder area [12]. Calhoon and Fry also stated that most weightlifting injuries occurred at the shoulder area rather than the knee and back [6]. This is because the shoulder joint is more mobile compared to other joints such as knee and hip. Shoulder

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gains stability through the muscles around the joint (e.g., rotator cuff muscles group) that secure the position of humeral head into the glenoid cavity. Therefore, flexing the shoulder into an extreme overhead position particularly during lifting heavy weight can greatly increases the risk of shoulder injuries. Due to the above mentioned factors, it is important to increase the strength of rotator cuff muscle to minimize the risk of injury.

Although rotator cuff muscles were highlighted as one of the important link in the kinetic chain of weightlifting, studies on the effects of different types of training specific to this muscle group are scarce. Typical weightlifting training involves lifting weights of constant load (e.g., isotonic) such as dumbbell and barbell. Examples of this type of training are biceps and triceps curl. An isotonic muscle contraction induced the greatest resistance only at the weakest mechanical point of the range of motion (ROM) of the conducted movement. In addition, the resistance remains constant throughout the ROM with varied angular velocity of the involved joint [13, 14]. However, the main problem with weightlifting is the inability to maintain the angular velocity towards the end of concentric phase in which the bar velocity slows down towards the end of ROM. Thus, power may be developed only at the initial segment of the ROM [15]. On the other hand, isokinetic training mode applied the principles of accommodating resistance following the amount of exerted force. This allows the athletes to reach a constant angular velocity across the full ROM of the involved joint. Therefore, a maximal effort can be experienced during isokinetic training because the maximal load is applied throughout the whole ROM [15].

The aim of the present study is to assess the rotator cuff muscle performance following isokinetic and isotonic training in terms of 1-RM and barbell velocity during critical phases of competitive weightlifting motions. Furthermore, the effects of these trainings were evaluated following one month after its cessation to provide insights regarding its long-term effects. Contrary to previous literature which emphasized on novice weightlifters, advance level adolescent weightlifters were recruited in the present study.

2. Methods

2.1. Experimental Approach to the Problem

Initially 24 state-level weightlifters were recruited and they were divided into two training groups: isokinetic and isotonic. However, five subjects dropped out from the study due to injury and lack of adherence to the prescribed training program. Therefore, only data from 19 subjects were analyzed.

The entire experiment was commenced during preparatory phase of the team's training mesocycle. All subjects were recruited from the same pool of advanced level of weightlifters who went through mandatory training provided by their coach. The training described in this study is an additional program to their mandatory training.

1-RM power clean and power snatch tests were conducted before the commencement of training program, immediately after the completion of training program and one month following the training cessation. During the one month follow up period, additional training program that we prescribed was attenuated, however the subjects continued their mandatory training as prescribed by their coach. The researchers confirmed that all subjects completed similar mandatory training program during the follow up period.

2D motions on sagittal plane of 1-RM power clean and power snatch were analyzed and compared across groups. The 1-RM is the heaviest weight that can be lifted at one time while maintaining the good form. It is the gold standard procedure for evaluating dynamic strength [16], which is identical to Olympic weightlifting movement.

2.2. Participants

A priori sample size calculation showed that eight subjects per group are sufficient to yield 0.8 power of the study with effect size of 0.6 [17]. Only weightlifters with at least two years of experience in competitive weightlifting and without previous history of shoulder injury were included. Their age was between 13 and 17 years old. Subjects were excluded from the study if they were unable to adhere to at least 85% of training loads during the intervention and/or have undergone rehabilitation for shoulder injury within the last two years.

Participants were provided with detailed explanation regarding the methodology of the study. Upon agreement, their written consent form was collected. Since they were under 18 years old, assent was obtained from their guardians. All participants were recruited voluntarily through a state-level sports council. All procedures were conducted with compliance to Declaration of Helsinki 1975. Ethical approval was obtained from Human Ethical Committee of Universiti Sains Malaysia (USM/JEPeM/14110457).

2.3. Procedures

The isokinetic training and tests were applied using an isokinetic dynamometer (Multi-joint System Biodex Pro, Shirley, NY, USA). For familiarization, all participants completed one set of 12 internal and external shoulder rotation, in concentric mode before the pre-test. The training program commenced following at least three days of recovery after the pre-test.

24 sessions of training were conducted three times per week for eight weeks. For each training sessions, ten minutes of warming-up emphasizing on the shoulder followed by a minute of active rest, was performed by participants. Following training session, participants performed a proper shoulder stretching and ice pack was applied on the shoulder for ten minutes to reduce muscle soreness.

In isokinetic group, participants were trained in the seated position with 45° of shoulder abduction for the first until the eighth training sessions. In this position, the scapular was positioned so that equal distribution of external rotators and internal rotators can be trained. The angular velocity set was at 120°.s^{-1}, with 12-15 repetitions for two sets. For the ninth to the 16th sessions, the seated position with 90° of shoulder abduction was selected. The angular velocity applied was 240°.s^{-1} with 10-12 repetitions for three sets. For the 17th to 24th sessions, training was conducted in standing position while diagonally lifting the bar. The angular velocity was set at 360°.s^{-1} with 8-10 repetitions for four sets. For all training positions, rest interval between the sets was provided for one minute.

Each training session was completed approximately in one hour including warm up and stretching sessions. Training was conducted for both sides of upper limb. Similar lifting positions, duration of rest interval between sets, number of sets and repetitions were applied by the isotonic group, however their training was conducted using a constant weight (e.g., dumbbells of 50% of their upper limb's weight) and the angular velocity was not fixed in isotonic group. Details of the training program were summarized in Table 1.

Table 1. Characteristics of Prescribed Isokinetic and Isotonic Training

Sessions	Body position	Reps	Sets	Rest (min)	Velocity (°.s^{-1})
1 to 8	Seated with 45° of shoulder abduction	12-15	2	1	120
9 to 16	Seated with 90° of shoulder abduction	10-12	3	1	240
17 to 24	Standing while lifting the bar diagonally overhead	8-10	4	1	360

Velocity was applied for isokinetic training only

1-RM tests were conducted prior to and at the end of 24 sessions of the training program and one month after its cessation. Prior to the test, warm up consisted of 5-10 repetitions of power clean at 40% to 60% of perceived maximum resistance followed by a minute of rest with light stretching were conducted. The perceived resistance was obtained from the weightlifters' previous record of best performance. Next, 3-5 repetitions of power clean at 60% to 80% of perceived maximum resistance was performed. Then, 2-5 kg of weight was added. The athlete was given 3-5 minutes of rest in succession of lifting the weight. The process continued until a failed attempt occurred. The last successful lift was recorded as the 1-RM. 1-RM power snatch test was conducted on separate days with similar procedure as described above.

The kinematic data at sagittal plane were recorded during 1-RM power clean and power snatch tests. A digital camera (SONY HDR-CX240, Japan) and Silicon Coach Pro software (version 8.1, The Tarn Group, UK) were used to collect and analyze the kinematics during both 1-RM tests.

2.4. Statistical Analyses

The data of 1-RM performance and barbell velocity during second pull and turnover phases were analyzed using Statistical Package for the Social Science (SPSS) version 22. The data were normally distributed as confirmed by Shapiro-Wilk test, hence parametric statistical test was applied. A general linear model 2-way analysis of variance (ANOVA) with repeated measure design was used for statistical analysis in which the within participants factor was three time points (e.g., prior to and after training, and one month after training cessation) and the between participants factor was two groups (e.g., isokinetic versus isotonic training groups). Interaction effects between group and time as well as main time effects were of interest. The accepted level of significance was set at $p < 0.05$. All data were expressed as mean ± standard deviation (SD). Percentage of difference was calculated following these equations:

$$\text{Percentage of difference (\%)} = \frac{\text{Post-test value} - \text{Pre-test value}}{\text{Pre-test value}} \times 100$$

$$\text{Percentage of difference (\%)} = \frac{\text{Post 1month-test value} - \text{Post-test value}}{\text{Post-test value}} \times 100$$

Table 2. Physical Characteristics of Participants

	Isokinetic Group (n=8)	Isotonic Group (n=11)
Age (years)	14.36 ± 1.06	14.82 ± 1.60
Height (m)		
Pre-test	1.59±0.07	1.58±0.11
Post-test	1.60±0.07	1.59±0.11
1 month after cessation	1.61±0.07	1.59±0.11
Body Weight (kg)		
Pre-test	70.82±19.63	57.00±10.79
Post-test	73.24±19.40*	58.25±10.88*
1 month after cessation	74.49±19.97**	65.00±25.28**
Body Fat Percentage (%)		
Pre-test	33.87±11.30	24.93±5.86
Post-test	36.31±10.57	27.96±6.14
1 month after cessation	36.31±10.58	26.74±7.18
Fat Free Mass (kg)		
Pre-test	45.44±8.64	46.63±15.47
Post-test	45.54±9.47	45.46±13.59
1 month after cessation	46.27±9.44	46.67±14.01

* Significantly different form its respective pre-test value
** Significantly different form its respective post-test value

3. Results

Table 2 summarizes the descriptive data of demographic and anthropometric characteristics of participants. The general linear model mixed ANOVA with repeated measure design revealed significant time and group interaction (df=2, F=7.137, $p<0.05$) and significant main effects of time (df=2, F=57.19, $p<0.05$) on mean body weight. An increment of body weight was observed in both groups at post-test compared to the pre-test and one month after training cessation compared to the post-test.

Table 3 summarizes the descriptive data and results of mean 1-RM power clean. The general linear model mixed ANOVA with repeated measure design revealed no significant time and group interaction (df=1.265, F=1.397, p=0.26) but there was significant main effects of time (df=1.265, F=5.80, p=0.02) on mean 1-RM power clean. A greater percentage of difference was observed in isokinetic group compared to isotonic group. However, the percentage of difference decreased in isokinetic group but increased for isotonic group following one month of training cessation.

Table 4 summarizes the descriptive data and results of mean 1-RM power snatch. The general linear model mixed ANOVA with repeated measure design revealed no significant time and group interaction (df=2, F=1.583, p=0.22) and but there was significant main effects of time (df=2, F=9.076, p=0.001) on mean 1-RM power clean. A greater percentage of difference was observed in isokinetic group compared to isotonic group. However, following one month of training cessation, the percentage of difference decreased in isokinetic group but increased in isotonic group.

Table 5 summarizes the descriptive data and results of mean barbell velocity of power clean during second pull and turnover phases. The general linear model mixed ANOVA with repeated measure design revealed no significant time and group interaction (df=1.35, F=1.12, p=0.32) but there was significant main effects of time (df=1.35, F=7.616, p=0.007) on mean barbell velocity at second pull phase only. During second pull phase, both groups showed positive percentage of difference at post-test while negative percentage of difference following one month of training cessation. Moreover, no significant time and group interaction (df=2, F=1.256, p=0.298) and no significant main effects of time (df=2, F=0.02, p=0.981) were observed with regards to the mean barbell velocity at turnover phase.

Table 6 summarizes the descriptive data and results of mean barbell velocity of power snatch at second pull and turnover phases. The general linear model mixed ANOVA with repeated measure design revealed no significant time and group interaction (df=2, F=0.154, p=0.858) but there was significant main time effects (df=2, F=3.863, p=0.031) on mean barbell velocity at second pull phase. During second pull phase, both groups showed positive percentage of difference at post-test and negative percentage of difference following one month of training cessation. Similarly, no significant time and group interaction (df=2, F=0.722, p=0.493) and no significant main effects of time (df=2, F=2.883, p=0.07) were observed on mean barbell velocity at turnover phase. During turnover phase, both groups showed negative percentage of difference at post-test and positive percentage of difference after one month of training cessation.

Table 3. Performance of 1-Repetition Maximum Power Clean

Groups	Pre-test	Post-test	1 month after cessation	% of difference (Post-Pre)	% of difference (Cessation-Post)
Isokinetic	57.62±15.66	62.75±13.86	60.87±12.51	+8.90	-2.99
Isotonic	69.27±33.24	74.09±32.63	77.72±33.05	+6.96	+4.90

Table 4. Performance of 1-Repetition Maximum Power Snatch

Groups	Pre-test	Post-test	1 month after cessation	% of difference (Post-Pre)	% of difference (Cessation-Post)
Isokinetic	43.12±11.78	47.00±12.00	46.50±10.94	+8.99	-1.06
Isotonic	51.36±23.00	54.00±21.89	57.45±23.15	+5.14	+6.39

Table 5. Barbell Velocity During 1-Repetition Maximum Power Clean

Groups	Phases	Pre-test	Post-test	1 month aftercessation	% of difference (Post-Pre)	% of difference (Cessation-Post)
Isokinetic	Second pull	2.36±0.17	2.43±0.76	1.87±0.19	+2.97	-23.04
	Turnover	0.94±0.41	1.01±0.34	1.16±0.28	+7.45	+14.85
Isotonic	Second pull	1.97±0.41	2.14±0.31	1.82±0.19	+8.63	-14.95
	Turnover	0.97±0.55	0.90±0.35	0.79±0.36	-7.22	-12.22

Table 6. Barbell Velocity During 1-Repetition Maximum Power Snatch

Groups	Phases	Pre-test	Post-test	1 month after cessation	% of difference (Post-Pre)	% of difference (Cessation-Post)
Isokinetic	Second pull	2.61±0.29	2.64±0.17	2.39±0.33	+1.15	-9.47
	Turnover	1.36±0.61	1.19±0.47	1.71±0.72	-12.50	+43.70
Isotonic	Second pull	2.46±0.27	2.49±0.29	2.32±0.18	+1.22	-6.83
	Turnover	1.15±0.43	0.99±0.49	1.19±0.48	-13.91	+20.20

4. Discussion

In the present study, the results showed a trend of positive improvement of 1-RM of power clean and power snatch following both types of training programs. In a previous study conducted among sedentary male students, it was found that both isotonic and isokinetic training improved the 1-RM performance following eight weeks of training with greater performance was observed in the isokinetic training group [18]. The duration and frequency of sessions of training (e.g., three times a week) and mode of isokinetic contraction (e.g. concentric type) were similar to the present study. However, in the present study no statistically significant difference was observed between both types of training, although there is a trend of increment in both groups compared to its respective pre-test value. This might be due to different population of subjects participated in the current study and in [18]. Furthermore, our results are in contrary to previous studies [19, 20] which showed that isotonic training would induce improvement in 1-RM.

Dias and colleagues reported a significant increase from 16.3% to 77.8% of 1-RM value after eight weeks of isotonic training of upper body among sedentary young men [21]. In contrast, Smith and Melton reported that six weeks of lower limb isokinetic training performed at low ($30°.s^{-1}$, $60°.s^{-1}$, $90°.s^{-1}$) or high velocity ($180°.s^{-1}$, $240°.s^{-1}$, $300°.s^{-1}$) was more effective to improve strength than isotonic training among sedentary adolescent males [22]. Compared to the present study, the difference in terms of muscle adaptation of upper extremity and the level of expertise of the participants (e.g., sedentary versus advanced level of weightlifters) may have affected the results. Therefore, more studies should be conducted to compare the effects of different types of training among advanced level of weightlifters particularly on upper extremity.

Great muscular strength is substantial in order to lift a heavy load. In weightlifting, muscular strength is measured in terms of 1-Repetition Maximum (1-RM) which is the maximal weight that can be lifted by an individual during an all-out effort [23]. Meanwhile, muscular power can be defined as the ability to produce large output of force in a short period of time [24]. In weightlifting, power is evaluated using power snatch and power clean test because these tests measured the barbell motion in relation to time which is similar to the angular velocity of the involved joints. Power is the product of force and velocity. Therefore, in order to maximize power performance, both components (e.g. force and velocity) should be specifically trained. The power-velocity curvilinear relationship indicates greatest potential for producing power when exercising at faster speed [25, 26].

It was found that isokinetic group showed a non-statistically significant decrement of percentage of difference compared to isotonic group after one month of training cessation compared to their respective post-test values in both 1-RM power clean and power snatch. Indeed, Faigenbaum stated that muscular strength and power will be lost upon six weeks of resistance training cessation [27]. Furthermore, due to their prescribed mandatory training, cessation of additional training may not result in a drastic drop in physical performance. Another possible reason for the decrement might be due to the nature of the training itself. Since isotonic group was applying the same training mode as their weightlifting training, the cessation effect might be slower compared to isokinetic group. However, to the best of our knowledge, studies that examine the cessation effects of resistance training program are lacking. Therefore, more research were needed to evaluate the cessation effects at various time points of different types of training particularly among advanced level weightlifters to compare our findings.

The present study showed that both types of training increase the velocity of barbell particularly during the second pull phase of 1-RM power clean and power snatch. Although the results were not significant, but the trend showed that the increment of velocity during second pull phase was greater in the isotonic group than isokinetic group. Meanwhile, the velocity of barbell during turnover phase of 1-RM power snatch and power clean decreased in both types of training. In contrast, after a month of training cessation, results showed that barbell velocity in the second pull phase of 1-RM power clean and power snatch reduced compared to their respective post-test values. Meanwhile, the velocity of the barbell during the turnover phase of 1-RM power snatch and power clean increases in both groups. The results indicate the potential of additional training program emphasized on shoulder joint, to increase barbell velocity during second pull phase and decrease the velocity during turnover phase. The barbell velocity values that returned to baseline level following cessation of additional training further highlighted the importance of specific shoulder joint training. To the best of our knowledge, no previous studies have investigated the cessation effects of specific training program on barbell velocity at different phases of 1-RM tests. Therefore, more studies with evaluation of cessation effects at different time points are warranted.

It was agreed that the second pull phase was a critical part of the lift whereby it determined whether the barbell will reach the optimum height for the catch [28]. Therefore, greater speed at the second pull phase was hypothesized to improve power output. Contrarily, increased in barbell velocity during turnover phase was speculated to jeopardized a successful lift as it will caused the lifters to squat down quickly to get ready for catch position [29]. However, this may only occur mostly among Asian lifter as they tend to pull the bar coupled with a backwards jump which results a catch position to be behind the initial position of the barbell [30] compared to U.S. lifters that tend to pull and catch the barbell at the front of its initial position [31, 32]. Nevertheless, the increased in velocity during this phase is vital as the barbell weights are getting heavier during the competition. This technique might ensure that the barbell can be lifted as quickly as possible. Therefore, the skills and lifting technique is important as they might need to squat down quicker when the weight becomes heavier.

Moreover, the adaptation of rotator cuff muscles may be different for isotonic and isokinetic groups because rotator cuff constitutes several different muscles. It was reported that the rotator cuff activation varied throughout snatch whereby supraspinatus activation increases starting from turnover phase until catch phase [11]. In contrast, the infraspinatus activation increases from second pull phase until turnover phase. Due to the different activation of rotator cuff muscles following phases of weightlifting, we prescribed additional training program in varied lifting positions. We hypothesized that these lifting positions may activate and trained all muscles that constitute the rotator cuff. However, lack of electromyographical data in this study refrain our conclusion regarding the effects of training on rotator cuff muscle activity.

5. Conclusions

We concluded that additional training program focusing on the shoulder joint is recommended to advanced level of weightlifters to improve their 1-RM power clean and power snatch performance. The mode of training could be either isotonic or isokinetic with training duration of at least eight weeks. Furthermore, faster barbell velocity during second pull phase and slower barbell velocity during turnover phase is desirable for better 1-RM performance. Our results showed that additional training program emphasizing on shoulder joint, whether isokinetic or isotonic, was able to increase barbell velocity during second pull phase in both 1-RM power snatch and power clean. Additionally, both training were able to reduce barbell velocity during turnover phase in 1-RM power snatch but not in 1-RM power clean. The beneficial effects of the additional training program on shoulder joint were further emphasized as the mean barbell velocity showed a trend of slower velocity during second pull phase and faster velocity during turnover phase, following one month of training cessation. Although the results were not significant, however the trend of improvement was of interest for advanced level athletes.

The strength of this study was the recruitment of advanced level of weightlifters compared to novice lifters or sedentary population recruited in previous literatures. Furthermore, the inclusion of the third time point of assessment which was the period after training cessation, also provides better long-term evaluation of both types of training.

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