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Kinematic Comparison of Snatch and Clean Lifts in Weightlifters Using Wearable Inertial Measurement Unit Sensors

RESEARCH

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ABSTRACT

There are two major lifts in weightlifting competition: the snatch and the clean and jerk. Most studies have focused on the snatch technique using conventional motion capture systems. There is a lack of information on the bilateral comparison of body segment movement during the entire phases of the weightlifting exercises. To our knowledge, no previous studies have directly compared the joint kinematics between the snatch and clean lifts. In this study, we investigated the trunk, shoulder, elbow, hip, and knee joint movements to find a difference between the snatch and clean lifts at each phase using wearable inertial sensors. Seven female Mongolian weightlifters participated. Each participant performed three snatches and three clean lifts at 70% of the one-repetition maximum. The joint angles were calculated using raw data from the inertial measurement unit (IMU) sensors. The main phases of the two techniques were defined based on knee and shoulder angle. The mean joint angle, the joint angle at each phase, and the proportion of the phases were compared between the two techniques. The mean angles of the trunk, shoulder, and elbow movements were significantly different ($p < 0.05$) while the hip ($p = 0.73$) and knee movements ($p = 0.06$) were similar. With detailed statistical analysis at each phase, subtle differences in the joint angles were observed. This study provides a detailed comparative analysis of the joint kinematics between the snatch and clean, which may help to deeply understand the similarities between the two techniques and enable us to best prescribe the appropriate exercises for improving weightlifting performance.

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INTRODUCTION

Weightlifting is a specific sport that requires high technique, explosive strength, and flexibility (Gourgoulis et al., 2002). There are two major lifting techniques involved in competition: the snatch and the clean and jerk, where the snatch is the first lift performed in competition and followed by the clean and jerk (Francisco Javier Flores et al., 2017). Both techniques start with the same movements until the second pull phase, then the body movement is differentiated during the turnover, catch, and recovery phases (Werner et al., 2021). The maximum power output during snatch is generally reported as higher than the clean (F. Javier Flores et al., 2017). Moreover, the second pull of snatch and clean is known to elicit the greatest amount of power output (Comfort et al., 2013; F. Javier Flores et al., 2017). During weightlifting, athletes need to perform with heavy loads and with very deep knee flexion, if the technical movements are not controlled well, they can easily suffer from injuries in the lower back and knee (Raske and Norlin, 2002; Shi and Sun, 2022).

Most of the previous studies have focused on the snatch technique in terms of the kinematics of the barbell and lower limb (Akkuş, 2012; Campos et al., 2006; Gourgoulis et al., 2002; Harbili, 2012; Korkmaz and Harbili, 2016; Lester Ho et al., 2011; Olaya-Mira et al., 2020). Gourgoulis et al. (2002) compared the lower limb kinematics of male and female weightlifters. Campos et al. (2006) studied kinematic differences between different weight categories. Moreover, a detailed kinematic (Akkuş, 2012) and kinetic (Harbili, 2012) analysis of the lower limb was reported during the explosive pulling phase. Korkmaz and Harbili (2016) investigated the linear kinematics and trajectory of the barbell. For the clean technique, lower extremity kinematics, barbell movement patterns, and power output were investigated (Ammar et al., 2018; Kipp, Redden, M Sabick, et al., 2012; Werner et al., 2021). Werner et al. (2021) showed that the movement pattern of the clean is affected by barbell weight. The lower extremity joint angles during the clean phases were only investigated by Kipp et al. (2012b). Recently, an applied method of technical analysis was presented for coaches (Chavda et al., 2021). There are a few studies that compared the difference between snatch and clean lifts on power output (F. Javier Flores et al., 2017) and barbell kinematics and kinetics (Rossi et al., 2007). Although the success of weightlifting depends on the power applied to the barbell, there is optimal coordination of the joint movements behind a successful lift. To our knowledge, no previous studies have directly compared the joint movements in the snatch and clean between weightlifters which may help to choose appropriate exercise and training strategies for improving the health and performance of weightlifting athletes.

While most research studies use optical motion capture systems (Akkuş, 2012; Ammar et al., 2018; Gourgoulis et al., 2002; Kipp, Redden, M Sabick, et al., 2012; Werner et al., 2021), video cameras (Campos et al., 2006; Harbili, 2012; Korkmaz and Harbili, 2016; Olaya-Mira et al., 2020), and vision-based systems (Balsalobre-Fernández et al., 2020), a few studies have used inertial measurement unit (IMU) sensors for barbell movement during weightlifting exercises (F. Javier Flores et al., 2017; Sato et al., 2012). Sato et al. (2012) efficiently used the accelerometer unit for capturing lifters' performance at the training site. A recent review study noted that IMU sensors represent the easier and quicker solution for recording the weightlifting movements because no additional equipment or operations are needed which is more convenient and efficient to the athletes when compared to video-based technologies (Clemente et al., 2021). Kinematic characteristics of national and college level weightlifters during the snatch technique were examined using IMU sensors (Tumurbaatar et al., 2021).

The purpose of this study was to find the kinematic difference between two techniques using the wearable IMU sensors which can contribute to an understanding of patterns of Olympic-style weightlifting. Each individual may differently perform the weightlifting movements due to their ability or performance level as well as training habits which can lead to injuries or other health issues. It was hypothesized that similarities would exist in the lower extremity joints, while differences would occur in the upper body joints between the snatch and clean techniques.

MATERIALS AND METHODS

In this study, seven female Mongolian weightlifters (age, 19.7 ± 2.1 years; height, 160.2 ± 6.5 cm; weight, 73.0 ± 16.3 kg; years of training, 5.5 ± 2.9 years) participated. This work was approved by the Institutional Review Board of the Mongolian University of Science and Technology (IRB#020). Written informed consent was obtained from each participant prior to experimentation.

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Two test sessions were carried out to record upper and lower extremity movements at the training site. The first sessions were snatch followed by clean. The trunk, shoulder, elbow, hip, and knee motion data were recorded using the IMU sensors, which were attached to the chest, waist, arm, forearm, thigh, and shank using the straps (Wearnotch, Notch Interface Inc.) (Figure 1a). The sensor raw data (three-axis acceleration and three-axis gyroscope data) during the lifting were collected with ±16 g and ±2000°/s with a sampling rate of 100 Hz (Cheon et al., 2020). The placement of the sensors was adjusted without interfering with the lifter's performance. Before the experiment, each participant was asked to perform 10 minutes of dynamic stretches, and 10 minutes of actual movements of the snatch and clean lifts with 50% of the repetition maximum (RM) as a warm-up. Then, each participant performed three snatch and clean lifts at 70% of the RM under supervision by the certified national weightlifting coach to ensure appropriate and consistent technique. The extension angles of the trunk, elbow, hip, knee, and flexion angle of the shoulder were calculated from the sensor's raw data using the Madgwick filtering algorithm developed in Matlab® (Choi et al., 2021; Madgwick S., 2010) (Figure 1b). In our previous study (Choi et al., 2021), the accuracy of the IMU sensors was compared against the optical motion capture system. The results showed that joint angles were strongly correlated between IMU sensors and optical motion capture system with ≤5.8% and a correlation of $r \leq 0.99$.

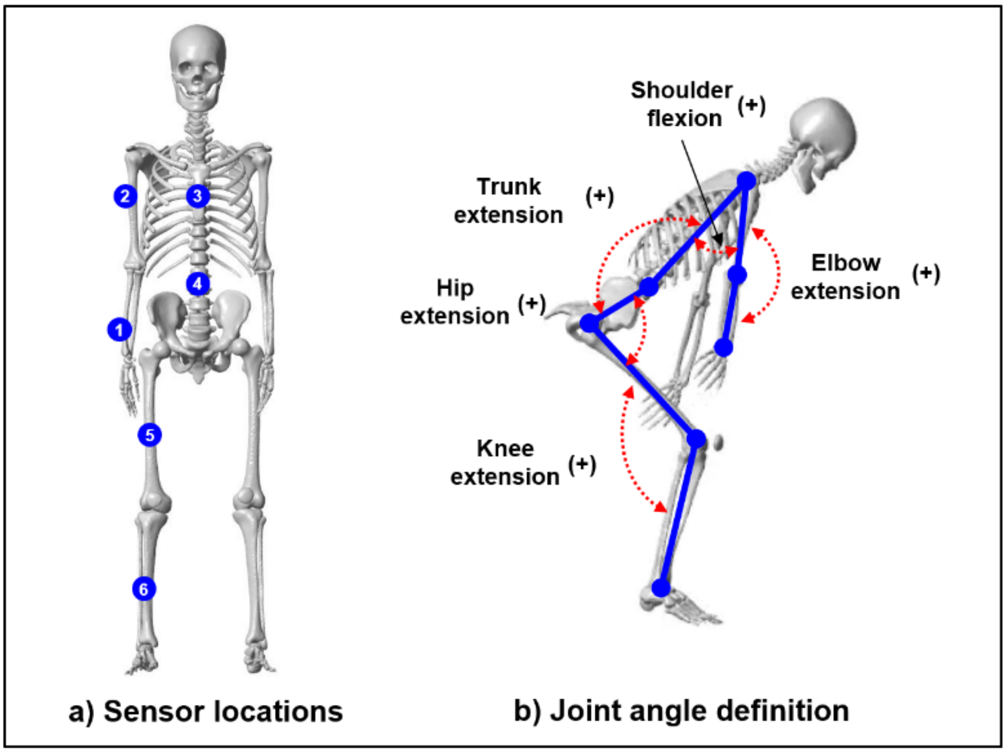

Figure 1 The sensor locations and joint angle definition.

After calculating the joint angles, the six main phases were defined for the snatch and clean based on knee and shoulder movement according to the previous studies (Chavda et al., 2021; Gourgoulis et al., 2002; Werner et al., 2021). The six main phases include the 1st pull, transition, 2nd pull, turnover, catch, and recovery phases (Figure 2). The 1st pull phase is defined as the first peak of knee extension, followed by the transition phase where the lifters need to execute small knee flexion effectively and quickly for the preparation of the 2nd pull phase. These three phases are the same for both techniques, then arm movements are differentiated, where the lifters move the barbell from the floor to overhead in the snatch and to the shoulder in the clean (Chavda et al., 2021). In the snatch, the shoulder flexion is increased from the turnover phase, then the arms become straight during the catch and recovery phase. In the clean, the arms are flexed from turnover to the recovery phases (Gourgoulis et al., 2002; Werner et al., 2021).

For each lift, joint angle data were normalized and divided into 100 steps. Then, each participant's data was averaged and compared for the snatch and clean groups, respectively. The trunk, shoulder, elbow, hip, and knee joint angles at each phase of the two techniques were defined for each participant. Also, the six main phases were averaged and proportioned for two techniques.

The barbell acceleration and velocity at the 2nd pull phase were estimated using the sensor on the forearm. Since the previous study measured the barbell velocity using the wrist IMU sensor during the resistance training exercises (Balsalobre-Fernández et al., 2017).

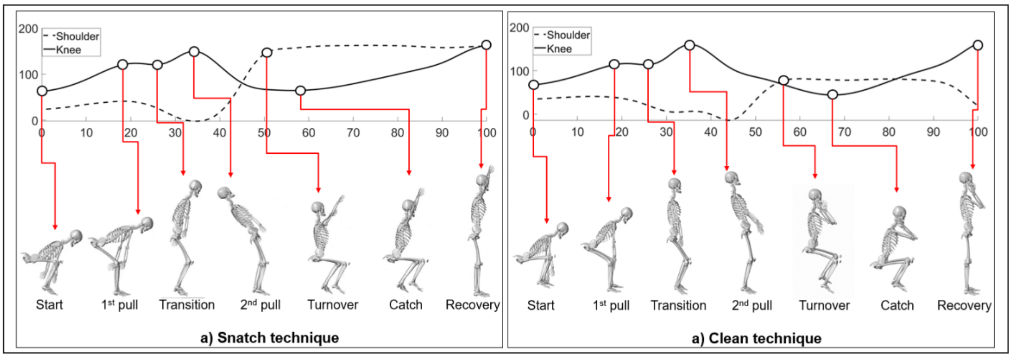

Figure 2 The main phases for snatch and clean techniques.

An independent sample t-test was used to compare the mean values of joint angles during the snatch and clean. To find subtle differences between the snatch and clean techniques, the joint angles at each phase were compared. A significance level of .05 was used for all statistical tests that were performed in Matlab®.

RESULTS

The maximum shoulder, elbow, trunk, hip and knee angles for snatch/clean were 160.8 ± 6.1° / 86.3 ± 9.5°, 187.7 ± 7.4° / 176.4 ± 3.9°, 162.9 ± 9.7° / 163.3 ± 10.7°, 172.6 ± 7.9° / 174.1 ± 5.2° and 162.9 ± 10.5° / 159.1 ± 4.6°, respectively (Figure 3). A statistical test showed a significant difference between the snatch and clean during the entire phase in shoulder flexion ($p < 0.05$), elbow extension ($p < 0.05$), and trunk extension ($p = 0.003$). Although the hip and knee joints were more extended during the clean when compared to the snatch, there was no significant difference was observed (Figure 3).

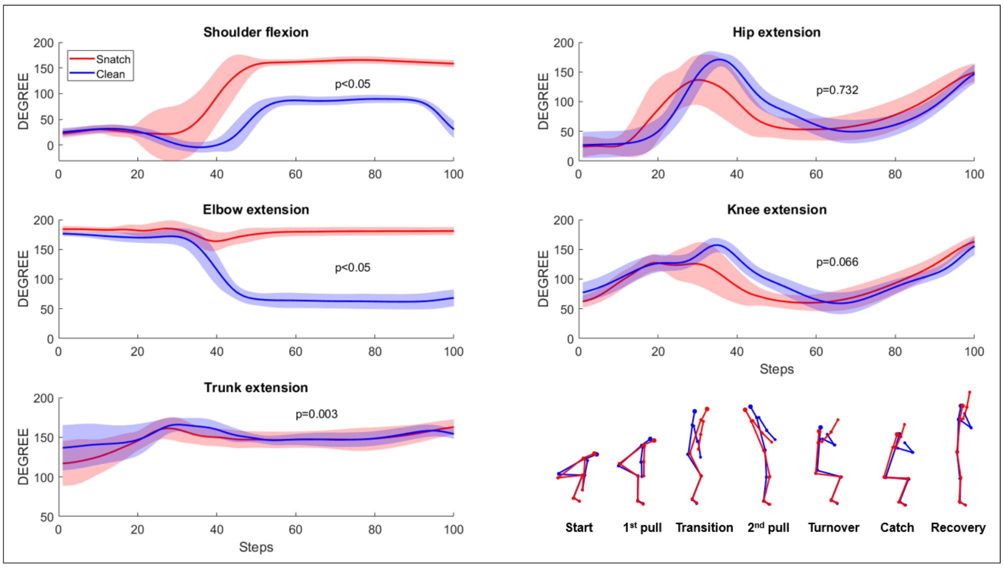

Figure 3 The joint angles during the snatch and clean technique with the p-value.

The statistical analysis of joint angles between snatch and clean at each phase was reported in Table 1. A significant difference in shoulder flexion was found after the turnover phase ($p < 0.05$). All phases were significantly different in the elbow ($p < 0.01$). The start ($p < 0.05$) and end ($p < 0.01$) of the trunk position were significantly different. The hip extension was not significantly different except for the turnover ($p < 0.05$). For knee extension, the start ($p < 0.01$), 1st pull ($p < 0.01$), 2nd pull ($p < 0.05$) and end ($p < 0.05$) phases were significantly different between the snatch and clean.

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		SHOULDER	ELBOW	TRUNK	HIP	KNEE
Start	Snatch	22.1 ± 8.0	184.0 ± 5.5	117.0 ± 28.2	24.3 ± 17.3	62.4 ± 10.1
	Clean	25.2 ± 7.6	176.4 ± 3.9**	136.8 ± 28.6*	27.0 ± 17.1	77.5 ± 12.1**
1st pull	Snatch	26.4 ± 11.4	183.0 ± 4.9	139.0 ± 17.5	48.7 ± 20.5	119.8 ± 9.6
	Clean	25.5 ± 7.5	170.7 ± 8.3**	148.2 ± 21.2	53.1 ± 20.8	129.6 ± 9.0**
Transition	Snatch	8.8 ± 13.5	187.7 ± 7.4	153.9 ± 19.7	101.9 ± 28.1	123.9 ± 9.5
	Clean	10.9 ± 9.6	172.0 ± 11.2**	159.1 ± 15.0	101.5 ± 16.0	126.8 ± 7.7
2nd pull	Snatch	1.2 ± 15.5	183.1 ± 10.3	157.5 ± 9.7	172.6 ± 7.9	154.3 ± 9.0
	Clean	– 5.1 ± 9.9	157.9 ± 17.4**	163.3 ± 10.7	174.1 ± 5.2	159.1 ± 4.6*
Turnover	Snatch	159.9 ± 6.9	176.0 ± 8.5	147.9 ± 10.4	60.6 ± 18.1	71.2 ± 11.8
	Clean	86.3 ± 9.5*	65.2 ± 12.6**	147.1 ± 5.5	74.9 ± 14.9*	77.0 ± 14.5
Catch	Snatch	160.8 ± 6.1	179.8 ± 7.5	146.5 ± 10.2	51.3 ± 17.9	58.4 ± 13.3
	Clean	85.5 ± 8.3*	63.2 ± 12.5**	147.0 ± 8.9	49.8 ± 15.4	58.4 ± 12.9
End	Snatch	158.4 ± 6.9	180.9 ± 6.7	162.9 ± 9.7	149.3 ± 14.9	162.9 ± 10.5
	Clean	30.5 ± 17.1*	68.3 ± 14.0**	154.3 ± 6.2**	146.9 ± 10.9	155.6 ± 10.0*

Table 1 Joint angle data (mean ± SD°) for snatch and clean at each phase.

Significantly different (*p < 0.05, **p < 0.01) from snatch.

The estimated barbell velocity and acceleration were 1.14 ± 0.51 m/sec and 8.59 ± 4.15 m/sec^2 for snatch, while these were 1.07 ± 0.66 m/sec and 11.51 ± 7.35 m/sec^2 for clean at the end of the 2nd pull phase. No significant difference was observed in the velocity (p = 0.68) and acceleration (p = 0.12) between the snatch and clean techniques.

The proportion of the lifting phases was different between the two techniques. The snatch group showed a 7% shorter pulling and 4% shorter turnover phase compared to the clean group (Figure 4a). While the clean exhibited a 4% shorter catch and 7% shorter recovery phase than the snatch lifts (Figure 4b).

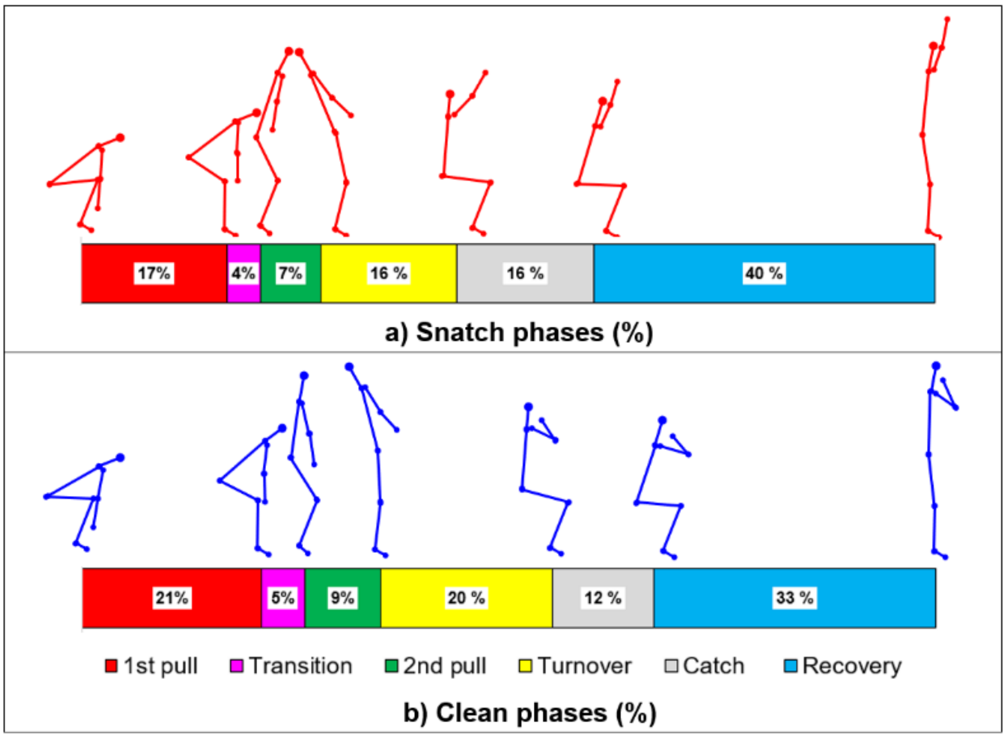

Figure 4 The phase comparison between the **a)** snatch and **b)** clean techniques.

DISCUSSION

This study compared the joint angles during the snatch and clean technique using wearable IMU sensors. The mean angles of the trunk, shoulder, and elbow movements were significantly different while the hip and knee movements were similar. It is clear that arm movements are different in two techniques; such as lifters moving the barbell from the floor to the overhead in the snatch and the shoulder in the clean (Chavda et al., 2021). Similar hip and knee extension patterns were observed which are known to elicit the greatest amount of power output in both snatch and clean during the explosive pulling phases (F. Javier Flores et al., 2017). Thus, it may suggest that a similar training exercise or strategy can be employed for weightlifting derivatives to reduce overtraining. Since it was previously reported that 60% of weightlifter's injuries were associated with tiredness (Keogh and Winwood, 2017). The simple training exercise can be pulling the bar from the ground until the midthigh position or end of the 2nd pull phase without executing the turnover, catch, and recovery phases. Although this information is known to coaches and athletes, it is better to be aware of the detailed body segment movements with the advance in motion analysis technology.

With detailed statistical analysis at each phase, subtle differences in the joint angles were observed even similar trends were observed throughout the entire phase. At the start position, the trunk extension was significantly greater and more stable in the clean than snatch. Since they use a shoulder-width grip in the clean which makes more vertical or higher trunk position than the snatch (Ammar et al., 2018; Storey and Smith, 2012). It was also suggested that a steady trunk position during pulling phases is important for weightlifting performance (Kipp, Redden, MB Sabick, et al., 2012).

It has been reported that the mechanical principles behind the 1st pull, transition, and 2nd pull of the clean are the same as those of the snatch (Storey and Smith, 2012). Interestingly, current results showed that the knee extension was significantly higher in the clean than snatch during the 1st and 2nd pulls. The knee extension at the 1st and 2nd pull for snatch/clean was 119.8 ± 9.6°/129.6 ± 9.0° and 154.3 ± 9.0°/159.1 ± 4.6°, respectively. These results were similar to previous studies. Many studies have reported knee extension angles of 129° – 140° and 159° – 170° at the 1st and 2 pull, respectively, during the snatch (Akkuş, 2012; Campos et al., 2006; Gourgoulis et al., 2000; Harbili, 2012; Korkmaz and Harbili, 2016). Only, Kipp et al. (2012b) reported the knee extension angle of 146° at the 2nd pull for clean. At the transition phase, all joints were almost identical for both techniques except elbow movement, and lifters increased their hip and trunk extension while maintaining constant knee angles. This is a preparation of the double knee-bend technique which utilizes more elastic energy from the knee extensor muscles for explosive power (Korkmaz and Harbili, 2016). During turnover, the hip flexion was significantly higher in the snatch than clean which can be explained by the lifter's pose since they need to descend more to receive the bar. It was previously reported that the maximum barbell rises in the snatch were ~10% higher than the clean lifts (Ammar et al., 2018; Chavda et al., 2021; Ho et al., 2014; Storey and Smith, 2012). At the catch phase, there was no significant difference was observed in the trunk, hip, and knee angle between the snatch and clean, which is known and identical to the full squat position (Ho et al., 2014; Storey and Smith, 2012).

From the phase analysis, it was found that the snatch technique had a faster pulling and turnover phase, and a longer catch and recovery phase than the clean technique. It was similar to previous studies: 0.51 – 0.63 sec for the 1st full, 0.10 – 0.14 sec for the transition, and 0.15 – 0.17 sec for the 2nd full phase in the snatch lifts (Akkuş, 2012; Harbili, 2012; Korkmaz and Harbili, 2016). Ammar et al. (2018) reported the times for the clean lifts as 0.72 sec for the 1st pull, 0.15 sec for the transition, and 0.15 sec for the 2nd pull phase. This is why the barbell velocity was higher during the snatch (1.14 – 0.51 m/sec) than the clean (0.07 – 0.66 m/sec) which was also consistent with previous reports, where they reported that velocity of 1.65 – 2.28 m/sec during the snatch and 0.88 – 1.78 m/sec during the clean (Ammar et al., 2018; Chavda et al., 2021; Ho et al., 2014; Storey and Smith, 2012). Therefore, snatch training focuses on the effective transference of generated high-level muscular power to the bar in a short period of time (Campos et al., 2006), while clean exercises need a longer time and greater range of motion to accelerate the barbell before the 2nd pull (Ammar et al., 2018).

Furthermore, the weight variations can influence the kinematics of the lifting and movement effectiveness. It was previously reported that lifting lighter load (less than 60% of the RM) does not seem to be effective for training and desired task goals, which may carry the risk of practicing movement patterns that are not optimal for lifting maximal loads (Werner et al., 2021). In contrast, weightlifting movements and their variations require a heavier relative load to maximise output as well as achieve the greatest velocity (F. Javier Flores et al., 2017). But, it should be noted that heavy loads produce large amounts of joint forces which may result in numerous injuries with poor technique (Keogh and Winwood, 2017). Therefore, we conducted lifting movements with 70% of the RM (F. Javier Flores et al., 2017; Werner et al., 2021).

Our study has several limitations. The major limitation is that a limited number of individuals have participated, but each participant performed three lifts for the snatch and clean technique, respectively. Moreover, a small error in the sensor's data can lead to an increased drift error. The drift error may be more severe in repetitive or cyclic movement (Purevsuren et al., 2018). To eliminate this error, we performed each lift separately during the experiment. The barbell velocity and acceleration were estimated from the sensor on the forearm in a previous study (Balsalobre-Fernández et al., 2017). The data were calculated at the end of the 2nd pull phase before the excessive elbow rotation that occurred during the turnover phase to avoid the measurement error. Thompson et al. (2020) also mentioned that movement around the elbow could create variability in the velocity metrics when using the wrist IMU sensor for clean movements. Finally, the lift variation can be caused by different weight categories, that have participated in this study. But, the technique of each participant is unique to the individual. Therefore, we aimed to find the difference between the snatch and clean lifts at the main phases. Future studies will consider the consistency in the lifts.

CONCLUSION

We investigated the trunk, shoulder, elbow, hip, and knee joint movements to find the difference between the snatch and clean technique at each phase using the wearable IMU sensors which can contribute to the understanding of patterns of Olympic-style weightlifting. Our results showed that the mean angles of the trunk, shoulder, and elbow movements were different while the hip and knee movements were similar between the snatch and clean techniques. This suggests that a similar training exercise or strategy can be employed for weightlifting derivatives to reduce overtraining such as pulling the bar from the ground until the midthigh position or end of the 2nd pull phase without executing the turnover, catch, and recovery phases. Although coaches and athletes have a general knowledge of the lifting exercises, a detailed comparative analysis of the joint kinematics may help to deeply understand the similarities between the two techniques and enable to best prescribe the appropriate exercises for improving weightlifting performance.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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REFERENCES

Akkuş, H. (2012). Kinematic Analysis of the Snatch Lift With Elite Female Weightlifters During the 2010 World Weightlifting Championship. *Journal of Strength and Conditioning Research*, *26*(4), 897–905. DOI: https://doi.org/10.1519/JSC.0b013e31822e5945

Ammar, A., Riemann, B. L., Masmoudi, L., et al. (2018). Kinetic and kinematic patterns during high intensity clean movement: searching for optimal load. *Journal of Sports Sciences*, *36*(12). Routledge: 1319–1330. DOI: https://doi.org/10.1080/02640414.2017.1376521

Balsalobre-Fernández, C., Geiser, G., Krzyszkowski, J., et al. (2020). Validity and reliability of a computer-vision-based smartphone app for measuring barbell trajectory during the snatch. *Journal of Sports Sciences*, *38(6)*, 710–716. Routledge. DOI: https://doi.org/10.1080/02640414.2020.1729453

Balsalobre-Fernández, C., Marchante, D., Baz-Valle, E., et al. (2017). Analysis of wearable and smartphone-based technologies for the measurement of barbell velocity in different resistance training exercises. *Frontiers in Physiology*, *8*(AUG), 1–10. DOI: https://doi.org/10.3389/fphys.2017.00649

Campos, J., Poletaev, P., Cuesta, A., et al. (2006). Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories. *Journal of Strength and Conditioning Research*, *20*(4), 843–850. DOI: https://doi.org/10.1519/R-55551.1

Chavda, S., Hill, M., Martin, S., et al. (2021). Weightlifting: An Applied Method of Technical Analysis. *Strength & Conditioning Journal*, *43*(4), 32–42. DOI: https://doi.org/10.1519/SSC.0000000000000614

Cheon, M., Khuyagbaatar, B., Yeom, J. H., et al. (2020). Analysis of swing tempo, swing rhythm, and functional swing plane slope in golf with a wearable inertial measurement unit sensor. *Journal of Mechanical Science and Technology*, *34*(7), 3095–3101. DOI: https://doi.org/10.1007/s12206-020-0640-3

Choi, Y. C., Khuyagbaatar, B., Cheon, M., et al. (2021). Kinematic Comparison of Double Poling Techniques Between National and College Level Cross-Country Skiers Using Wearable Inertial Measurement Unit Sensors. *International Journal of Precision Engineering and Manufacturing*, *22*(6), 1105–1112. DOI: https://doi.org/10.1007/s12541-021-00511-3

Clemente, F. M., Akyildiz, Z., Pino-Ortega, J., et al. (2021). Validity and reliability of the inertial measurement unit for barbell velocity assessments: A systematic review. *Sensors*, *21*(7), 1–19. DOI: https://doi.org/10.3390/s21072511

Comfort, P., Mcmahon, J. J., & **Fletcher, C.** (2013). No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *Journal of Strength and Conditioning Research*, *27*(2), 363–368. DOI: https://doi.org/10.1519/JSC.0b013e31825489c6

Flores, Francisco Javier, & **Redondo, J. C.** (2017). Optimal Load and Power Spectrum During Jerk and Back Jerk in Competitive Weightlifters. *Journal of Strength and Conditioning Research*, *31*(3). 809–816. Routledge. DOI: https://doi.org/10.1519/JSC.0000000000001544

Flores, F. Javier, & **Redondo, J. C.** (2017). Optimal load and power spectrum during snatch and clean: differences between international and national weightlifters. *International Journal of Performance Analysis in Sport*, *17*(4), 521–533. Routledge. DOI: https://doi.org/10.1080/24748668.2017.1366758

Gourgoulis, V., Aggeloussis, N., Antoniou, P., et al. (2002). Comparative 3-Dimensional Kinematic Analysis of the Snatch Technique in Elite Male and Female Greek Weightlifters. *The Journal of Strength and Conditioning Research*, *16*(3), 359. DOI: https://doi.org/10.1519/1533-4287(2002)016<0359:CDKAOT>2.0.CO;2

Gourgoulis, V., Aggelousis, N., Mavromatis, G., et al. (2000). Three-dimensional kinematic analysis of the snatch of elite Greek weightlifters. *Journal of Sports Sciences*, *18*(8), 643–652. DOI: https://doi.org/10.1080/02640410050082332

Harbili, E. (2012). A gender-based kinematic and kinetic analysis of the snatch lift in elite weightlifters in 69-kg category. *Journal of Sports Science and Medicine*, *11*(1), 162–169.

Ho, L. K. W., Lorenzen, C., Wilson, C. J., et al. (2014). Reviewing Current Knowledge in Snatch Performance and Technique. *Journal of Strength and Conditioning Research*, *28*(2), 574–586. DOI: https://doi.org/10.1519/JSC.0b013e31829c0bf8

Keogh, J. W. L., & **Winwood, P. W.** (2017). The Epidemiology of Injuries Across the Weight-Training Sports. *Sports Medicine, 47*(3), 479–501. Springer International Publishing. DOI: https://doi.org/10.1007/s40279-016-0575-0

Kipp, K., Redden, J., Sabick, M., et al. (2012b). Kinematic and Kinetic Synergies of the Lower Extremities During the Pull in Olympic Weightlifting. *Journal of Applied Biomechanics*, *28*(3), 271–278. DOI: https://doi.org/10.1123/jab.28.3.271

Kipp, K., Redden, J., Sabick, M. B., et al. (2012). Weightlifting Performance Is Related to Kinematic and Kinetic Patterns of the Hip and Knee Joints. *Journal of Strength and Conditioning Research*, *26*(7), 1838–1844. DOI: https://doi.org/10.1519/JSC.0b013e318239c1d2

Korkmaz, S., & **Harbili, E.** (2016). Biomechanical analysis of the snatch technique in junior elite female weightlifters. *Journal of Sports Sciences*, *34*(11), 1088–1093. DOI: https://doi.org/10.1080/02640414.2015.1088661

Lester Ho, K. W., Williams, M. D., Wilson, C. J., et al. (2011). Using Three-Dimensional Kinematics to Identify Feedback for The Snatch: A Case Study. *Journal of Strength and Conditioning Research*, *25*(10), 2773–2780. DOI: https://doi.org/10.1519/JSC.0b013e31820f500e

Madgwick, S. (2010). An efficient orientation filter for inertial and inertial/magnetic sensor arrays.

Olaya-Mira, N., Soto-Cardona, I. C., Palacio-Peña, R. T., et al. (2020). Kinematic Analysis of the Snatch Technique in High Performance Weightlifters. *Apunts. Educacion Fisica y Deportes*, *140*, 70–76. DOI: https://doi.org/10.5672/apunts.2014-0983.es.(2020/2).140.10

Purevsuren, T., Khuyagbaatar, B., Kim, K., et al. (2018). Investigation of knee joint forces and moments during short-track speed skating using wearable motion analysis system. *International Journal of Precision Engineering and Manufacturing*, *19*(7), 1055–1060. DOI: https://doi.org/10.1007/s12541-018-0125-9

Raske, Å., & **Norlin, R.** (2002). Injury incidence and prevalence among elite weight and power lifters. *American Journal of Sports Medicine*, *30*(2), 248–256. DOI: https://doi.org/10.1177/03635465020300021701

Rossi, S. J., Buford, T. W., Smith, D. B., et al. (2007). Bilateral comparison of barbell kinetics and kinematics during a weightlifting competition. *International journal of sports physiology and performance*, *2*(2), 150–158. DOI: https://doi.org/10.1123/ijspp.2.2.150

Sato, K., Sands, W. A., & **Stone, M. H.** (2012). The reliability of accelerometry to measure weightlifting performance. *Sports Biomechanics*, *11*(4), 524–531. DOI: https://doi.org/10.1080/14763141.2012.724703

Shi, Z., & **Sun, D.** (2022). Conflict between Weightlifting and Health? The Importance of Injury Prevention and Technology Assistance. *Physical Activity and Health*, *6*(1), 1–4. DOI: https://doi.org/10.5334/paah.158

Storey, A., & **Smith, H. K.** (2012). Unique Aspects of Competitive Weightlifting. *Sports Medicine*, *42*(9), 769–790. DOI: https://doi.org/10.2165/11633000-000000000-00000

Thompson, S. W, Rogerson, D., Dorrell, H. F., et al. (2020). The Reliability and Validity of Current Technologies for Measuring Barbell Velocity in the Free-Weight Back Squat and Power Clean. *Sports*, *8*(7), 1–17. DOI: https://doi.org/10.3390/sports8070094

Tumurbaatar, M., Khuyagbaatar, B., Kim, Y. H., et al. (2021). Kinematic Characteristics of National and College Level Weightlifters during the Snatch Technique Using Wearable Inertial Sensors. In: *The 8th International Electronic Conference on Sensors and Applications*, Basel Switzerland, 1 November 2021, p. 22. MDPI. DOI: https://doi.org/10.3390/ecsa-8-11255

Werner, I., Szelenczy, N., Wachholz, F., et al. (2021). How Do Movement Patterns in Weightlifting (Clean) Change When Using Lighter or Heavier Barbell Loads?—A Comparison of Two Principal Component Analysis-Based Approaches to Studying Technique. *Frontiers in Psychology*, *11*(January), 606070. DOI: https://doi.org/10.3389/fpsyg.2020.606070

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