KNEE AND TRUNK COORDINATION PATTERNS IN THE SNATCH: A PILOT STUDY ON THE INFLUENCE OF LOAD AND PHASE

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The purpose of this study was to investigate the effect of load on trunk and knee coordination during different phases of the snatch. Four elite weightlifters performed the snatch from submaximal to maximal loads (~85-100%), while video data were collected with eight cameras. The video data were processed with markerless motion capture software, and trunk and knee joint angles were calculated. Trunk-knee coupling angles were calculated via vector coding analysis. During the pull phase, an increase in the frequency count of trunk-knee coordination patterns in response to an increase in load, indicated that the pull phase lengthened as the loads increased. Each weightlifter, however, made load-specific adjustments in their trunk-knee coordination pattern across the different phases, which may suggest the need for individualized technique training.

KEYWORDS: sports, biomechanics, weightlifting, vector coding, kinematics

INTRODUCTION: In Olympic weightlifting, the snatch requires lifting a barbell from the floor to an overhead position in one continuous movement (Gourgoulis et al., 2009). To achieve a successful lift, weightlifters must adequately control multiple joint angles throughout the snatch. Previous studies on weightlifting biomechanics investigated changes of individual joint angles and identified key patterns during specific phases (Gourgoulis et al., 2009; Ikeda et al., 2012). For example, the knee joint undergoes extension during the first pull, flexion during transition, and rapid extension during the second pull. However, since effective force production during the snatch relies on well-coordinated movements across multiple joints, information solely about individual joint angles may be insufficient to wholistically understand the snatch movement.

Kim (2019) investigated intra-limb coordination by calculating coupling angles between lower limb joint angles to indicate how one joint influence another joint. They found that weightlifters used different coordination patterns between two-joints during heavy loads compared to lighter loads in a snatch pull. Another study indicated that during the clean, less hip extension during the first pull and second-knee bend transition, and rapid hip extension during the second pull were associated with the ability lift larger loads (Kipp et al., 2012). Although trunk angle or multi-joint were not directly measured, the study highlighted the importance of optimal hip and trunk motion in facilitating force generation during the second pull phase. However, it remains unclear if and how the trunk and knee angle are coordinated during the snatch, especially under different load conditions. Therefore, this study investigated the effect of load on the trunk and knee coordination during different phases of the snatch using vector coding analysis.

METHODS: Four elite weightlifters (2F, 2M; age: 25±5 years; mass: 60.3±7.9 kg) from the USA senior national team participated in this study. After individualized general and specific warm-ups, weightlifters performed multiple single repetitions with loads that ranged from 80-100% of their one-repetition snatch maximum. Video data were recorded with eight Sony RX0 II cameras (120 Hz). The videos were processed with Theia3D software. A cutoff frequency of 6Hz was used to filter the inverse kinematic data. C3D files were generated and processed with Visual3D. Three to four successful snatch trials (~85-100%) were analyzed. Absolute trunk angle (with respect to the global coordinate system) and relative knee joint angle (shank with respect to thigh segment) in the sagittal plane were calculated. Data from each snatch were trimmed from beginning of lift-off to end of the catch phase (Valenzuela Barrero et al., 2023), and were time normalized to 101 points (0-100%) via spline interpolation. Coupling angles between the two angles were calculated using vector coding analysis (i.e., calculating vector orientations between two adjacent data points to the right horizontal line) (Robertson et al., 2013) and classified into four different coordination patterns (Needham et al., 2020); in-phase coordination (represents angular motion of two joints in the same direction), anti-phase coordination (represents angular motion of two joints in opposite direction), and proximal or distal joint dominance (represents greater rotational change of one joint than the other). These patterns represent IPPD: in-phase trunk dominancy, IPDD: in-phase knee dominancy, APPD: anti-phase trunk dominancy, APDD: anti-phase knee dominancy. Coupling angles were sub-divided into three technical phases of the snatch, which were based on the estimated vertical barbell velocity (v_{bar}), used by the average of distal hand markers. Three phases were defined as pull ($v_{bar} \geq 0.03$ m/s to maximum v_{bar}), turnover (~ to minimum v_{bar}) and catch phase (~ to zero v_{bar}) (Figure 1). The frequency counts of each of the four coordination patterns in each phase of the time-normalized snatch cycle (100%) were used to provide distribution of coordination pattern and predominant coordination patterns across phases.

RESULTS: The basic joint angle patterns during the pull, turnover, and catch phase along with the associated angle-angle plot are shown in Figure1.

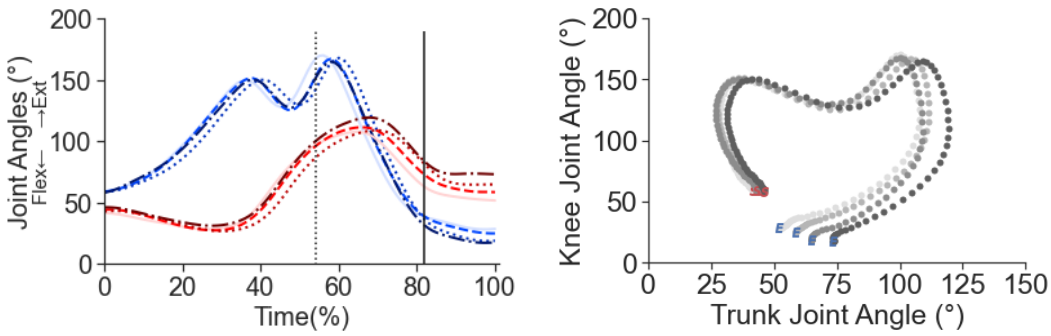

Figure 1. Left: Trunk (red) and knee (blue) joint angles during the pull (dotted line), turnover (solid line), and catch phases. Right: Trunk and knee angle-angle plot ('S': start; 'E': end) for one weightlifter. Darker color gradients indicate heavier loads.

The percentage breakdowns of the relative duration of the pull, turnover, and catch phases were 54.9 ± 1.9, 27.6 ± 1.5, and 17.5 ± 3.3. As load increased, the frequency counts of coordination patterns during the pull phase also increased, while frequency counts of coordination patterns during the turnover and catch phases showed minimal changes (Figure 2). All weightlifters exhibited predominantly APDD and IPDD coordination patterns during the *pull phase* across all loads. In addition, all weightlifters exhibited an increase in APPD when lifting the heaviest load compared to the lightest load during the pull phase. With respect to subject-specific changes in coordination patterns, at the heaviest load weightlifter 1 (W1) exhibited lower IPDD and greater APDD, weightlifter 3 (W3) increased APDD, while weightlifter 4 (W4) showed greater IPDD compared to the lighter loads. During the *turnover phase*, IPDD was the predominant coordination pattern across all loads. While IPDD was also the dominant coordination pattern during the *catch phase*, there were individualized strategy changes in trunk and knee coordination patterns among individual weightlifters as the load increased. Specifically, weightlifter 2 (W2) reduced IPDD and IPPD and increased APDD. In contrast, W3 showed greater IPPD but lower IPDD, whereas W4 showed lower APDD but greater APPD.

DISCUSSION: The purpose of this study was to investigate the effect of load on trunk and knee coordination patterns during different phases of the snatch using vector coding analysis. The results revealed a general increase in the frequencies of trunk-knee coordination patterns during the pull phase as the load increased, which indicated a temporal lengthening of the pull with heavier loads. In addition, unique trunk-knee coordination strategies among weightlifters (WL) were noted during all snatch phases in response to the increase in load.

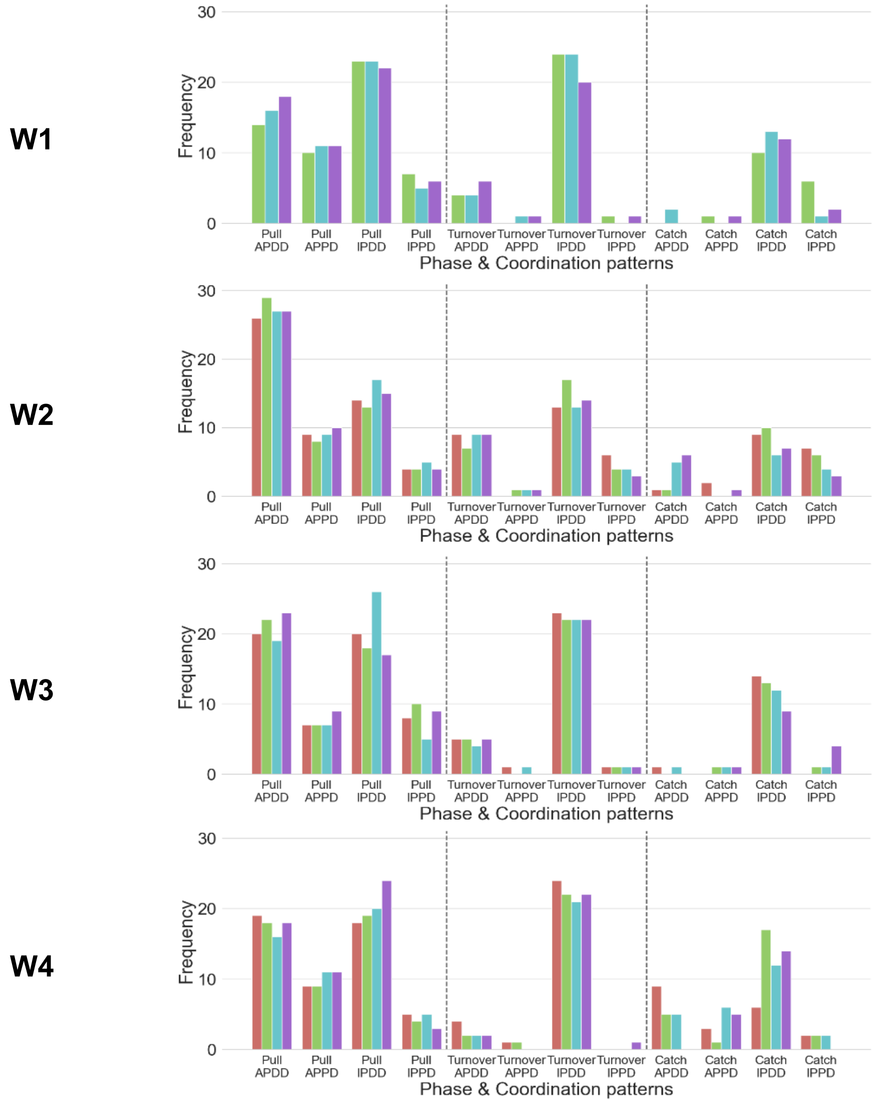

Figure 2. Distribution of trunk and knee coordination patterns for four weightlifters (W1-4) during three phases across different loads (red: 85%, green: 90%, blue: 95%, purple: 100% of 1-RM).

During the pull phase, the frequency counts of coordination patterns among all WLs increased as the load increased. Lifting heavier loads typically results in prolonged duration of this phase (Gourgoulis et al., 2009; Hadi et al., 2012). Therefore, our finding that WLs used a longer relative duration in the pull phase with heavier loads, aligns with earlier research (AkkuS, 2012). Regarding specific coordination patterns, APDD and IPPD were two major coordination patterns among all WLs regardless of the loads. Since APDD and IPDD were prominent coordination patterns during the first and second pull in our study, they were consistent coordination patterns across all WLs irrespective of the loads. With respect to joint dominancy, the pull phase was dominated by the knee joint rather than the trunk. These findings support the previous study by Kipp et al. (2012), which showed that less trunk motion during the first pull is associated with lifting greater loads. In addition, all WLs exhibited greater APPD at the 100% load compared to the 85-90% load. The APPD coordination pattern “appears” when the knee transitions from extension to flexion while the trunk continues to extend. Therefore, this finding suggests that the increase in APPD with heavier loads may be attributed to the additional time required for the lifter to align their trunk vertically, thereby maximizing the force producing capacity of the extensor muscles in preparation for the second pull (Enoka, 1979).

During the turnover phase, WLs exhibited primarily the IPDD across all loads. This indicated that WLs flexed both trunk-knee after reaching maximum extension as they aimed to quickly reposition themselves under the barbell during this phase. It is noteworthy that W1 showed greater APDD and lower IPDD with increasing load, which may indicate that peak trunk extension and subsequent repositioning the body under the bar were delayed due to the heavy load. Although the relative duration of this phase seemed unchanged, the point at which trunk extension peaked was delayed compared to the point at which knee extension peaked, leading to an increase in anti-phase, and a decrease in in-phase, coordination patterns. Given that dropping the body rapidly under the bar during the turnover phase is associated with skilled-snatch performance (Ikeda et al., 2012), greater APDD, rather than IPDD, coordination patterns might be more relevant for successfully performing heavy snatches.
The catch phase was dominated by the IPDD as lifters flexed their knees while their trunks remained relatively constant or flexed slightly as they aimed to decelerate and stop the barbell's downward motion. As the load increased, the lifters used individualized coordination strategies to catch the bar. For example, W2 showed more APDD, indicating that the trunk was slightly extended while the knee was dominantly flexed. W3 showed greater IPPD, indicating that both joints were flexed but the trunk kept flexing with heavier loads. Finally, W4 showed lower APDD but greater APPD, indicating that trunk extension was more controlling at this phase. Considering that the WLs demonstrated various coordination patterns with heavy loads during this phase, it may be important to pay attention to each weightlifter's trunk-knee coordination strategy to enhance individualized snatch training. Although the findings were based on the small number of trials per load, this is a general limitation of weightlifting research because it is not possible for WLs to perform multiple lifts at maximal loads. Further, individual factors such as competing experience may influence trunk and knee coordination strategies as load increases, thus future studies are needed to consider these factors.

CONCLUSION: The current study investigated the effect of load on trunk-knee coordination patterns during phases of the snatch using vector coding analysis. The results showed that the number of total trunk-knee coordination patterns increased during pull phase with increasing load among all players. Further, weightlifters used unique individualized strategies to adjust trunk-knee coordination across different phases in response to increased loads.

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