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Research article

Effects of Expertise on Muscle Activity during the Hang Power Clean and Hang Power Snatch Compared to Snatch and Clean Pulls – An Explorative Analysis

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Abstract

The purpose was to compare the electromyographic (EMG) activity of the Hang Power Clean (HPC) and Hang Power Snatch (HPS) with the Hang Clean Pull (HCP) and Hang Snatch Pull (HSP). Additionally, the influence of weightlifting expertise (beginner, advanced and elite) on EMG activity was analyzed. Twenty-seven weightlifters (beginner: n = 11, age: 23.9 ± 3.2 years, bodyweight: 75.7 ± 10.5 kg; advanced: n = 10, age: 24.8 ± 4.5 years, bodyweight: 69.4 ± 13.9 kg; elite: n = 6, age: 25.5 ± 5.2 years, bodyweight: 75.5 ± 12.5 kg) participated in this study. Participants performed two repetitions of HPC, HPS, HCP, and HSP at 50%, 70%, and 90% 1RM, respectively. The EMG activity of vastus lateralis (VL), gluteus maximus (GM), erector spinae (ES), rectus abdominis (RA) and trapezius (TZ) was recorded and normalized to the maximum voluntary isometric contraction (MVIC) of each muscle. There were significant differences in RA and ES EMG activity at 70% and 90% 1RM during HPC compared to HCP in the beginner group ($p < 0.05$, Hedges $g = 0.50 - 1.06$). Significant greater ES activity was observed in the beginner, advanced, and elite groups ($p < 0.05$, $g = 0.27 - 0.98$) during the HPS when compared to the HSP at 50-90% 1RM. TZ muscle activity was significantly greater at 50% and 70% 1RM in the HCP compared to the HPC in the elite group ($p < 0.05$, $g = 0.61 - 1.08$), while the beginner group reached significance only at 50% 1RM favoring HPC ($p < 0.05$, $g = 0.38$). Moreover, the EMG activity of the TZ during the HSP and HPS was significantly different only at 50% 1RM in the elite group and favored HSP ($p < 0.05$, $g = 0.27$). No differences were observed between the levels of weightlifting expertise. Based upon the results of this study, the overall pattern of EMG activity of the predominant muscles involved in HPC/HPS and the corresponding weightlifting pulling derivatives, apart from the stabilizing muscle (RA and ES), is similar at higher intensities (>70% 1RM) and expertise does not influence muscle activity.

Key words: Electromyography; weightlifting; expertise; motor learning; muscle recruitment; muscle excitation.

Introduction

Weightlifting exercises (i.e., snatch, clean and jerk) and their derivatives (i.e., exercises that represent elements of the snatch, clean and jerk; (Suchomel et al., 2018)) are commonly used in training programs to improve strength and performance outcomes (Ebben et al., 2004; Simenz et al., 2005; Suchomel et al., 2015; Tricoli et al., 2005). In general, it is believed that incorporating weightlifting exercises into an athlete's training routine results in superior performance outcomes (i.e., strength and power) when compared to traditional strength (Hoffman et al., 2004; Morris et al., 2022), jump (Tricoli et al., 2005), and kettlebell (Otto et al., 2012) training. One possible explanation for the superior training responses related to weightlifting-based exercises is to overload the synergistic extension of the hips, knees, and ankles (i.e., triple extension) that occurs during the second pull of the clean, snatch, and their pulling derivatives. This movement pattern may improve the transferability of training effects to the execution of jumps, sprints and change of direction performance in real sports scenarios (Garhammer and Gregor, 1992; Hori et al., 2008; Morris et al., 2022). Therefore, it is not surprising that it is a common for practitioners to implement weightlifting movements into their athlete’s training programs (Ebben et al., 2004; Simenz et al., 2005). A recent position statement published by the National Strength and Conditioning Association highlights its effectiveness in strength and conditioning programs when exercises and load are properly incorporated (Comfort et al., 2023).

Non-weightlifting athletes seek to improve their power generating and rapid force generating capacity by incorporating weightlifting movements (Kawamori and Haff, 2004). However, comprehensive weightlifting lifts, such as the full snatch or full clean, may pose excessive technical challenges for non-weightlifting athletes to acquire proficiently. Consequently, it may be reasonable to implement partial rather than full weightlifting movements, given the reduced complexity in execution (Suchomel and Sato, 2013). This approach might promote improved technique and subsequently provide the opportunity to effectively develop force production and power (Suchomel et al., 2015; Comfort et al., 2023).

Interestingly, when looking at the force-time curve characteristics associated with weightlifting (i.e., snatch, clean, power snatch and power clean) the second pull portion of these lifts elicit the highest peak power, peak force, and rate of force development compared to the other phases of the lift (Enoka, 1979; Garhammer and Gregor, 1992; Häkkinen and Kauhanen, 1986; Häkkinen et al., 1984;

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Souza et al., 2002). For instance, Häkkinen and Kauhanen (1986) reported not only a significantly shorter duration of the first pull and transition phase during the power snatch/power clean compared to the regular snatch/ clean, but also a significantly higher ground reaction force in the second pull of both the power snatch/clean.

Furthermore, in some instances performing weightlifting pulling derivatives could lead to superior acute and longitudinal strength outcomes. For instance, Comfort and colleagues (Comfort et al., 2011a; 2011b) have reported greater peak forces and rates of force development during the mid-thigh clean pull compared to the power clean and hang power clean in non-weightlifters when the same absolute load is lifted. Longitudinally, Comfort and colleagues (Comfort et al., 2018) reported no differences in changes to countermovement jump performance or isometric mid-thigh pull performance after 8-weeks of training when comparing training with catching or pulling derivatives. Moreover, Suchomel et al. (Suchomel et al., 2020) investigated the force-time characteristics of the countermovement jump and squat jump after 10 weeks of training with load-matched weightlifting catching and pulling derivatives, as well as pulling derivatives performed with an force and velocity overloaded stimulus. No significant in countermovement jump or squat jump performances were noted between load-matched pulling and catching derivatives, as well as pulling derivatives performed with an overload. In addition, Takei and colleagues (Takei et al., 2021) compared the hang power clean to the hang high pull across relative loads from 40% to 100% 1RM of the hang power clean and reported significantly greater peak power output at 40, 60, and 70% 1RM favoring the hang power clean. Conversely, there were no statistical differences at higher intensities. Therefore, high acute and chronic force and power characteristics were also observed to a similar degree when the catching phase was removed.

Given that there is a positive correlation between muscular force and the electromyographic (EMG) activity of the respective muscles, although not always linear, conclusions about the contribution of individual muscles during the performance of a given exercise can be made (Besomi et al., 2019; Merletti and Farina, 2016). For instance, EMG studies may be useful for illustrating muscle involvement during weightlifting catching and pulling derivatives, providing further decision support for the specific implementation of weightlifting exercises as part of a comprehensive strength training program. However, several researchers to date have investigated the neuromuscular activation of the muscles involved during the power clean (Barnes et al., 2021; Dryburgh and Psycharakis, 2016; Häkkinen and Kauhanen, 1986; MacKenzie et al., 2014; Nagao and Ishii, 2021), although only Häkkinen and Kauhanen (1986) have additionally investigated and compared the power snatch/power clean with the full snatch/clean as well as the full snatch/clean with the snatch pull/clean pull during the pulling motions. Concerning the comparison between the 100% full clean/snatch and the 100% clean/snatch pull, the authors observed higher vastus lateralis muscle activity and lower erector spinae muscle activity during the second pulling motion of the clean pull/snatch pull compared to the full clean/full snatch, while erector spinae activity was higher during the transition phase in the pulling derivatives, suggesting different muscle contributions.

To date, only a few studies have addressed how the level of proficiency within a particular sports discipline affects movement control and muscle excitation (Kristiansen et al., 2015; Rousanoglou et al., 2014; Santos et al., 2020; 2021). Santos and colleagues (2021), for instance, reported that weightlifters exhibit intergroup variation in muscle activation patterns during the power clean when compared to untrained individuals. Furthermore, untrained individuals maintain their individual and synergistic organization of the engaged muscles across multiple sets and days during the power clean (Santos et al., 2020), suggesting that disparities in muscle synergies between different levels of proficiency may reflect differences in neural adaptation processes (i.e., intermuscular coordination) as a result of specific resistance training (Santos et al., 2021). Although not in weightlifting, studies on handball (Rousanoglou et al., 2014) and bench press expertise (Kristiansen et al., 2015) have identified differences in muscle activation patterns. In terms of activation variability during the bench press, Kristiansen and colleagues (2015) observed an overall higher variability in muscle activation during the concentric portion of the bench press in experts compared to novices, again suggesting the development of an individual execution strategy. Taken together, it is possible that athletes with different weightlifting experience also develop different execution strategies, as indicated by different muscle activation patterns.

The purpose of the present study was to compare the EMG activation of the major muscles (i.e., vastus lateralis [VL], gluteus maximus [GM], rectus abdominis [RA], erector spinae [ES], and trapezius [TZ] muscles) associated with the performance of the hang power clean (HPC), hang power snatch (HPS), hang clean pull (HCP) and hang snatch pull (HSP) in athletes with varying weightlifting experience (i.e., beginner, intermediate, elite). Based on EMG findings of earlier work by Häkkinen and Kauhanen (1986), we hypothesized that neuromuscular activation of the vastus lateralis and erector spinae muscles will differ between weightlifting exercises (i.e., HPC and HPS) compared to their derivatives. Furthermore, we also hypothesized that EMG activity would differ with increasing weightlifting expertise. The outcomes of this study are anticipated to contribute valuable insights for practitioners in understanding and enhancing the synergistic neuromuscular activity during weightlifting. These findings will aid in the identification and development of effective lifting techniques, as well as the selection of suitable weightlifting derivatives for integration into training programs.

Methods

Experimental approach to the problem

In a multi-center study, muscle activity during HPC and HPS, as well as HSP and HCP, were examined using surface EMG (sEMG) analysis in beginner, advanced, and elite weightlifting athletes. The 1RM in the HPS and HPC were determined one week prior to the primary testing session so that appropriate loadings could be employed across

Table 1. Subject characteristics.

Performance category	Weightlifting experience (y)	Training sessions/week (each exercise)	Competition
Beginner	0 - 2 years	0 - 2	None, irregular or sporadic
Advanced	1 - 5 years	1 - 3	Regular national competitions
Elite	≥ 5 years	2 - 6	Regular national and international competitions

exercises. At the primary testing session, participants were randomly allocated to commence one of the two pulling derivatives: 1) HCP or 2) HSP. Following the execution of the specific pulling derivative, participants executed the catching derivative associated with the respective pull. Thus, if participants started with the HCP, the HPC followed. This was succeeded by the second pulling derivative and the subsequent catching derivative.

For all exercises, muscle activity was assessed at 50%, 70%, and 90% of 1 RM. A total of two repetitions were performed at each training load. All measurements were carried out at the IST- University of Applied Science in Dusseldorf, the German Sport University in Cologne, and at the National Performance Centre for Weightlifting in Leimen, Germany.

Participants

A G*power analysis was performed to determine the required sample size for our study (Faul et al., 2007). The alpha level was set at 0.05 and the power was set at 0.8 based on an analysis of variance within-between repeated measures model with a moderate effect size of f = 0.25 and a correlation among repeated measures of 0.7. Thus, 24 participants were required. To account for potential dropouts, a total of 27 participants were recruited for the study (m = 15; w = 12). Eleven participants (m = 6; w = 5) were assigned to the beginner group, ten participants (m=5; w = 5) to the advanced group and six participants (m = 4; w = 2) to the elite group. All participants were healthy female or male weightlifters who were free of injury and had consistently trained for a minimum of six months prior to participation in this study. All participants had at least one year of barbell training experience. The participants were categorized according to their weightlifting-specific training experience and training frequencies in the snatch and clean as well as their participation in competition. In Table 1, the participant characteristics for the athletes who were classified as beginner, advanced, and elite weightlifters are presented. To be classified as being an elite weightlifter, all three conditions of the respective level had to be fulfilled, otherwise the participants were automatically assigned to the category below. Prior to participation in the study, all participants were informed in writing about the study design and provided voluntary informed consent. All research procedures were performed in accordance with the Declaration of Helsinki and approved by the local ethics committee of the IST University of Applied Sciences (Nr. 072021IST233).

One-repetition maximum testing

During the 1RM testing session, participants performed a 5-minute self-selected dynamic warm-up and a 5-minute weightlifting-specific warm-up. Participants were then randomized to one of two treatment orders: 1) HPC/ HPS (first hang power clean then hang power snatch) or 2) HPS/ HPC (first hang power snatch then hang power clean). A 15kg (women) or 20kg (men) weightlifting barbell (Eleiko® Halmstad, Sweden) and International Weightlifting Federation (IWF) bumper plates were used for all tests. Participants started with two sets of five repetitions at 50% of the estimated 1RM, followed by two sets of two repetitions at 70% of the estimated 1RM and one set of one repetition at 90% of the estimated 1RM. Each participant then had three attempts to find their respective 1RM. Between each set or intensity, the participants rested for four minutes. During the test, the participants moved the barbell with a self-selected stance and grip. All participants wore weightlifting shoes, but no pulling aids, wrist or knee wraps, or weightlifting belts were used. The participant grasped the barbell and lifted the load until the knees and hips were extended. From an upright position, participants placed the barbell in a hanging position (just above the knee) for one second before accelerating the respective load to perform the HPS/HPC. An attempt was considered valid if 1) the bar was accelerated from the hanging position with a short pause, 2) the hip joint was higher than the knee joint during the catch phase, 3) and there was no exaggerated further attempt to extend the elbow joints within the snatch after the catch. If the attempt was valid, the load was increased by 2.5 - 5kg after discussion with the test supervisors. If the attempt failed, the participant was allowed to repeat the attempt a second time.

Procedures

Neuromuscular activity of the left VL, GM, TZ, and ES were analyzed. These muscles were selected for study as they are responsible for barbell acceleration and, therefore, relevant for power output (Dryburgh and Psycharakis, 2016). To ensure an adequate recovery, a one-week recovery period was included between the 1RM testing and the sEMG recordings. The sEMG data for all exercises were obtained during the same session in order to ensure identical electrode placement.

Before the electrodes (AI/AGgCI) were attached, the participants performed a five minute self-selected warm up and a five-minute weightlifting specific warm up similar to warm-up used for the 1RM test. After warming up, the skin was prepared and the electrodes were placed according to the SENIAM guidelines (Hermens et al., 2000). The first electrode was placed at the TZ (pars descendens) while the participant was sitting in an upright position with their arms hanging vertically. The electrode was placed on the line between the acromion and the cervical vertebra C7. For the placement of the electrode on the VL, the participant sat on a table with their knees slightly bent and with their upper body bent slightly backwards. The electrode was placed on 2/3 of the line from the spina iliaca anterior superior to the lateral side of the patella. For the placement of the electrode on the GM, the electrode was placed halfway between the sacral vertebra and the greater trochanter while the participant was lying on a table in a prone position. For the placement of the electrode on the ES, the electrode was placed two finger widths lateral to the spinous process of L1 while the participant was in a prone position with the lumbar spine slightly flexed. For RA, the electrode was placed at the left aspect of the umbilicus (Drysdale et al., 2004). Prior to the placement of all electrodes the corresponding area was marked, shaved, and cleaned with 70% isopropanol. All electrodes were placed on the center of the muscle belly, aligned parallel to the muscle fibers and Fixomull® Stretch patches were used to ensure fixation (Diamant et al., 2021).

After each electrode placement, a maximal voluntary isometric contraction (MVIC) was performed to allow for muscle activity during the respective exercise to be normalized with the MVIC. Two MVIC tests were performed with 60 s rest between each trial for each muscle to minimize errors due to fatigue (Konrad, 2005). Participants were instructed to build tension to a maximum voluntary contraction within 3 s and maintain this contraction for 5 s. To increase motivation, participants were verbally encouraged by the researchers. The MVIC for the TZ was performed in a standing position in front of a wall bar anchored to the floor, against which the participant supported themself with their outstretched arms. The participant attempted to pull the shoulders cranially against the resistance of the wall bars. To test the VL, the left foot of the seated participant was fixed to the chair leg with a rope in a knee flexion of approx. 90°. While the participant held on to the chair with their arms, the leg was extended maximally against the resistance. For the MVIC of the GM, the participant was lying in a prone position on a transverse box placed in front of a wall bar. The left foot was then fixed to the wall bars with a rope while the knee and hip were slightly flexed. At the instructor's signal, the participant attempted to extend their hip against the resistance. For the ES, participants were in a prone position. A barbell with an unmovable weight was placed over the upper body (i.e., scapulae). The participants were asked to develop maximum tension against the barbell. For the RA, participants lay on their back with their legs slightly tucked in (i.e., sit-up position). The spine was flexed approximately 30 degrees. A barbell with an unmovable weight was placed over the upper body (e.g., pectoralis major). The participants were allowed to hold onto the barbell with their hands and should develop maximum tension against the barbell.

A 15kg (Women) or 20kg (men) weightlifting barbell (Eleiko® Halmstad, Sweden) and bumper plates according to IWF standards were used for all tests. Prior to the start of each test, the test protocol was explained to each participant and the barbell was loaded with 50%, 70% or 90% of the participant's 1RM HPC or HPS and then placed on wooden blocks to standardise the starting position and eliminate the first phase of the pull. During the test, as soon as the participant grasped the barbell, the command "up" was given, and the EMG recording started. The barbell was raised to the hips so that the knees and hips were extended. At the moment the barbell was raised, the wooden blocks were removed by the lead researcher. The command "start" served as a signal to bring the barbell into the hanging position (just above the knee) and to hold it for about one second. This was done to ensure visual separation of the EMG data from the pause to the movement. The pause was followed immediately (without a command) by the pull or the HPC/ HPS. For each intensity (i.e., 50%, 70%, and 90% of 1RM), two repetitions were performed with a break of 60 seconds between trials. The subsequent exercise started as soon as all intensities of an exercise were completed. If there was a technical error (e.g., due to the EMG software), the lift was incorrectly executed (e.g., missing pause in the hang position), or the barbell contacted the electrode, the trial was repeated. All EMG measurements and repetitions were logged using a Microsoft Word file. The pulling exercises were randomized with their corresponding weightlifting-specific exercise (e.g., HCP and HPC).

EMG Analysis: A wireless SEMG (*Delsys® Trigno™*, Boston, MA) was used to record the raw EMG signal. Measurements were performed at a sampling rate of 1926 Hz with a bandwidth of 20-450 Hz. To record the raw EMG data, *EMGworks® Acquisition* (Delsys, Natick, MA, USA) was used. Apart from serving as a measuring instrument for muscle excitation, the EMG electrodes contained additional acceleration sensors. This enabled the start of the pulling movement to be determined with the aid of the vertical acceleration sensor on the vastus lateralis muscle. Based on biomechanical studies (Enoka, 1979; Nagao and Ishii, 2021), the relevant duration from the onset of the second pull to the end position of the lift was determined to be approximately 300 ms. For further processing, the recorded data were imported into the analysis software *EMGWorks® Analysis* (Delsys, Natick, MA, USA*)*. The data were checked for a possible zero-line offset. A correction with the Remove-Mean calculation was applied to correct a possible offset. For the MVIC test, an RMS with a window length of 500 ms was calculated. The EMG values of the exercises were calculated with an RMS window length of 50 ms. For the MVIC measurement as well as the RMS values of the given lift, the highest value was considered (Diamant et al., 2021; Nagao and Ishii, 2021).

Statistical analyses

For the statistical analysis, the EMG data were transcribed and transferred to SPSS (Version 27.0; IBM Corporation, New York, USA). All measurement parameters were checked for normal distribution within the groups using the Shapiro Wilk test. Consequently, the Kruskal-Wallis and Dunn-Bonferroni post-hoc tests were used to analyze differences in expertise (i.e., beginner, advanced, elite) within each loading condition (i.e., %1RM). The Wilcoxon signed rank test was used to compare the HPC and HPS with the corresponding pull at the respective intensity. The significance level was set at $p < 0.05$. To determine the magnitude of change between the catching and pulling movements, the effect size Hedge's g was calculated. Effect sizes were categorized as trivial, small, moderate, and large accordingly to the thresholds <0.20, 0.20 - 0.49, 0.5 - 0.79, and > 0.8 respectively (Cohen, 1988).

Table 2. All information on training experience, training frequency, and maximum performance in Hang Power Clean and Hang Power Snatch.

Performance Level	Participants	Age (y)	Bodyweight (kg)	Barbell experience (y)	Training sessions/week (#)	Weightlifting experience (y)	Training sessions/week (each exercise) (#)	Hang Power Clean 1RM (kg)	Rel. 1RM Hang Power Clean (kg.kg^{-1})	Hang Power Snatch 1RM (kg)	Rel. 1RM Hang Power Snatch (kg.kg^{-1})
Beginner	m (n = 6)	24.5 ± 3.9	84.8 ± 3.6	7.8 ± 3.8	3.3 ± 0.9	1.0 ± 0.6	1.3 ± 0.4	89.6 ± 10.3	1.05 ± 0.09	66.3 ± 7.0	0.78 ± 0.07
	w (n = 5)	23.2 ± 2.2	64.8 ± 4.0	3.5 ± 1.8	3.2 ± 0.4	1.0 ± 0.5	1.3 ± 0.4	56.8 ± 9.7	0.87 ± 0.12	40.8 ± 5.1	0.63 ± 0.05
	Total (n = 11)	**23.9 ± 3.2**	**75.7 ± 10.5**	**5.7 ± 3.9**	**3.3 ± 0.8**	**0.9 ± 0.5**	**1.2 ± 0.3**	**74.7 ± 18.7**	**0.97 ± 0.13**	**54.7 ±14.1**	**0.71 ± 0.10**
Advanced	m (n = 5)	25.8 ± 4.5	82.2 ± 8.0	5.0 ± 1.2	3.8 ± 0.7	2.4 ± 0.8	2.0 ± 0.8	105.8 ± 9.7	1.29 ± 0.10	79.8 ± 5.7	0.97 ± 0.07
	w (n = 5)	23.8 ± 5.2	56.6 ± 3.5	5.2 ± 2.4	4.0 ± 1.1	3.8 ± 3.1	2.0 ± 06	62.4 ± 12.8	1,10 ± 0,20	47.9 ± 8.4	0.85 ± 0.14
	Total (n = 10)	**24.8 ± 4.5**	**69.4 ± 13.9**	**5.1 ± 2.2**	**3.9 ± 1.0**	**3.2 ± 2.5**	**2.0 ± 0.7**	**84.1 ± 24.0**	**1,20 ± 0,18**	**63.9 ± 17.5**	**0.91 ± 0.14**
Elite	m (n = 4)	25.3 ± 6.2	79.5 ± 13.3	20.3 ± 6.2	6.5 ± 1.9	20.3 ± 6.2	3.3 ± 0.3	128.8 ± 14.9	1.64 ± 0.13	103 ± 14.5	1.30 ± 0.05
	w (n = 2)	26.0 ± 2.0	67.5 ± 1.5	17.0 ± 8.5	7.5 ± 3.5	17.0 ± 8.5	3.5 ± 0.7	92.5 ± 7.5	1.37 ± 0.08	75 ± 5.0	1.11 ± 0.05
	Total (n = 6)	**25.5 ± 5.2**	**75.5 ± 12.5**	**19.2 ± 6.3**	**6.8 ± 2.2**	**19.2 ± 6.3**	**3.3 ± 0.4**	**116.7 ± 21.4**	**1.55 ± 0.17**	**93.7 ± 18.8**	**1.24 ± 0.10**

Values are presented as mean ± SD

Results

All 27 athletes successfully completed the study. Participants' characteristics (i.e., anthropometric data, training experience, training frequency, maximum performance) are presented in Table 2.

Comparison of the clean derivatives

Differences and magnitudes of effect are displayed in Table 3. Briefly, there were no significant differences in VL and GM activation between HPC and HCP, regardless of intensity (Figure 1A-B). However, there was a significant difference in the amount of RA activity between the HPC and HCP at loads of 70% (HPC: 43.74 ± 44.38%, HCP: 19.56 ± 32.40%, p = 0.037, g = 0.62) and 90% of 1RM (HPC: 83.44 ± 110.92%, HCP: 16.31 ± 20.41%, p = 0.003, g = 0.84) in the beginner group favoring HPC with moderate and large magnitudes of effect (Figure 1C). In addition, significant differences in ES muscle activity between HPC and HCP were observed at 70% 1RM (HPC: 42.67 ± 40.91%, HCP: 23.03 ± 37.05%, p = 0.037, g = 0.50) and 90% 1RM (HPC: 72.56 ± 67.01%, HCP: 17.83 ± 23.37%, p = 0.003, g = 1.06), with moderately and largely augmented activity, respectively, during the HPC in the beginner group (Figure 1D).

With respect to the difference in TZ muscle activity, there were significant differences at 50% and 70% 1RM (Figure 1E). The elite group achieved significantly greater activity (large effect) during HCP at 50% 1RM (HPC: 60.53 ± 32.11%, HCP: 67.36 ± 35.60%, p = 0.028, g = 1.08) and moderately greater activation at 70% 1RM (HPC: 69.58 ± 39.12%, HCP: 94. 62 ± 43.46%, p = 0.028, g = 0.61), while in the beginner group, a significantly greater TZ activation of small magnitude was found during HPC compared to HCP at 50% 1RM (HPC: 138.05 ± 120.65%, HCP: 98.55 ± 82.83%, p = 0.008, g = 0.38).

Comparison of the snatch derivatives

Findings obtained for the HPS and HSP conditions are depicted in Table 4. For VL, GM, and RA, no significant differences in activity were observed between HSP and HPS regardless of intensity (Figure 2A-C). There were, however, significant differences in ES activity between HSP and HPS at all three intensities (Figure 2D). At 50% 1RM, there was moderate and significantly greater activation in the advanced group favoring the HPS (HPS: 175.69 ± 134.95%, HSP: 101.97 ± 99.91%, p = 0.047, g = 0.62), whereas the elite group had greater activation during the HPS (HPS: 294.28 ± 152.77%, HSP: 147.35 ± 147.64%, p = 0.043, g = 0.98). Moreover, the elite group exhibited large and significantly greater activation at 70% 1RM during HPS (HPS: 337.02 ± 268.49%, HSP: 141.21 ± 150.60%, p = 0.043, g = 0.87). Furthermore, ES activation at 90% 1RM was different in the beginner group with greater activation of a small magnitude during the HPS compared to the HSP (HPS: 215.68 ± 321.69%, HSP: 144.53 ± 185.68%, p = 0.026, g = 0.27) and in the elite group with a moderate magnitude (HPS: 371.62 ± 271.60%, HSP: 211.80 ± 190.72%, p = 0.043, g = 0.67). Concerning the TZ muscle (Figure 2E), significantly greater activity with a small magnitude was observed during the HSP compared to the HPS at 50% 1RM in the beginner group (HPS: 71.69 ± 23.21%, HSP: 78.58 ± 27.10%, p = 0.028. g = 0.27).

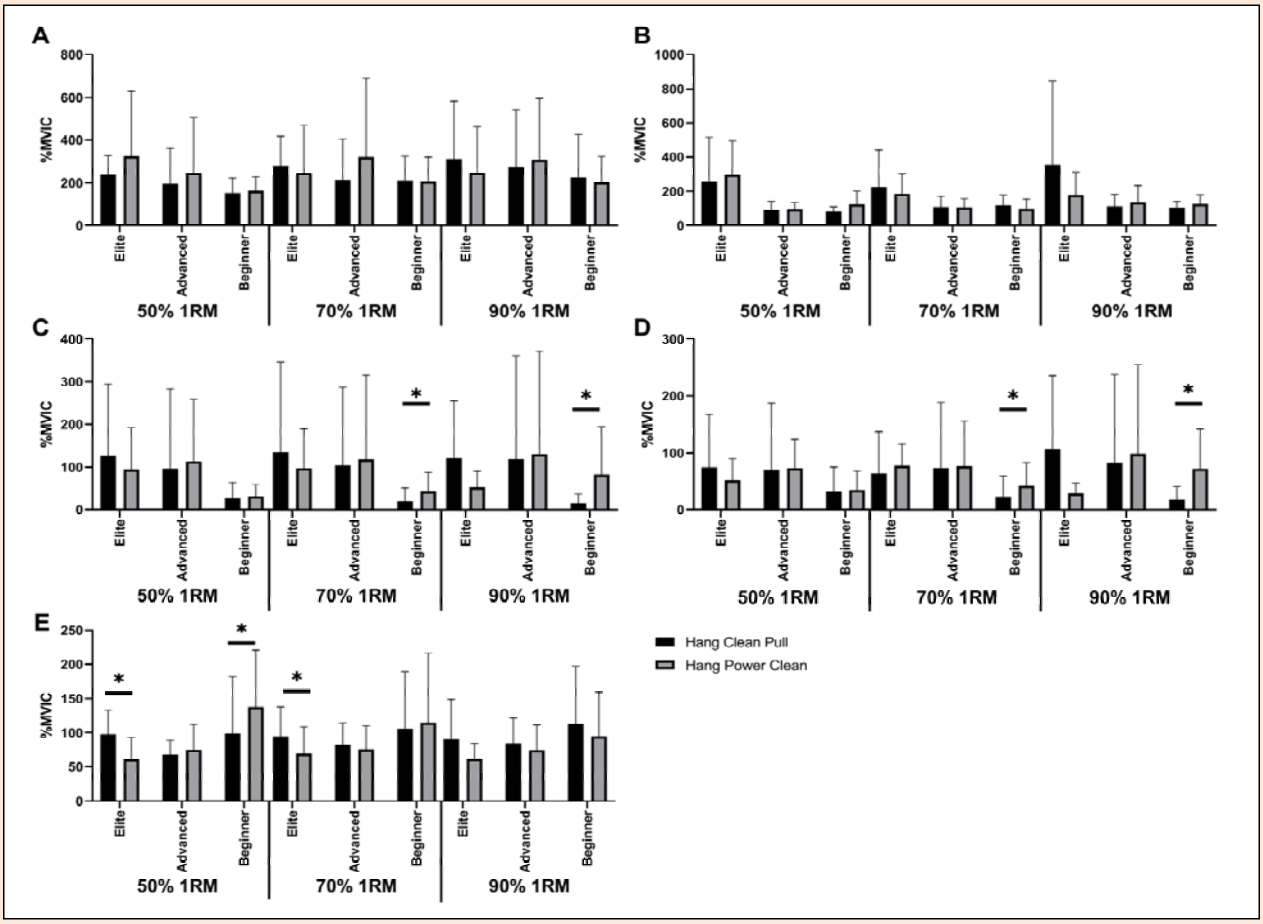

Figure 1. EMG analysis of the M. vastus lateralis (A), M. gluteus maximus (B), M. rectus abdominis (C), M. erector spinae (D), and M. trapezius (E) during the Hang Power Clean and Hang Clean Pull. Error bars indicate standard deviation. MVIC = maximal voluntary isometric contraction. *denotes a significant difference between lifts. $p < 0.05$.

Comparison of the level of expertise

There were no significant differences in muscle activation in any muscle between the three levels of expertise for neither HPS, HSP nor HPC ($p > 0.05$). However, significant differences in ES EMG activation were noted between the levels of expertise when the HCP was performed with 70% 1RM ($p = 0.046$). Nevertheless, after performing a Dunn-Bonferroni correction for multiple tests, there were no significant differences noted ($p > 0.05$).

Discussion

In the present study, for the first-time neuromuscular activation of several major muscles (i.e., VL, GM, RA, ES, and TZ) were compared between the HPC/HPS and their corresponding pulling derivatives. Additionally, the impact of training experience on these activation patterns were examined. The primary findings of the present study indicated significant differences in ES, RA, and TZ muscle activation patterns between the HPC and HCP. Further, significant differences were present in ES and TZ muscle activation the HPS and HSP. However, VL muscle activity was not significantly different between catching and pulling derivatives. Thus, the present results were partly in agreement with our hypothesis. Furthermore, we found no significant difference between the level of weightlifting expertise (i.e., beginner, advanced, and elite) in any condition.

When comparing the HPC to HCP and the HPS to HSP, no significant differences were observed in VL and GM activity at any of the intensities tested. This finding contrasts with the results reported by Häkkinen and Kauhanen (1986), who observed increased VL activation favoring the second pull of the clean/ snatch pull compared to the full clean/snatch when 100% loads were employed. However, the authors reported the integrated EMG value of each muscle analyzed, which differs from our normalization strategy since it represents the percentage of individual muscle contribution to the total EMG signal. Interestingly, the authors also observed higher VL muscle activation during the second pulling motion of the power snatch when compared to the full snatch. Although this was not tested in the present study, it remains questionable whether VL muscle activity during the power clean differs from the clean pull, as they are more similar in terms of activity profile (Häkkinen and Kauhanen, 1986).

Given that the function of the VL and GM muscles is knee and hip extension, respectively, and both weightlifting catching and pulling movements begin from a similar starting position, it is not surprising that there is no difference in normalized muscle activity during the second pull. Both muscles are involved in the synergistic triple extension that occurs during the second pull when performing weightlifting, sprinting, and jumping (Garhammer and Gregor, 1992; Hori et al., 2008). Since the neuromuscular activation does not appear to differ between HPC, HPS, and their pulling derivatives, this may also explain why long-term intervention studies have reported similar performance outcomes when training with weightlifting catching derivatives are compared to training with pulling derivatives with identical absolute loads (Comfort et al., 2018; Suchomel et al., 2020).

In the present study, activation of the GM muscle was similar under all conditions. The GM is particularly involved during hip extension, which plays a key role in the completion of the pulling motion during weightlifting (Kipp et al., 2012)). Although not measured in previous work (Häkkinen and Kauhanen, 1986), Häkkinen and Kauhanen reported similar biceps femoris integrated EMG values during the transition phase and second pull when comparing the full snatch/clean and the snatch/ clean pulling derivatives. It is important to note that we did not measure biceps femoris muscle activity. Nonetheless, the biceps femoris is also a huge hip extensor and might explain similar hip extensor involvement during weightlifting catching and pulling movements.

Somewhat surprisingly, the normalized EMG values of the trunk stabilizing muscles (RA, ES) in the beginner group were significantly different during the 70% 1RM and 90% 1RM conditions with greater activation during the HPC (g = 0.50 - 1.06), but without any statistically significant differences being noted at any intensity when the exercise was completed by the advanced and elite groups. However, it is important to note that the normalized EMG values displayed by the advanced and elite groups were highly variable, which may have masked any possible differences between HPC and HCP. Similarly to the findings in the present study, advanced athletes have been reported to have a higher degree of muscle activation variability than those displayed by beginners when performing the clean (Santos et al., 2021), bench press (Kristiansen et al., 2015), and javelin throw (Bartlett et al., 2007). Based upon these findings it is likely that more advanced athletes adopt a more individualized motor strategy due to years of resistance training (Kristiansen et al., 2015). In contrast, in the present study the differences in the level of proficiency were not significant after performing a Dunn-Bonferroni post-hoc test.

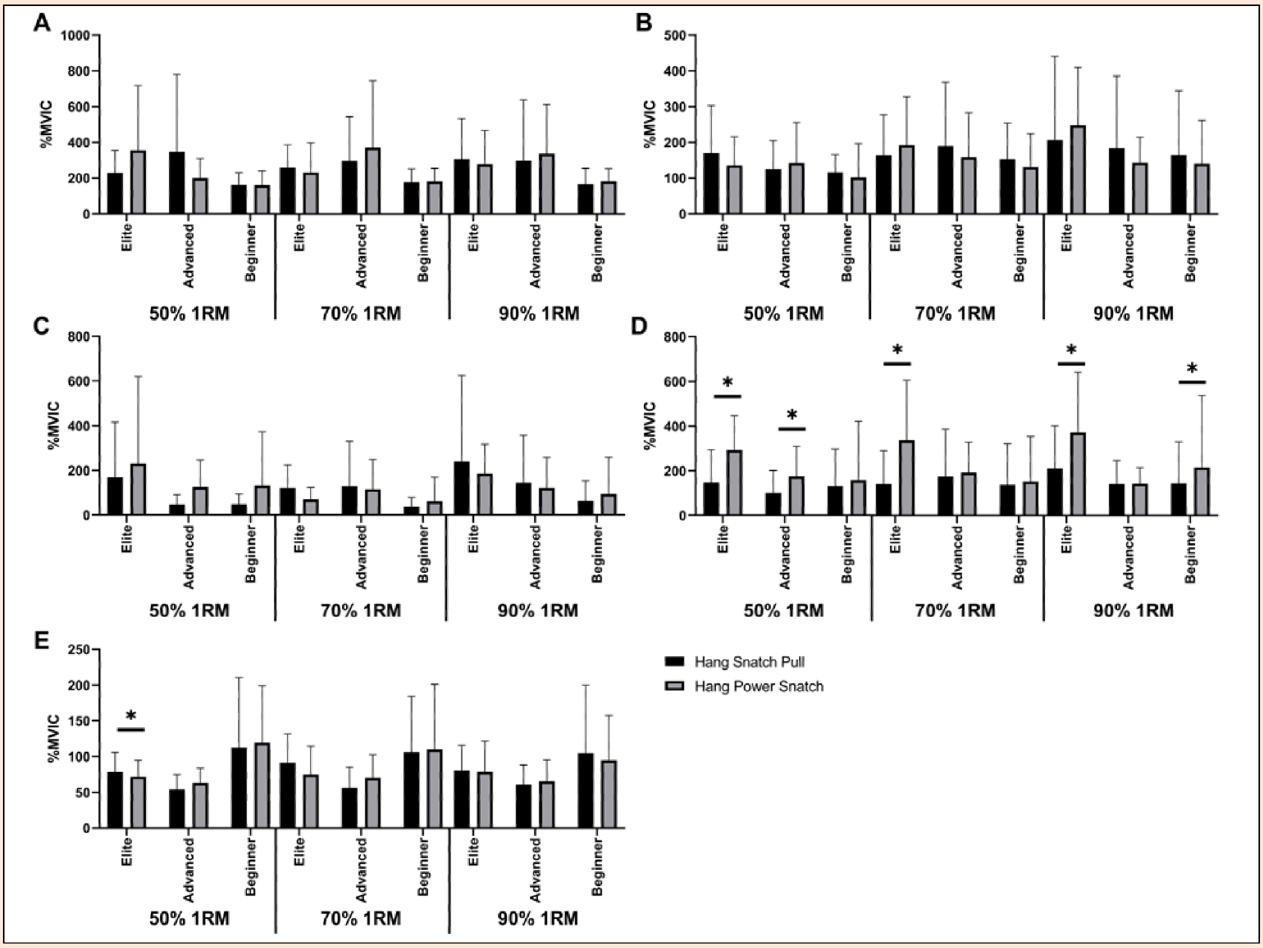

Figure 2. EMG analysis of the M. vastus lateralis (A), M. gluteus maximus (B), M. rectus abdominis (C), M. erector spinae (D), and M. trapezius (E) during the Hang Power Snatch and Hang Snatch Pull. Error bars indicate standard deviation. MVIC = maximal voluntary isometric contraction. *denotes a significant difference between lifts. $p < 0.05$.

Table 3. Differences in muscle activity between HPC and HCP.

Muscle	Intensity		Beginner		Advanced		Elite	
			HPC (%MVIC)	HCP (%MVIC)	HPC (%MVIC)	HCP (%MVIC)	HPC (%MVIC)	HCP (%MVIC)
VL	50% 1-RM	Mean	163.82	152.72	247.70	195.47	324.41	239.40
		SD	64.41	70.36	259.48	165.81	305.15	86.53
		P	0.508		0.445		0.600	
		Hedges'g	0.16		0.24		0.38	
	70% 1-RM	Mean	208.20	213.18	321.09	215.58	248.37	279.38
		SD	113..02	111.04	367.87	189.90	221.22	138.83
		P	0.575		0.093		0.345	
		Hedges'g	0.04		0.36		0.17	
	90% 1-RM	Mean	203.96	225.98	307.97	273.86	249.30	311.81
		SD	119.85	201.09	288.30	271.11	213.53	271.74
		P	0.575		0.074		0.6	
		Hedges'g	0.13		0.12		0.26	
GM	50% 1-RM	Mean	124.91	81.67	97.20	90.53	298.74	258.65
		SD	76.67	27.32	37.72	52.44	195.54	258.35
		P	0.11		0.575		0.463	
		Hedges'g	0.75		0.15		0.18	
	70% 1-RM	Mean	99.50	118.62	107.70	109.90	186.84	228.31
		SD	56.46	61.97	49.80	64.81	118.48	214.59
		P	0.286		0.575		0.753	
		Hedges'g	0.32		0.04		0.24	
	90% 1-RM	Mean	126.81	105.92	138.84	112.02	181.07	355.86
		SD	54.65	37.07	97.81	72.81	131.97	492.89
		P	0.182		0.074		0.6	
		Hedges'g	0.45		0.31		0.48	
RA	50% 1-RM	Mean	31.62	27.43	113.37	96.82	95.00	127.65
		SD	27.20	37.10	145.63	186.46	96.78	167.54
		P	0.386		0.139		0.917	
		Hedges'g	0.13		0.10		0.24	
	70% 1-RM	Mean	43.74	19.56	118.89	104.47	98.13	135.09
		SD	44.38	32.40	197.11	182.67	92.01	211.88
		P	**0.037***		0.386		0.345	
		Hedges'g	0.62		0.08		0.23	
	90% 1-RM	Mean	83.44	16.31	131.48	119.30	53.31	121.47
		SD	110.92	20.41	240.55	242.76	37.95	133.22
		P	**0.003***		0.646		0.6	
		Hedges'g	0.84		0.05		0.70	
ES	50% 1-RM	Mean	34.80	31.33	73.37	70.27	51.78	74.84
		SD	33.50	43.94	50.72	117.20	37.84	92.60
		P	0.386		0.139		0.753	
		Hedges'g	0.09		0.03		0.33	
	70% 1-RM	Mean	42.67	23.03	77.15	74.09	78.04	63.95
		SD	40.91	37.05	78.53	114.27	38.01	73.67
		P	**0.037***		0.878		0.917	
		Hedges'g	0.50		0.03		0.24	
	90% 1-RM	Mean	72.56	17.83	99.40	83.41	29.21	107.41
		SD	67.01	23.37	155.99	154.43	18.19	128.61
		P	**0.003***		0.646		0.686	
		Hedges'g	1.06		0.10		0.81	
TZ	50% 1-RM	Mean	138.05	98.55	74.96	67.59	60.53	67.36
		SD	120.65	82.83	37.14	20.83	32.11	35.60
		P	**0.008***		0.093		**0.028***	
		Hedges'g	0.38		0.24		1.08	
	70% 1-RM	Mean	115.20	106.18	76.01	82.35	69.58	94.62
		SD	110.94	83.04	34.12	32.21	39.12	43.46
		P	0.594		0.333		**0.028***	
		Hedges'g	0.10		0.19		0.61	
	90% 1-RM	Mean	94.90	112.94	72.52	84.69	61.55	90.81
		SD	64.66	84.36	36.78	36.81	23.20	58.43
		P	0.11		0.093		0.116	
		Hedges'g	0.24		0.28		0.66	

Values are presented as mean ± SD. MVIC = maximal voluntary isometric contraction; VL = M. vastus lateralis; GM = M. gluteus maximus; RA = M. rectus abdominis; ES = M. erector spinae; TZ = M. trapezius. *Statistically significant difference

Table 4. Differences in muscle activity between HPS and HSP.

Muscle	Intensity		Beginner		Advanced		Elite	
			HPS (%MVIC)	HSP (%MVIC)	HPS (%MVIC)	HSP (%MVIC)	HPS (%MVIC)	HSP (%MVIC)
VL	50% 1-RM	Mean	161.72	162.98	200.14	347.69	355.34	229.35
		SD	78.06	66.63	110.41	433.84	361.10	125.90
		P	0.721		0.799		0.753	
		Hedges‘g	0.02		0.47		0.47	
	70% 1-RM	Mean	183.34	177.61	371.76	296.96	232.42	258.21
		SD	70.96	73.35	374.29	246.56	166.54	127.68
		P	0.646		0.139		0.345	
		Hedges‘g	0.08		0.24		0.17	
	90% 1-RM	Mean	184.20	169.07	337.64	297.68	279.68	308.30
		SD	67.51	85.82	276.45	342.17	224.60	279.68
		P	0.575		0.333		0.345	
		Hedges‘g	0.20		0.13		0.14	
GM	50% 1-RM	Mean	102.43	115.92	142.50	125.22	135.18	169.33
		SD	94.50	50.27	112.90	80.28	81.17	134.25
		P	0.182		0.386		0.345	
		Hedges’g	0.18		0.18		0.31	
	70% 1-RM	Mean	130.88	153.79	159.29	189.33	192.78	164.75
		SD	94.50	99.62	124.30	179.64	135.16	112.78
		P	0.477		0.386		0.917	
		Hedges’g	0.24		0.19		0.23	
	90% 1-RM	Mean	141.19	165.12	143.97	183.92	249.03	207.87
		SD	120.77	179.79	71.51	202.54	161.38	233.46
		P	0.657		0.953		0.345	
		Hedges’g	0.16		0.26		0.21	
RA	50% 1-RM	Mean	132.30	50.30	125.63	49.19	231.29	169.27
		SD	240.25	44.51	121.07	42.74	389.60	247.92
		P	0.213		0.059		0.753	
		Hedges‘g	0.47		0.84		0.19	
	70% 1-RM	Mean	63.24	37.82	114.74	129.32	70.52	121.23
		SD	106.33	42.14	134.45	200.52	53.18	102.85
		P	0.445		0.959		0.075	
		Hedges’g	0.32		0.09		0.62	
	90% 1-RM	Mean	95.32	64.93	120.70	144.87	186.08	240.58
		SD	164.57	88.98	138.22	211.84	131.53	385.17
		P	0.169		0.721		0.753	
		Hedges‘g	0.23		0.14		0.19	
ES	50% 1-RM	Mean	158.05	131.26	175.69	101.97	294.28	147.35
		SD	264.05	166.40	134.95	99.91	152.77	147.64
		P	0.721		**0.047***		**0.043***	
		Hedges‘g	0.12		0.62		0.98	
	70% 1-RM	Mean	152.22	136.82	193.99	175.52	337.02	141.21
		SD	201.86	185.73	134.95	212.25	268.49	150.60
		P	0.155		0.241		**0.043***	
		Hedges‘g	0.08		0.10		0.87	
	90% 1-RM	Mean	215.68	144.53	142.79	141.28	371.62	211.80
		SD	321.69	185.68	72.54	106.05	271.60	190.72
		P	**0.026***		0.878		**0.043***	
		Hedges‘g	0.27		0.02		0.67	
TZ	50% 1-RM	Mean	119.57	112.60	63.29	54.32	71.69	78.58
		SD	79.96	97.90	20.82	20.74	23.21	27.10
		P	0.722		0.333		**0.028***	
		Hedges‘g	0.08		0.43		0.27	
	70% 1-RM	Mean	109.64	105.92	70.61	56.59	75.14	91.47
		SD	91.53	78.37	32.01	29.02	39.50	40.39
		P	0.657		0.169		0.116	
		Hedges‘g	0.04		0.46		0.41	
	90% 1-RM	Mean	94.91	104.71	65.61	61.19	78.86	80.91
		SD	62.79	95.46	29.87	27.19	43.16	34.97
		P	0.790		0.721		0.600	
		Hedges‘g	0.12		0.15		0.05	

Values are presented as mean ± SD; MVIC = maximal voluntary isometric contraction; VL = M. vastus lateralis; GM = M. gluteus maximus; RA = M. rectus abdominis; ES = M. erector spinae; TZ = M. trapezius. *Statistically significant difference

Another explanation for the greater ES and RA activation when the beginners performed the HPC with loads that ranged between 70 - 90% of 1RM might be related to an inefficient transition from the pulling motion to the catch during the clean which may have resulted in possible destabilization. Indeed, previous studies inducing instability through unstable loading (Lawrence and Carlson, 2015) or unstable surfaces (Saeterbakken and Fimland, 2013) within the squat movement have resulted in an increased abdominal muscle activation. Furthermore, there was no difference in ES and RA activation in the advanced and elite groups, which may be consistent with the findings of Wahl and Behm (Wahl and Behm, 2008), who reported that more experienced resistance-trained individuals do not easily experience increased muscle activation (e.g., lower abs) under instability.

During the HSP and HPS, the ES resulted in similar activation patterns as those seen for the HCP and HPC conditions. Specifically, greater ES activity was noted during the HPS for the elite group with all intensities ranging from 50 - 90% 1RM (g = 0.67 - 0.98), for the advanced group during the 50% 1RM condition (g = 0.62), and for the beginner group during the 90% 1RM condition (g = 0.27). A possible explanation for these findings may be related to the movement execution itself, where the barbell is accelerated more quickly to achieve a transition from the pull to catch that phase when compared to the HSP. Since the barbell load is anterior to the ES, a faster acceleration of the barbell would create the higher trunk flexion toques that are needed to be resisted throughout the movement and, therefore, potentially increase the normalized EMG activity in the ES (Aspe and Swinton, 2014). Partially contradicting this assumption was the significantly lower ES muscle activation during the second pulling motion of the snatch pull / clean pull compared when compared to the full snatch/clean observed by Häkkinen and Kauhanen (1986), although each pulling motion (i.e., first, transition, second pull) of the full clean/ snatch as well as power clean/snatch were performed at faster velocities than the various pulling derivatives. Since no kinematic data was collected for the present study, future studies could consider adding kinematic analysis alongside the EMG to investigate the snatch/ clean and snatch/ clean derivatives.

With regards to TZ, greater muscle activity was found in the HSP at 50% 1RM (g = 0.27) and in the HCP at 50% and at 70% 1RM with moderate to large effect sizes (g = 0.61 - 1.08), while the beginners displayed greater activation during the HPC when loads of 50% 1RM were used (g = 0.38). A particular function of the TZ muscle is to initiate the shrug motion (Netter, 2017). Since the primary emphasis of the pulling derivations is to pull the barbell to a higher degree than would be required for the clean of snatching process, where the function of TZ is paramount, this may account for the increased activity of the TZ. Nagao and Ishii (2021) observed that, with increasing weight, less TZ activation during the HPC occurred, likely due to a decrease in range of motion after the second pull. Since all groups utilized the same weight in each pull and clean/snatch comparison, it is possible that the described observation by Nagao and Ishii (2021) also applies to general weightlifting tasks. Except at lower intensities (<70% 1RM), the TZ does not appear to be a primary contributor to weightlifting movements that require the barbell to be caught when compared to the corresponding pulling movements.

When interpreting the results of the current study there are several limitations that must be considered. First, all three groups utilized loads corresponding to their individual 50, 70, 90%-1-RM in the HPS/HPC. However, the participants employed the identical load for the pulling derivatives, leaving unanswered whether technique-related barriers in less experienced lifters (e.g., beginner group) may have an impact on the actual 1RM in the specific exercise. Therefore, future studies should seek to establish a 1RM for each exercise evaluated (i.e., pulling and catching) as this might lead to different results (Suchomel et al., 2020).

Furthermore, the EMG output of each weightlifting condition exceeded the MVICs, an observation also noted in a previous study (Bautista et al., 2020). A likely underlying factor that contributed to partly extremely high NEMG values and a high variability may be due to the different contraction types and joint angles of the MVIC compared to the tested dynamic weightlifting exercises (Besomi et al., 2019). Consequently, it might be reasonable to adapt the normalization task to the respective contraction type and/or joint angle of the given exercise (i.e., isometric squat or isometric mid-thigh pull). Additionally, we analyzed muscle activation based on the percentage of MVIC. However, future studies should consider analyzing the EMG rate of change. In this way, muscle activity can be displayed throughout the execution of weightlifting derivatives and compared to other weightlifting derivatives as well as to the level of expertise. As our study is an exploratory analysis, future studies analyzing the EMG profile of weightlifting exercises at different levels of proficiency should consider larger sample sizes to reduce the variability in muscle activation.

Conclusion

In conclusion, by comparing the HPC/ HPS with the corresponding weightlifting derivatives, at higher intensities (i.e., >70% 1RM), similar muscle recruitment strategies appear to apply to the predominant muscles involved in triple extension, regardless of the three levels of weightlifting expertise.

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Key points

- There were no significant differences in vastus lateralis, trapezius or gluteus maximus muscle activity at higher intensities (> 70% 1RM) between the hang clean pull and the hang power clean or the hang snatch pull and the hang power snatch.
- Muscle activity in the stabilizing muscles (M. rectus abdominis, M. erector spinae) is significantly different between pulling and catching weightlifting derivatives.
- Regarding the level of expertise, there is no significant difference in muscle activity between beginners, advanced and elite weightlifters in any weightlifting derivative.

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