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Low Back Biomechanics during Repetitive Deadlifts: A Narrative Review

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Abstract

Background: Low back pain is a significant problem and one of the primary musculoskeletal conditions affecting active duty service members. There is a need to comprehensively assess the effects of repetitive deadlifts as a physical training modality on lumbar spine loads and the potential mechanisms involved in lumbosacral injuries among soldiers.

Purpose: The purpose of this narrative review is to summarize studies of low back biomechanics during repetitive deadlifts as used in training programs to improve lifting capacity.

Methods: PubMed and Google Scholar were searched for studies of lifting that met our inclusion and exclusion criteria. Only full text articles in English were included, and their reference lists were further searched.

Results: Heavy deadlifts can result in large compressive and shearing spinal loads that range from 5 – 18 kN, and 1.3 – 3.2 kN, respectively. No studies of lower back biomechanics during repetitive deadlifts were found. However, findings of studies that investigated lower back biomechanics during other types of repetitive lifting suggest a high likelihood for adverse changes in lower back biomechanics that can increase risk of lower back injury.

Conclusion: Repetitive deadlifting is increasingly implemented as a training modality to develop maximal lifting capacities required in military occupations. Further research is needed to understand the effects of such a training modality on lower back biomechanics and risk of injury.

Keywords

Deadlift; biomechanics; lumbar spine; injury prevention; repetitive lifting

1. Introduction

Low back pain is a significant problem and one of the primary musculoskeletal-related conditions affecting active duty service members (AFHSB, 2017). Approximately 34% of all outpatient visits and 54% of all hospitalization by active duty soldiers were visits

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Conflict of Interest
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related to vertebral column injuries, of which 78% of the outpatient visits and 55% of the hospitalizations were due to injuries in the lumbosacral region (APHC, 2016; Punnett et al., 1991). Low back pain, therefore, not only imposes considerable medical cost to the military, but also negatively affects training participation and deployment readiness.

The Army Combat Fitness Test (ACFT) is a new battery of physical tests that, in part, is aimed at reducing musculoskeletal disorders among service members by assuring that soldiers meet a minimum level of physical fitness (Nindl et al., 2017). These tests were designed to quantify a soldier's ability to perform soldiering tasks in a deployed environment (Foulis, Redmond, et al., 2017; Foulis, Sharp, et al., 2017). However, one of the ACFT events, the deadlift, places a considerable mechanical load on the lower back and may be associated with risk of low back injury, particularly because preparation for the deadlift test typically involves a repetitive lifting training program (Hales, 2010; Stand, 2009). Military unit physical fitness training takes place five times per week during the weekdays to improve warfighter performance (Field-Manual 7–22, 2020). However, increasing lifting capacity through periodization and programming to balance the natural effects of fatigue (Travis & Walters, 2020) is not well implemented/understood due to the array of challenges seen in the military environment from logistics to physiological diversity in the population (Wardle & Greeves, 2017). The premise behind the adaptation of repetitive deadlift training, particularly using a repetitions-to-failure (RTF) methodology, is its effectiveness in causing muscle hypertrophy (Dinyer et al., 2019; Haff & Triplett, 2016; Stefanaki et al., 2019). However, low back injuries are prevalent among deadlifters, specifically those training to increase their one-repetition maximum deadlift (Bengtsson et al., 2018; Calhoon & Fry, 1999). Considering the likely utilization of RTF training to pass a deadlift event requirement, especially with the popularization of CrossFit-type exercise training and given the associated injury risk for the lower back, it is important to gain a better understanding of the lower back biomechanics under repetitive deadlifting.

Repetitive loading of spinal tissues, particularly under high magnitude spinal loads, has been associated with high risk of fatigue failure in spinal tissues (Amin et al., 2020). It is hence important to verify that service members do not put themselves at high risk of low back injury in preparation to pass the deadlift event of the ACFT. Therefore, the purpose of this narrative review was to summarize studies of low back biomechanics during repetitive deadlift. Such a summary of scientific evidence will highlight the level of risk for low back injury that is associated with repetitive deadlift training. It can further reveal the gaps in the existing literature concerning the impact of repetitive deadlift training on low back biomechanics and the associated risk of low back injuries.

2. Methods

A review of the literature was conducted by using PubMed and Google Scholar search engines for English language articles until December 2019. Two sets of key word searches were used: [(deadlift) AND ((biomechanics) OR (spine))] and [((repetitive lifting) OR (box lift) OR (deadlift)) AND (fatigue) AND ((biomechanics) OR (spine))]. Inclusion and exclusion criteria are indicated in Table 1. Only full text articles were included, and their reference lists and “related articles” in Google Scholar were further searched to find relevant sources that were not identified during database searches.

3. Results

An initial search of the key words yielded 108 articles, which was narrowed down using the exclusion and inclusion criteria (Table 1), leading to the final 17 articles (Figure 1). The first author reviewed all potential articles starting with key words in titles, followed by reading abstracts, and retrieving full text articles. The final decision on the inclusion of articles was made by two of the authors (VR and BB). All of the identified deadlift studies involved one to three repetitions of a deadlift with varying relative loads. More specifically, no study on deadlift RTF was found that analyzed any aspect of lower back biomechanics. However, eight studies reported changes in different aspects of lower back biomechanics under repetitive lifting techniques other than deadlift that have also been included in this review, which were only included if they were symmetrical lifts from the floor to waist level. Accordingly, the findings of reviewed studies are presented in two sections; section one is focused on biomechanics of the lower back under a typical deadlift task, and section two is focused on changes in biomechanics of the lower back during repetitive lifting other than deadlifting. The Appendix summarizes each reviewed article in terms of methodology and relevant findings.

Lower back kinetics during deadlifting has been characterized using measures of net moment, and compressive and shearing forces at the lower portion of the lumbar spine, and these outcomes were found to be dependent on the magnitude of lifted load (e.g., a given percent of maximum load that can be lifted in one repetition, or 1RM), bar type (e.g., straight bar, low handle hexagonal bar, and high-handle hexagonal bar), and gender. Swinton et al. (2011) assessed the L5/S1 net moments over a range of relative loads (10% 1RM to 80% 1RM) between the straight bar deadlift (mean 1RM: 244.5 ± 39.5 kg) and low handle hexagonal bar deadlift (mean 1RM: 265.0 ± 41.8 kg). When deadlifting with the straight bar, they found that peak lumbar net moment increased from 245 ± 46.3 Nm at 10% 1RM, to 446.9 ± 73.9 Nm at 80% 1RM. When lifting with the hexagonal bar, peak lumbar net moment at 10% 1RM was 209 ± 48.6 Nm and increased to 409.2 ± 73.9 Nm at 80% 1RM. Significant differences in net moments between the two bar types were found only within the 10% to 60% 1RM range.

Cholewicki et al. (1991) found that the L4/5 net moments ranged from 254.6 to 460.1 Nm among women, and 445 to 1071 Nm among men, when performing a 1RM deadlift (women mean 1RM: 145.8 ± 18.4 kg; men mean 1RM; 256.7 ± 29.9 kg) with the straight bar. While performing a 75% 1RM deadlift (mean 1RM: 107.0 ± 40.6 kg), Eltoukhy et al. (2016) reported lumbar shear forces to be greatest at the L5 level of the lumbar spine, with a peak value of 1,903 ± 936 N for generally fit males, while Cholewicki et al. (1991) found shear forces ranged from 2,150 N to 3,276 N among competitive male lifters, and from 1,363 N to 1,778 N among competitive female lifters. Eltoukhy et al. (2016) reported peak axial compressive forces of 7,963 ± 2,784 N, which occurred at the L5 level among male lifters during the final phase of the lift (standing). The L4/5 compressive forces at the time of lift off was reported by Cholewicki et al. (1991) to range from 7,942 to 18,449 N and from 5,090 to 8,018 N in male and female participants, respectively, when performing a 1RM.

While Eltoukhy et al. (2016) recruited generally fit males with lower 1RM (men: 107 ± 40.6 kg), the study population in the Cholewicki et al. (1991) study consisted of competitors during a Powerlifting Competition who had much higher 1RM. This difference in study samples suggests that the differences in the magnitudes of lumbar loading can be attributed in part to the loads lifted. Contrasting the findings of Cholewicki et al. (1991) and other earlier studies of spinal loads during lifting, Eltoukhy et al. (2016) reported the maximum compressive force to occur at the standing position as opposed to the time of lift off. Such contradictory results are likely due to the absence of muscles in the biomechanical model used by the latter group to estimate spinal loads. In the absence of muscle forces, the major contributor to spinal load is gravitational force, which is more directionally aligned with and tends to contribute more to compressive spinal force in upright standing versus a forward bent posture.

Lower back kinematics during the deadlift has generally been characterized using a measure of trunk posture/rotation and has been investigated in terms of the effects of lifting styles and bar types. Escamilla et al. (2000) and McGuigan and Wilson (1996) found significant differences between trunk angles at lift off between the sumo style and the conventional style of deadlifts while performing a 1RM. A sumo style lift places the trunk in a more vertical position (ranging from 57° to 65.5°), while in conventional style deadlifts the trunk is in a more horizontal position (ranged from 66.7° to 73.4°). Swinton et al. (2011) found no differences in maximum trunk flexion during the straight bar deadlift (55.2 ± 9.8°) versus the low handle hexagonal bar deadlift (57.9 ± 9.8°). It should be mentioned that all of aforementioned studies recruited skilled competitive powerlifters, similar to Cholewicki et al. (1991).

Activity of the trunk muscles during heavy deadlifts has also been investigated. In general, trunk muscle activity was not found to be affected by lifting style and bar type. According to Escamilla et al. (2002), there were no differences in muscle activation at the L3 and the T12 paraspinals when performing three repetitions of a 12RM deadlift between sumo and conventional styles. Similarly, Camara et al. (2016) found that erector spinae muscle activities were similar during the concentric phase (lifting phase) of a low handle hexagonal bar deadlift and a conventional straight bar deadlift.

Alterations in biomechanics of the lumbar region during repetitive lifting have been reported in work-site settings. Unlike the deadlift, which requires lifting extremely heavy weights, studies in the occupational setting were performed that required lifting 10 – 13 kg boxes from the floor to waist level (Bonato et al., 2003; Boocock et al., 2015, 2019; Dolan & Adams, 1998; Ebenbichler et al., 2002; Potvin & Norman, 1993; Sparto et al., 1997a, 1997b). Although substantially different in the magnitude of the load compared to deadlifts, results of these studies highlight changes in biomechanics of the lumbar spine due to fatiguing effects of repetitive lifting (see the following paragraphs) – an effect that is likely to be much larger for repetitive heavy deadlift (Gallagher & Heberger, 2013). Repetitive lifting is further discussed in the following paragraphs under two conditions: a self-selected pace and a pre-selected pace (metronome).

Similar to studies of the deadlift, lumbar kinetics have been characterized using measures of net moment, and compressive and shearing forces at the lower portion of the lumbar spine. Dolan and Adams (1998) used a self-selected pace for a fatiguing lifting task (100 lifts with 10 kg weight) and found a decrease in compressive forces at the lumbar spine from 3,588 ± 823 N to 3,190 ± 1139 N. They also found an increase in passive bending moments from 20% to 27.1% of the elastic limit of the osteo-ligamentous lumbar spine, and that the net moment acting on the L5/S1 significantly decreased by 11.9%. Sparto et al. (1997b) conducted a maximal-lifting rate protocol that involved lifting 25% of maximal iso-inertial lifting capacity as many times as possible and compared kinetics during the initial and final three repetitions. Although lifting frequency remained unchanged (39 lifts/minute), they reported a significant decrease in average lifting force (i.e., from 254 ± 94 N to 205 ± 31 N) and adecrease in lumbar net moment (i.e., from 188 ± 39 Nm to 159 ± 24 Nm).

Boocock et al. (2019) explored repetitive lifting to exhaustion of a 13 kg box at a pre-selected rate of 10 lifts/minute for 20 minutes, finding an increase in passive bending moment of the L5/S1 from 46.2 Nm to 95.8 Nm between the first and last minutes of the task. Although passive bending moments did increase, they reported no significant change in the L5/S1 net moment. During a faster paced repetitive lifting task (i.e. 20 lifts/minute for 20 minutes), these same authors reported larger differences in the L5/S1 net moment between younger versus older (179.6 Nm versus 153.1 Nm) manual material handlers throughout the task. Bonato et al. (2003) also explored the effects of repetitive lifting to fatigue while performing 12 lifts/minute for 4.5 minutes of a 13 kg box on lower back kinetics. They reported a decrease in net moment, an increase in peak compressive forces, and an increase in peak absolute shear force at L4/5 at the time of maximum vertical box acceleration. Using the same load and rate of lifting as the Bonato et al. (2003) study, Ebenbichler et al. (2002) found contradictory results, specifically a significant increase in the L4/5 net moment during the lifting task. Differing methodologies of data collection and analysis may have contributed to the conflicting results regarding lumbar net moments and compressive forces in studies that used a pre-selected pace. Dolan and Adams (1998) used a 3SPACE ISOTRAK to collect lumbar spine kinematics and obtained electromyography (EMG) of the erector spinae, and estimated compressive force acting on the lumbar spine by dividing the peak extensor moment by the equivalent level arm for the back muscles. Ebenbichler et al. (2002), Bonato et al. (2003), and Boocock et al. (2019), in contrast, all implemented an inverse dynamics approach to estimate lumbar kinetics using kinematic data along with ground reaction forces each collected by a different systems.

Kinematic alterations in the lumbar region have been reported for repetitive occupational lifting using trunk, lumbar, and lumbosacral angles. Boocock et al. (2019) compared kinematic variables between the first minute and the final minute of repetitive lifting to failure. They found that percent lumbosacral and trunk flexion significantly increased from 71.7% to 98.4% and 63.9% to 87.7%, respectively. In a similar methodological study, Boocock et al. (2015) explored age-related differences among manual material handlers. Changes in lumbosacral flexion were found to be influenced by participant age, such that older participants started with a greater percent lumbosacral flexion compared to younger participants, but end up completing the task at a lower percent of lumbosacral flexion (98.5% vs 81.6%). Consistent with the results of Boocock et al. (2019) and independent of age differences, lumbosacral flexion of participants was found to increase from the first minute to the final minute of repetitive lifting. Bonato et al. (2003) reported an increase in trunk range of motion and no changes in postural index during repetitive lifting. They also reported a trend over time, where those that started with a stoop lift changed to a more squat lift. Conversely, Ebenbichler et al. (2002) found a transition from a squat lift to a stooped lifting style while utilizing the same repetitive lifting task as Bonato et al. (2003). Dolan and Adams (1998) also found a significant increase in percent peak lumbar flexion over time, which increased from 83.3% to 90.4%. The maximal-lifting rate protocol (as many lifts as possible) use by Sparto et al. (1997b) induced an increase in peak lumbar spine flexion (35 ± 16° to 38 ± 16°) over the duration of the lifting protocol, which equates to approximately 34 ± 23% of the osteo-ligamentous elastic limit. Similar to Ebenbichler et al. (2002), Sparto et al. (1997a) found a postural strategy shift from a squat lift to a more stooped lifting style. Sparto et al. (1997a) also found an increases in both the average lumbar spine phase angle (68 ± 11° to 77 ± 13°) and the average hip-lumbar spine relative phase angle (14 ± 12° to 22 ± 18°) were reported during a repetitive lifting task to fatigue. But, frontal- and transverse-plane motions of the trunk were not affected by fatigue, showing sagittal plane motion was mostly affected by the symmetrical lifting task.

Potential muscle fatigue in the erector spinae during repetitive lifting is typically measured via changes in EMG median frequency. Boocock et al. (2015) found EMG median frequency intercepts decreased pre- to post-repetitive lifting in young and old individuals. However, within the young individuals there was a greater decrease in the lower erector spinae median frequency intercept (12% decrease) compared to the upper erector spinae (9.4% decrease). Dolan and Adams (1998) also examing pre- and post- isometric strength testing of the lumbar spine and found significant decreases in median frequency intercept and gradient at L3, indicating that the dynamic task caused measurable fatigue. Similarly, Potvin and Norman (1993) found a significant decrease in mean power frequency in the lumbar muscles during a 20-min lifting session and in the thoracic muscles during a 2-hour lifting session.

4. Discussion

The purpose of this literature review was to summarize earlier evidence of lower back biomechanics during repetitive deadlifts in the sagittal plane. Deadlifting a load representing 75 to 100% of an individual’s maximum lifting capacity, particularly among competitive lifters, imposed very large mechanical demands on the lower back. The “starting” or “lift off” was reported to be the lifting position associated with the greatest mechanical demand on the lumbar spine during the deadlift. Specifically, the maximum compressive forces reached 18 kN among men and 8 kN among women, and the maximum shearing forces reached 3 kN among men and 2 kN among women (Cholewicki et al., 1991; Eltoukhy et al., 2016). While several research groups have investigated different aspects of lower back biomechanics during one to three cycles of deadlifting, we could not identify any earlier studies of lower back biomechanics during repetitive deadlifts.

Shearing and compressive forces contribute to intervertebral disk pathologies including disk protrusions and prolapse (Adams & Dolan, 2005; Gordon et al., 1991; Seidler et al., 2003). Reported injury thresholds for lumbar spine segments range between 5 – 10 kN and between 1 – 2 kN for compressive and shearing forces, respectively (Gallagher & Marras, 2012; Schmidt et al., 2012). Gallagher and Marras (2012) reported a maximum shear limit of 1,000 N for occasional exposure to shear loading based on ≤ 100 lifts/day; yet as was described in the results section, this maximum shear limit is easily exceeded during the deadlift, even with appropriate techniques (Cholewicki et al., 1991; Eltoukhy et al., 2016). Therefore, it appears that repetitive deadlifts, while having physiological benefits (Stand, 2009), are associated with a high risk of spinal injury particularly if performed under high repetitions. Additionally, because the deadlift puts a high demand on lower back musculature (Cholewicki et al., 1991; Gotshalk, 1984), fatigue-induced changes in posture can further increase spinal loads and the subsequent risk of lower back injury (Dolan & Adams, 1998). Specifically, fatigue-induced increases in trunk flexion during repetitive heavy lifting will likely put larger mechanical demands on internal trunk tissues (muscles and ligament) to assure spine equilibrium and stability, ultimately leading to higher spinal loads.

Only two studies were found that reported spinal loads during the deadlift (Cholewicki et al., 1991; Eltoukhy et al., 2016). However, the spinal loads reported by Eltoukhy et al. (2016) were actually net joint reaction forces and not spinal loads; this was because the model used in Eltoukhy et al (2016) did not include muscles, and as such the predictions represented reaction forces due to external loads. Muscle contributions to spinal loads comprise up to 90% of compression forces experienced at the lower portion of the lumbar spine (i.e., L5-S1; Arjmand & Shirazi-Adl, 2005; McGill & Norman, 1986). Therefore, neglecting muscle contributions could result in a significant underestimation of spine compressive force. On the other hand, the Cholewicki et al. (1991) study, though accounting for muscle contributions, used a very simple single-muscle model. Compared to multi-muscle models, single-muscle models of the spine have been suggested to underestimate spinal compressive and shearing forces by 45% and 70%, respectively (Granata & Marras, 1995). However, the moment arm and orientation of the single-muscle model in Cholewicki et al. (1991) – 6 cm moment arm and 5° posterior angles – were selected to best replicate the estimation of compressive spinal loads by a 50-muscle model of McGill and Norman (1986) for a range of lifting loads and techniques (stoop vs squat). Nevertheless, there is a strong need for the application of a more robust computational models to quantify spinal loads during the deadlift.

Reported changes in kinematics of lower back during repetitive lifting were generally consistent and included increases in lumbar flexion (Bonato et al., 2003; Boocock et al., 2019; Sparto et al., 1997a). One the other hand, reported changes in the net, passive, and active moments at the lower back (i.e., measures of lower back kinetics) were contradictory (Bonato et al., 2003; Boocock et al., 2015, 2019; Dolan & Adams, 1998; Sparto et al., 1997b); such differences might have been due in part to the differences in repetitive lifting protocols used (details can be found in Appendix). Future research is thus required to not only determine potential changes in kinematics and kinetics of the spine during repetitive heavy lifting or deadlift, but also to verify potential changes in spinal loads during repetitive lifting of lighter loads.

Although the physiological effects of repetitive deadlifts have been capitalized upon by rehabilitation specialists and strength coaches alike to elicit muscle adaptations (Dinyer et al., 2019), repetitive lifting has been shown to fatigue the lumbar paraspinal musculature (Hart et al., 2006; Lattanizio et al., 1997; Trafimow et al., 1993). Lumbar muscle fatigue has been linked to a deterioration in postural control and increase in injury risk in occupational settings (Lin et al., 2012; Punnett et al., 1991). However, the effects of lumbar muscle fatigue during repetitive deadlifting on lower back biomechanics are not known. The body’s ability to maintain postural control and stability during repetitive deadlifting is a fundamental component of injury prevention that should be accounted for when implementing training regimens such as repetitive deadlifting.

5. Conclusions and practical implications

Deadlift training programs that seek to maximize strength and hypertrophy via muscle failure protocols are promoted due to their known physiological benefits. Despite the significant causal role of lower back loading (or biomechanical loading) in musculoskeletal injuries, there is very limited knowledge related to the biomechanical impacts of deadlifting training on the lower back and the associated risk of injury. Addressing such a knowledge gap is critical, particularly when lifting capacity, quantified using the deadlift, is a requirement for military service retention and recruitment for other occupations. In the absence of such knowledge, trainers and practitioners should be cautious in promoting a training protocol that is likely to put the spinal column at extremely high risk of injury. Furthermore, future research, aimed at evaluating lower back biomechanics during repetitive deadlifts with an emphasis on accurate quantification of spinal loads, can be of value to practitioners in the prevention of low back injuries during training aimed at passing the ACFT deadlift test. Finally, the immergence of exoskeletons (Antwi-Afari et al., 2021) is likely to alter the physical demands of military tasks for service members, changes that should be accounted for in the design of physical readiness tests like the ACFT.

Based on the results of the present review, we offer the following key points and suggestions:

- The physiological benefits of repetitive deadlifting training may be overshadowed by the associated risk of lower back injury during this type of training.
- While performing 75 to 100% of individual 1RM, maximum compressive spinal forces can reach 18 kN among men and 8 kN among women, and maximum shearing spinal forces can reach 3 kN among men and 2 kN among women. These values are concerning given reported injury thresholds for the lumbar spine segments that range between 5 – 10 kN and 1 – 2 kN, for compressive and shearing forces, respectively.
- While more research is needed to characterize the biomechanical impacts of repetitive deadlifts on the spine, trainers and practitioners should be aware that

training protocols or physical readiness tests that involve heavy deadlifts expose the spinal column to an extremely high risk of injury.

- Knowledge of spinal loads and muscle forces during repetitive deadlifting, specifically with changes in posture, may inform the design of training modalities involving repetitive deadlift that help minimize the risk of low back injuries.

Appendix.: List of reviewed studies.

Study (author, year)	Demographics	Lift Type	Lift Weight	Instrumentation
Eltoukhy et al., 2016	• 5 (M) • Weight lifting experience	• Conventional deadlift • One cycle defined as lifting the straight bar from the floor to full standing	• 75% of 1RM: 107 ±40.6 kg	• 10 motion capt cameras • Four Kistler Fo
Cholewicki et al., 1991	• 13 (F) and 44 (M) • Powerlifting competitors	• Conventional versus Sumo deadlift • One cycle defined as lifting the straight bar from the floor to full standing	• Female 1RM: 145.8 ± 18.4 kg • Male 1RM: 256.7 ±29.9 kg	• Video recordin plane view at 6
McGuigan et al., 1996	• 29 (M) • Sumo style n = 10; conventional style n = 19 • Powerlifting competitors	• Sumo versus conventional deadlift • One cycle defined as lifting the straight bar from the floor to full standing – Reps subdivided into 3 phases, 1) lift off, 2) knee pass, 3) lift complete	• Sumo deadlift 1RM: 218 ±32.1 kg • Conventional deadlift 1RM: 215 ±33.2 kg	• Video recordin plane view at 5
Escamilla et al., 2000	• 24 (M) • Sumo style n = 12; conventional style n = 12 • Powerlifting competitors (>40 years old)	• Sumo versus conventional deadlift • One cycle defined as lifting the straight bar from the floor to full standing – Reps subdivided into 3 phases, 1) lift off (LO), 2) knee pass (KP), 3) lift	• Sumo deadlift 1RM: 214.6 ±33.2 kg • Conventional deadlift 1RM: 221.6 ±33.8 kg	• Two synchroni cameras at 60 F

Study (author, year)	Demographics	Lift Type	Lift Weight	Instrumentation
		complete (LC)		
Camara et al., 2016	• 20 (M) • Deadlifting experience	• Conventional versus low-handle hexagonal bar deadlift • One cycle included both concentric (floor to standing) and eccentric (standing to floor) phase of lift	• Hexbar deadlift 1RM: 181.1 ±27.6 kg • Conventional deadlift 1RM: 181.4 ±27.3 kg	• Velocity transd • 1 AMTI force p • EMG channel l – bice fem – vast late – erec (lon • EMG was norm with 1RM conc phase of conve for both lifts
Swinton et al., 2011	• 19 (M) • Scottish powerlifting association members	• Conventional versus low-handle hexbar deadlift • One cycle defined as lifting the bar from the floor to full standing	• Straight bar (SB) 1RM: 244.5 ±39.5 kg • Hexbar 1RM: 265.0 ± 41.8 kg	• 7 motion captu at 200 Hz • 2 Kistler force 1200 Hz
Escamilla et al., 2001	• 13 (M) • Division I college football players, experience with sumo and conventional deadlifts	• Conventional versus sumo deadlift, with and without a belt • One cycle defined as both ascending and descending phase of the lift in a slow continuous manner – Ascending and descending phases were divided into three phases each based on knee angle from 90 to 0deg (0deg being full ext.): 90–61 deg; 60–31 deg; 30–1 deg	• 12RM: 123.1 ± 18.6kg • Same 12RM weight was used for both deadlift styles; 12RM estimate from current football training regimen	• 6 motion captu at 60 Hz • 16 channel EM Hz; muscles in – rect – vast late – vast mec – bice fem – sem tenc mer – late gast – mec gast – tibi ante – hip

Study (author, year)	Demographics	Lift Type	Lift Weight	Instrumentation
				– glut max – L3 para – T12 para – mid trap – rect abd – exte obli • MVIC was con each muscle gr EMG normaliz
Lockie et al., 2017	• 21 (M) and 10 (F) • Strength training experience	• Conventional versus high-handle hexbar deadlift • Once cycle was defined as lifting the bar from the floor to full standing	• Hexbar deadlift 1RM: 154.5 ±45.3 kg • Conventional deadlift 1RM: 134.7 ±40.6 kg	• Linear position transducer • Testing perforn day
Lake et al., 2017	• 11 (M) • Proficient in both deadlift variations	• Conventional versus low-handle hexbar deadlift • Once cycle was defined as lifting the bar from the floor to full standing	• Hexbar deadlift 1RM: 183 ±22 kg • Conventional deadlift 1RM: 194 ± 20 kg	• Linear position transducer • Testing perforn days
Boocock et al., 2019	• 36 (M) • No manual material handling experience • Biofeedback group n = 18; Non-biofeedback group n = 18	• Box with handles, where handles are 32cm above the floor level • Once cycle was defined as lifting the box from the floor to full standing and back down to floor	• A 13kg box with handles, lifted and lowered at 10 lifts/ minute, encouraged to continue as long as possible, but stopped at 20 minutes	• 9 motion captu at 120 Hz • Two AMTI forc at 1200Hz • Two IMUs plac L1 and S1 that high pitched to 80% of max lun flexion was exc • Lumbosacral p feedback was g inertial sensors an audible high tone when luml

Study (author, year)	Demographics	Lift Type	Lift Weight	Instrumentation
			• Metronome used for lift frequency	flexion reached max flexion
Boocock et al., 2015	• 28 (M) – 14 young (mean age 24.4 years) and 14 older (mean age 47.2 years) • No manual material handling experience	• Box with handles, where handles are 32cm above the floor level • Once cycle was defined as lifting the box from the floor to full standing and back down to floor	• A 13kg box with handles, lifted and lowered at 10 lifts/ minute, encouraged to continue as long as possible, but stopped at 20 minutes • Metronome used for lift frequency	• 9 motion captu at 60 Hz • 2 AMTI force p 1200Hz • EMG channels over upper and erector spinae r
Dolan & Adams, 1998	• 6 (M) and 9 (F)	• Disc lifted from floor to waist height shelf • Once cycle was defined as lifting the disc from the floor to full standing and back down to floor	• 10 kg weight-lifter's disc lifted 100 times • Lifts performed at self-selected posture and instructed to try to maintain a constant self-selected pace	• 3-space Isotrak L1 and S1 to m lumbar ROM a • EMG of erecto T10 and L3 lev • Fatigue measur median frequer immediately be after the lift
Ebenbichler et al., 2002	• 14 (M)	• Box lifted from knee height and to full standing • Once cycle was defined as lifting the box from the floor to full standing and back down to floor	• 13kg box repetitively lifted over 4.5 minutes at a rate of 12 lifts/m in • Tested 3 times over 2 days, with 30 min rests	• Two camera ste photogrammetr at 100 Hz • EMG channels over 14 muscle contralateral pa

Study (author, year)	Demographics	Lift Type	Lift Weight	Instrumentation
			between all tests (both static and dynamic)	
Bonato et al., 2003	• 14 (M) • Involved in regular physical • fitness training	• Box lifted from lower shelf at mid-shank height to upper shelf at waist height • Once cycle was defined as lifting from the floor to full standing	• 13kg box repetitively lifted at 12 lifts/min for 4.5 minutes • Metronome used for lift frequency	• EMG channels sites (7 contrala pairs) – para at L T10 – upp trap – glut max – vast late – bice fem • Two camera ste photogrammetr at 100 Hz • Five-sec maxin lifting task was before and afte lifting task to m change in stren EMG fatigue in
Potvin & Norman, 1993	• 8 (M)	• Box lift with handles • Lift from table to floor height (table height = 0.75 m; floor to handle height = 0.15 m) • Once cycle defined as lifting from table to floor height and back to table	• Load mass was based on individual maximum trunk extensor moment • 2-hour lift protocol pace was 6 lifts/min • 20-min lift protocol pace was 8 lifts/min	• EMG surface e on both left and sides included: – Lun erec – Tho erec – Ext obli mus
Sparto et al., 1997	• 12 (M)	• LIDOLift lifting simulator • Once cycle was defined as lifting from	• Repetitive lifting with load equal to 25% of maximal iso-inertial	• Lumbar Motion for triaxial lum motion • Hip Monitor us biaxial hip mot

Study (author, year)	**Demographics**	**Lift Type**	**Lift Weight**	**Instrumentation**
		the floor to full standing	lifting capacity • Self-selected pace	• One video cam sagittal plane f ankle, knee, sh and elbow • One Bertec for • Heart rate mon to track exertio terminated if h 180 bpm
Sparto et al., 1997	• 12 (M)	• LIDOLift lifting simulator • Once cycle was defined as lifting from the floor to full standing	• Repetitive lifting with load equal to 25% of maximal iso-inertial lifting capacity • Self-selected pace	• Lumbar Motio for triaxial lum motion • Hip Monitor us biaxial hip mot • One video cam sagittal plane f ankle, knee, sh and elbow • One Bertec for • Heart rate mon to track exertio terminated if h 180 bpm

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OCCUPATIONAL APPLICATIONS

Heavy deadlifting is used as a screening tool or training protocol for recruitment and retention in physically-demanding occupations, especially in the military. Spinal loads experienced during heavy deadlifts, particularly shearing forces, are well above recommended thresholds for lumbar spine injury in occupational settings. Although members of the noted occupation likely have stronger musculoskeletal systems compared to the general population, experiencing shearing forces that are 2 to 4 times larger than the threshold of injury, particularly under repetitive deadlift, may transform a screening tool or training protocol to an occupationally-harmful physical activity.

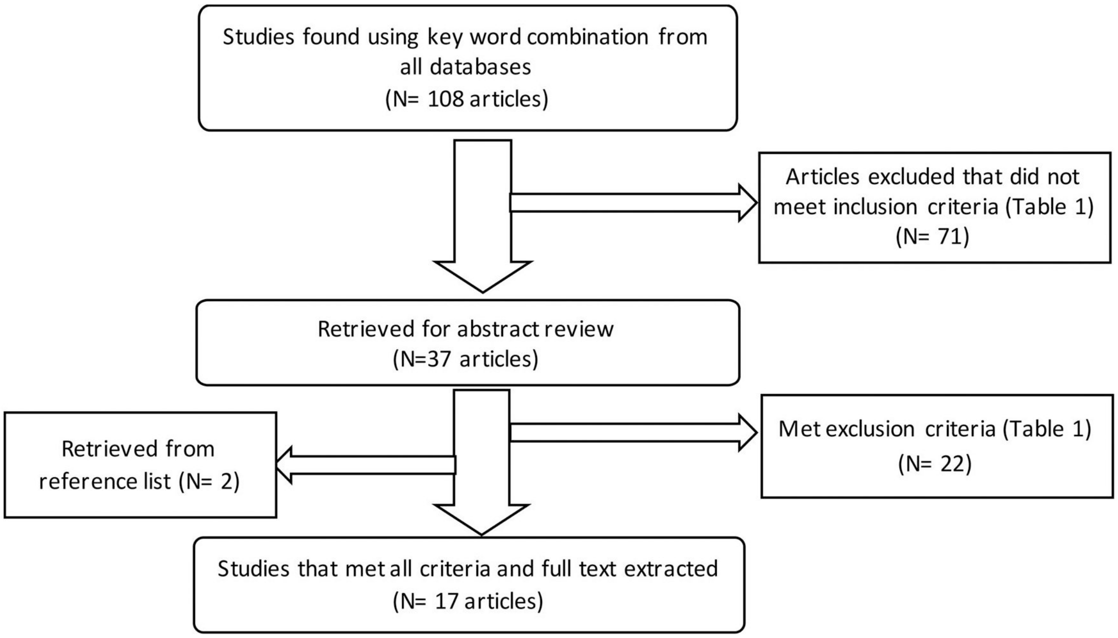

Figure 1.

Study exclusion flow diagram.

Table 1.

Inclusion and exclusion criteria for literature search.

Inclusion criteria:

1. Published in a peer reviewed journal, in English
2. Instrumentation identified using 2D/3D motion capture, force plates, or electromyography
3. Performing the deadlift with a conventional or hexagonal bar
4. Repetitive lifting with the purpose to induce fatigue
5. Lifting from floor to mid-thigh/waist height

Exclusion criteria:

1. Stooped lifting or lifting from a constrained position
2. Asymmetrical lift