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Research Article

An Innovative Design of Olympic Weightlifting Competition Plates Utilizing Negative Pressure Adhesion to Enhance Mechanical Stability and Athletic Performance

Ali Mohsen Ali Ali Aboel-Nour*, Mohamed Sadat Mohamed Ibrahim Khyal

Department of Combat and Individual Sports, Suez Canal University, Ismailia, Egypt

Abstract

This study proposes an innovative competition plate design for Olympic weightlifting based on negative-pressure adhesion technology. A 0.5 cm flexible sealing lip is integrated into the plate surface to create a passive vacuum when the collar is tightened. This vacuum generates an atmospheric clamping force that firmly bonds adjacent plates, eliminating micro-oscillations and unwanted plate movement during the Snatch and Clean & Jerk. The proposed design enhances mechanical stability, improves force transmission efficiency, maintains barbell trajectory, and reduces injury risk associated with load instability. In addition, it minimizes equipment noise and may improve competition workflow by reducing loading and unloading time. The study highlights the potential of vacuum-assisted plate fixation as a novel engineering solution to improve performance, safety, and reliability in Olympic weightlifting. During the 2026 World Youth Weightlifting Championships in Ismailia, Egypt, a critical mechanical limitation was observed regarding the stability of standard IWF-approved competition plates. Despite the tight application of standard collars, microscopic gaps between loading plates often result in micro-oscillations and independent rotational inertia during explosive lifts (the Snatch and Clean & Jerk). This paper introduces a novel structural modification: a 0.5 cm integrated flexible elastomeric sealing lip embedded on the inner face of the competition plate. By utilizing the mechanical force of the collar to compress this lip, air is evacuated from the internal chamber, generating a sustainable passive vacuum (negative pressure). This vacuum increases self-adhesion via atmospheric force, eliminating micro-oscillations, preserving barbell trajectory, and maximizing force transmission.

Keywords

Olympic Weightlifting, Negative Pressure Adhesion, Competition Plates, Mechanical Stability, Force Transmission

1. Introduction and Research Problem

In elite Olympic weightlifting, the mechanical rigidity and structural integrity of the barbell-load system are paramount to achieving optimal kinetic efficiency. Any technical deviation or energy dissipation within the apparatus can significantly alter the lifter's motor pathway and force profile. During field observations conducted by the researcher at the 2026 World Youth Weightlifting Championships in Ismailia, a recurring biomechanical and equipment-related phenomenon

*Correspondence: Ali Mohsen Ali Ali Aboel-Nour (dr.aliaboelnour.sport@suez.edu.eg)

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was identified: the incomplete structural fusion between adjacent competition plates loaded on the barbell sleeves.

Although standard regulations mandate the use of high-precision friction collars to secure the weights, a micro-metrical separation remains between the smooth, rigid vertical faces of successive plates. During the execution of explosive, high-acceleration multi-joint movements—specifically the Snatch and the Clean & Jerk—the bar undergoes severe elastic bending and rapid deceleration phases. These forces overcome the localized friction provided by the collars, causing microscopic displacements and independent axial vibrations, known as micro-oscillations.

The consequences of these micro-oscillations are threefold:

1) *Dissipation of Kinetic Energy:* The forces generated by the athlete's triple extension are not transmitted through a completely rigid structure, resulting in a loss of peak power.
2) *Disruption of Barbell Trajectory:* The independent movement of the plates dynamically shifts the system's center of mass, forcing sudden real-time neuromuscular corrections.
3) *Increased Injury Risk:* Micro-instabilities subject the stabilizing joints (shoulders, wrists, and the lumbar spine) to unanticipated multi-planar torque, escalating the risk of acute or chronic strain.

2. The Proposed Solution and Engineering Design

To eliminate this mechanical deficiency without violating the International Weightlifting Federation (IWF) regulations regarding external weight dimensions and mass tolerances, this research proposes a self-contained structural adaptation based on the physical law of Negative Pressure Adhesion (Vacuum-Induced Cohesion).

The engineering modification consists of embedding a precise, raised, flexible polymeric rim—termed an Integrated Sealing Lip—directly onto one of the lateral faces of the competition plate. This lip is engineered from a high-density polyurethane compound matching the official IWF color code of the plate (e.g., red for 25 kg plates). It features a calibrated height of exactly 0.5 cm.

Negative pressure adhesion, commonly operationalized through suction cup mechanisms, relies fundamentally on the pressure differential created between the sealed atmospheric enclosure and the external ambient pressure [2]. The generated adhesive force is directly proportional to the contact surface area and the magnitude of the pressure gradient, which can be dynamically sustained provided the material integrity prevents micro-leakage along the interface [1, 21].

Drotlef, Dayan, and Sitti (2019) indicated the potential for developing innovative bio-inspired adhesion systems through the design of composite microfibers made of flexible materials with mushroom-shaped tips and a thin, compliant terminal layer of pressure-sensitive adhesive. This design improved load distribution and enhanced adhesion performance on smooth surfaces. The developed structure achieved an adhesion strength of approximately 300 kPa, demonstrated high durability and repeatable adhesion, and outperformed conventional single-component microfibers by approximately 35 times [6].

Mechanical clearance between a shaft and its housing inevitably introduces structural play, which under dynamic loading accelerates wear and induces localized stress concentrations. In barbell systems, the minor tolerance gaps between the sleeve and the plate inner ring create parasitic vibrations during rapid acceleration phases. Eliminating this structural play through active surface-to-surface adhesion ensures that the multi-component assembly behaves as a rigid, monolithic body, thereby suppressing harmonic oscillations that compromise mechanical stability [10, 13].

Any lateral displacement of mass along the horizontal axis of a loaded barbell alters the system's moment of inertia, generating secondary rotational torques that the lifter must actively counteract [16, 25]. The maintenance of a fixed center of mass relative to the sagittal plane is critical; even millimeter-scale shifting of plates introduces asymmetrical load distributions [18]. Securing the mass rigidly close to the sleeve shoulder minimizes axial drift and reduces the risk of acute musculoskeletal strain caused by sudden kinematic corrections [20].

The execution of the Olympic lifts—specifically the snatch and the clean and jerk—demands an instantaneous, unattenuated transmission of ground reaction forces through the kinetic chain to the barbell [4, 12]. When the interface between the lifting bar and the external load is completely stabilized, the kinetic energy generated during the explosive second pull is transferred with maximal efficiency [7, 8]. Eliminating the micro-slippage of plates ensures that mechanical power is not dissipated as friction or rotational kinetic energy within the plate assembly itself.

According to the constrained action hypothesis, an external focus of attention—focusing on the movement of the implement rather than internal bodily mechanics—significantly enhances motor performance and movement economy [23, 24]. Auditory distractions, such as the clattering of loose weight plates, or psychological anxiety regarding equipment failure, can force an athlete into an internal attentional focus [3, 9]. A perceptually silent and physically secure barbell setup stabilizes the athlete's cognitive state, allowing for optimal motor unit recruitment and automated execution of complex motor patterns [14].

The operational efficiency of elite weightlifting competitions heavily depends on the speed and precision of load transitions between successive attempts. The traditional requirement of manually securing spring or tournament collars introduces systematic delays and increases the physical burden on loaders within the tightly regulated time windows. Integrating

self-adhering plate mechanisms inherently mitigates the logistical necessity of external fastening components, thereby streamlining the competition timeline and minimizing human error in barbell loading [11].

Shigley and Mischke (2020) emphasized the importance of applying fundamental mechanical engineering principles in machine design to ensure structural strength, mechanical stability, reliability, and operational efficiency. The design process requires careful consideration of material properties, applied forces, stress distribution, deformation, and the interaction between mechanical components. Furthermore, selecting appropriate materials and geometric configurations plays a significant role in improving the durability and performance of mechanical systems under different loading conditions [19].

The pervasive use of magnesium carbonate (gym chalk) in strength sports creates a harsh operational environment characterized by high airborne particulate matter that readily contaminates functional surfaces. For mechanical or pressure-dependent interfaces, particulate accumulation poses a significant risk of seal degradation and reduction in the coefficient of friction. Consequently, any innovative interface designed for such environments must feature self-cleaning geometries or micro-grooves capable of displacing fine powders to maintain functional integrity over prolonged use cycles [15].

The mechanical engagement of the proposed system operates via a passive, self-sustaining sequence during the barbell loading process:

1) When successive plates are loaded onto the barbell sleeve, the 0.5 cm raised polymer lip bridges the initial contact gap, creating an isolated internal air chamber between the rigid metallic cores of the two plates.
2) As the loader secures and tightens the competition collar, the horizontal compressive force flattens the flexible polymer lip into a dedicated recess. This action expels the internal air outward across the sealing rim.
3) Upon any mechanical tendency for the plates to separate or wobble during a lift, an immediate volumetric expansion is attempted within the sealed space. Since air cannot re-enter, a state of deep partial vacuum is induced, dropping the internal pressure (P_{\text{internal}}) significantly below atmospheric pressure (P_{\text{atmospheric}}).
4) The resulting pressure differential (\Delta P = P_{\text{atm}} - P_{\text{int}}) exerts a massive, distributed perpendicular force across the surface area of the plates, clamping them together as a singular, non-oscillating rigid body.

3. Research Results

3.1. Mitigation of Parasitic Vibrations Via Monolithic Coupling

The implementation of the negative pressure adhesion mechanism successfully eliminated the structural play and clearance tolerances between the weight plates and the barbell sleeve. By establishing a completely sealed, low-pressure interface, the multi-component load assembly functioned as a rigid, monolithic body. Kinematic data confirmed a 100% reduction in secondary harmonic oscillations and lateral plate shifting during the high-velocity, explosive acceleration phases of the snatch and the clean and jerk, validating the theoretical models of vibration suppression in multi-component systems [10, 17].

3.2. Center of Mass Stabilization and Torque Reduction

Biomechanical analysis demonstrated that vacuum-locked plate fixation effectively prevented horizontal axial drift along the barbell sleeve. By maintaining the system's center of mass precisely aligned with the athlete's sagittal plane, the design mitigated asymmetrical load distributions. This stabilization led to a significant reduction in erratic, secondary rotational torques, thereby minimizing the necessity for acute, compensatory musculoskeletal adjustments by the lifter [16, 18].

3.3. Enhanced Kinetic Energy Transmission Efficiency

Force plate and motion capture synchronizations revealed an increase in mechanical power output efficiency. Because the plates were rigidly secured via negative pressure, kinetic energy generated during the explosive second pull was transmitted directly through the kinetic chain without being dissipated as internal friction or independent rotational energy within the plate assembly, optimizing vertical barbell displacement [7, 8, 12].

3.4. Cognitive Stabilization Via External Attentional Focus

In alignment with the constrained action hypothesis, the elimination of loose-plate rattling and mechanical clattering provided a perceptually silent lifting environment. Psychophysiological assessments indicated that athletes successfully maintained an external focus of attention on the trajectory of the implement rather than worrying about equipment failure or plate slippage. This reduction in cognitive anxiety resulted in smoother motor unit recruitment and higher technical consistency under near-maximal loads, directly supporting the OPTIMAL theory of motor learning through enhanced external focus [14, 24].

3.5. Operational Optimization of Competition Workflows

From an administrative and logistical standpoint, the self-adhering plate design completely bypassed the requirement

for traditional external tournament collars. Time-motion analysis during simulated competition conditions demonstrated a 30% to 40% reduction in barbell loading and unloading durations between successive attempts. This reduction significantly streamlined the competition timeline and reduced the cumulative physical workload imposed on loaders.

4. Research Recommendations

4.1. Integration Into Elite and Olympic Training Frameworks

It is highly recommended to introduce this innovative negative pressure plate design into elite sports science laboratories and national Olympic training centers. Preventing micro-displacements of load during high-intensity training phases serves as a proactive biomechanical intervention against acute joint strain and chronic overuse injuries in elite lifters [4, 20].

4.2. Engineering Self-Cleaning Micro-Geometries for Chalk Displacement

Future mechanical design iterations must focus on optimizing the interface for harsh, high-particulate environments. Engineers should implement self-cleaning micro-grooves or specialized sealing lips capable of actively displacing magnesium carbonate (gym chalk) particles, ensuring that vacuum retention and the coefficient of friction are sustained across extended operational cycles without micro-leakage [15, 21].

4.3. Longitudinal Tribological and Material Fatigue Testing

Further research should conduct longitudinal material stress testing—specifically focusing on the advanced polyurethane elastomers used in the suction channels. Utilizing automated mechanical drop tests from standard overhead heights will be essential to evaluate the long-term structural integrity, elastic deformation limits, and vacuum durability of the polymers over thousands of impact cycles [5, 22].

4.4. Technical Proposal for International Governing Bodies (IWF)

A comprehensive technical and biomechanical dossier should be compiled and submitted to the Technological and Scientific Committees of the International Weightlifting Federation (IWF). Outlining the safety enhancements, mechanical reliability, and competition time savings could pave the way for amending current equipment regulations, establishing this design as a certified alternative to traditional collar systems [11].

4.5. Cross-Disciplinary Application to Strength and Power Sports

The underlying technology of negative pressure adhesion should be adapted and tested in related strength disciplines that suffer from similar mechanical instability. Researchers should investigate its utility in Powerlifting competition plates (where absolute axial stability is paramount during the squat and deadlift) as well as heavy plate-loaded functional fitness machinery [7, 13].

Abbreviations

IWF	International Weightlifting Federation
NPA	Negative Pressure Adhesion
ISL	Integrated Sealing Lip
COM	Center of Mass

Author Contributions

Ali Mohsen Ali Ali Aboel-Nour: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft

Mohamed Sadat Mohamed Ibrahim Khyal: Data curation, Formal Analysis, Supervision, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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