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Neuromuscular and Kinetic Comparison of Ballistic vs. Non-Ballistic Upper Extremity Training Modalities in Resistance-Trained Males

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Abstract—Optimizing neuromuscular activation and mechanical output during resistance training is a central concern in kinesiology and exercise science, particularly for enhancing explosive performance. This investigation compared kinematic, kinetic, and electromyographic profiles between two upper-body training modalities: a traditional pressing movement performed explosively and a ballistic throwing movement, both executed at 45% of one-repetition maximum. Seventeen resistance-trained males performed both conditions while bar displacement, ground reaction forces, and muscle activation of the pectoralis major, anterior deltoid, triceps brachii, and biceps brachii were recorded. Results demonstrated that the ballistic condition produced significantly greater mean and peak velocity, force output, mechanical power, and integrated EMG activity across all prime movers. Notably, the traditional press exhibited a prolonged deceleration phase comprising 40% of the concentric movement, accompanied by reduced neuromuscular activation. These findings suggest that ballistic loading strategies better maintain force production and neural drive throughout the full range of motion, providing a more specific stimulus for power development. This study underscores the importance of movement modality selection in exercise prescription for improving explosive capacity in applied kinesiology contexts.

Index Terms—Ballistic training, Explosive strength, Electromyography, Kinetics, Bench press, Power development.

I. Introduction

THE development of explosive muscular power is a primary objective in athletic conditioning and rehabilitation protocols. Many sporting actions, such as throwing, striking, and jumping, require the rapid application of force rather than maximal strength alone. Consequently, training methodologies have evolved from traditional heavy resistance training towards modalities that prioritize rate of force development and high power output. A common practice involves performing conventional resistance exercises, like the bench press, with the intent to move the load as rapidly as possible, often utilizing lighter relative loads. However, the efficacy of this approach for optimally overloading the neuromuscular system has been questioned. The fundamental biomechanical constraint of traditional exercises is the requirement to decelerate the load at the terminal range of motion to bring it to a controlled stop. This deceleration phase can constitute a substantial portion of the concentric movement, leading to a reduction in force output and concomitant decrease in agonist muscle electromyographic (EMG) activity. This phenomenon suggests that the neuromuscular system may not be fully stimulated throughout the entire range of motion during rapid traditional lifts. In contrast, ballistic movements, where the resistance is projected from the body (e.g., a bench throw), eliminate the need for a terminal deceleration phase. This allows for continued acceleration throughout the concentric phase, potentially creating a more favorable loading condition for power development. The primary aim of this study was to conduct a comprehensive comparative analysis of a traditional explosive bench press and a ballistic bench throw. Kinematic, kinetic, and neuromuscular activation parameters were quantified to determine the differential effects of these two modalities on movement velocity, force production, mechanical power, and muscle activation patterns in resistance-trained individuals.

II. Related Work

Previous studies across health sciences, allied health, biomedical engineering, and computational modeling have highlighted the need to explore the neuromuscular activation and mechanical efficiency of human systems to optimize functionality and performance. Research examining dependence on substances and cessation of further use reveal interactions between physiological signalling pathways, objective biomarkers and behavioural interventions that impact longterm outcomes. Measurable biological responses have value when designing interventions [10]. Despite being predominantly on dependence biology, the focus on indicators that can be measured like neuromuscular, physiological is consistent with performance-related studies which quantify force production, power output, and any activation pattern to measure the effectiveness of the training.

In allied health and physiotherapy contexts, structural configurations, resources and interventions dictate outcomes; strong evidence from organizational and service-delivery research [11]–[13]. These evidence-based decisions re-iterate the importance of making choices of a therapeutic or training nature (without proof) with regard to the healthcare system. This view is pertinent to neuromuscular performance research whereby movement modalities that provide mechanical loading and a neural drive throughout the range of motion is critical for prescription.

Technological advances in rehabilitation and assistive systems underscore the importance of the interpretation of electromyographic signals and neuromuscular control. Sensors and data-driven frameworks can show the ability of EMG-driven prosthetic control systems to realizable control signals using signals [8]. Approaches of this type resemble the biomechanical study of integrated EMG, kinematic and kinetic data to distinguish between movement strategies, thereby establishing the relevance of neuromuscular measurement on which performance training and rehabilitation technologies are grounded.

Computational modeling of the cellular stress response at the biological systems level shows that sustained activation effects during diverse loading conditions are facilitated by feedback regulation [20]. Despite operating at distinct levels, the findings are conceptually similar to what is observed in neuromuscular studies that demonstrate how enhanced functionality is achieved through continuous force production and activation through a movement. Likewise, the improvement of physiological monitoring using non-invasive sensing technologies highlights the importance of measurements with high resolution and high temporal fidelity for evaluating system performance under dynamic conditions [21].

Research into robotics and control systems provides additional methodological contributions. The stability and performance under the influence of nonlinear dynamics of datadriven control strategies and optimization methods and continuous adaptation rather than premature stop or limitation [15], [16]. There is a close alignment between these principles and findings from biomechanical research. Ballistic movements outperform their non-ballistic counterparts because they do not terminate the movement in deceleration. Rather, they maintain acceleration through the bulk of the movement.

Advances in computational mechanics and materials science ultimately emphasize efficient modeling of nonlinear behavior and energy transport under complex boundary conditions [18], [19]. The different studies that exist on it may be applied in various domains but enforce a general scientific principle that system performance will depend upon how forces, energy and constraints are managed in the operational domain. In summary, previous literature shows that studying movements that allow mechanical and neuromuscular loading through the full range of motion may be relevant and this is what the study attached does.

III. Interdisciplinary Relevance and Translational Context

As well as strengthening conditioning the enclosed paper draws on current literature to offer translation into health sciences allied health and biomedical engineering. The study finds evidence that the intent to move cannot be the only reason that elicits a change due to structural constraints that compels

prolonged deceleration. All things being equal, ballistic upperextremity movements produce a higher force, velocity, and neuromuscular activation during the concentric phase. The fact that explosive movement capacity can be restored to previously injured athletes' limbed extremities has implications for

exercise prescription systems in performance training and latestage rehabilitation, where restoration of explosive capacity and neuromuscular coordination is typically a main goal [3].

The health system view on the evidence based modality selection is similar to what is increasingly happening in the systematic evaluation of the effectiveness of interventions through objective measurement outcome assessment [11]–[13]. The paper we attach provides mechanistic clarity by linking movement mechanics to neuromuscular demand. As such it allows a practitioner to rationalise a choice of modality with objective performance metrics rather than subjective intent. The alignment of mechanistic evidence with practical implementation is reminiscent of approaches taken in other health areas, where biomarkers and validated measurement are combined to guide treatment choice [10].

Technological and engineering fields can also draw valuable lessons from the study's insights. According to the citation the sentence EMG-informed control strategies in prosthetic and assistive devices rely on consistent, high quality neuromuscular signals to enable responsive and intuitive motion. Gaining insights into loading strategies, and their effect on the magnitude and timing of activation could help in the making of training protocols to enhance signal consistency and motor control. Furthermore, predictive control and optimization principles indicate that maintaining acceleration and preventing early constraint increases performance in a variety of systems, including robotic manipulators and human movement [15], [16].

The study also resonates at a broader scientific level with systems-oriented thinking that emphasizes dynamic adaptation under loading, such as models of biological stress and research on physiological monitoring [20], [21]. This paper frames ballistic movement as a way of keeping the system engaged continuously. It offers a synthetic perspective on mechanical design, neural control, measurement fidelity and their interplay concerning functional outcomes. The work outlined here has exercise science, health-related human performance and applied engineering in the main position. Thus, it is relevant to more than one field of study while remaining anchored in neuromuscular biomechanics.

IV. Methods

A. Participants

The study involved seventeen healthy male volunteers. Participants had been engaged in recreational weight training for at least six months and could bench press their own body weight. The cohort had a mean age of 20.6 years with a mean height of 1.79m and a mean body mass of 83.7kg. Individuals who participated in the study did not have any injuries and used no drugs. Approval was obtained for the study from assigned ethics committee and informed consent was acquired from all participants in writing before the study [6].

B. Experimental Design and Procedures

The research utilized a within-subjects crossover design. The testing occurred over two sessions, four days apart. The subjects' one-repetition maximum (1RM) for a traditional bench press was established using a Plyometric Power System and systematic instruction during the first session. As part of the study, participants engaged in a familiarization protocol

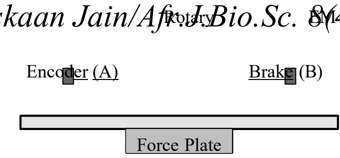


Fig. 1: Compact schematic of the Plyometric Power System (PPS) experimental setup showing the bar assembly, bench, and force plate instrumentation.

with the ballistic bench throw movement at 45% of their determined 1RM. This was conducted to enhance their technical competency and prevent any injury [9].

The second session involved the main experimental trials. After the standardized warm-up, participants performed two movement conditions in a counterbalanced order. 1) An explosive bench press, 2) a ballistic bench throw. Both conditions were executed with load set on 45% of the subject's 1RM. Participants were instructed to lower the bar to their chest and then push the bar upwards as fast as they could. The movement should stop with arms extended, and control should be maintained over the bar. The instructions for the ballistic throw were the same except participants were to project the bar vertically for maximum height and release it from their hands at the end of the concentric phase. The bar was automatically stopped from ascending after release, thanks to the Polymetric Power System's patented braking device. We collected three successful trials for each condition, with sufficient rest in between trials and conditions to reduce fatigue [1].

C. Instrumentation and Data Acquisition

A custom-designed Plyometric Power System was utilized for all testing. This apparatus allowed for both traditional and ballistic movements while ensuring participant safety. A high-resolution rotary encoder attached to the system sampled bar displacement data at 876 Hz. Vertical ground reaction forces were measured via a force platform integrated into the bench assembly. Surface electromyography was used to record muscle activity from the sternal portion of the pectoralis major, the anterior deltoid, the long head of the triceps brachii, and the biceps brachii. Standard skin preparation procedures were followed to ensure signal quality, and electrode impedance was verified to be below 5 kΩ. EMG signals were pre-amplified at the source, band-pass filtered, and sampled synchronously with kinematic and kinetic data at 876 Hz [4].

D. Data Processing and Analysis

For each participant and condition, the trial demonstrating the highest mean power output was selected for detailed analysis. The concentric phase of the movement was defined as the period from the point of lowest bar position (zero velocity) to the point of full elbow extension for the press, or bar release for the throw. Displacement data were digitally filtered. Average velocity, peak velocity, average force, peak force, average power, and peak power were calculated for the concentric phase. Instantaneous power was computed as the product of vertical force and bar velocity. EMG signals were full-wave rectified. Average EMG for the concentric phase was calculated via integration and time-normalized. To compare activation patterns across the movement, the concentric phase was divided into ten equal segments (every 10% of displacement), and integrated EMG was calculated for a 50ms window around each point. These values were normalized to the corresponding EMG level from the 1RM trial.

TABLE I: Comparison of Kinematic and Kinetic Variables Between Press and Throw Conditions (Mean ± SD)

Variable	Press	Throw	p-value
Concentric Time (ms)	590 ± 80	440 ± 50	< 0.001
Avg. Concentric Velocity (m/s)	0.66 ± 0.07	0.84 ± 0.06	< 0.001
Peak Concentric Velocity (m/s)	0.96 ± 0.08	1.31 ± 0.13	< 0.001
Avg. Concentric Force (N)	559 ± 124	757 ± 125	< 0.001
Avg. Power Output (W)	350 ± 97	595 ± 80	< 0.001
Peak Power Output (W)	568 ± 133	950 ± 174	< 0.001

E. Statistical Analysis

Differences in kinetic, kinematic, and EMG variables between the press and throw conditions were assessed using appropriate paired-sample statistical tests. The significance level was set a priori at $p \leq 0.05$. Data are presented as mean ± standard deviation unless otherwise noted.

V. Results

A. Kinematic and Kinetic Performance Variables

The ballistic throw and explosive press also had apparently different kinematic and kinetic characteristics. The ballistic condition exhibited a 27

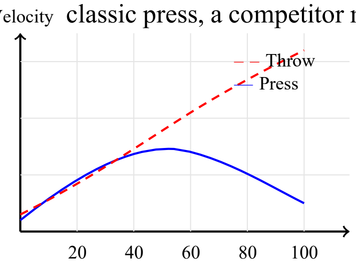
The output of force and power was greater in the throw condition. The throwing exerted 35% greater average concentric force compared to pressing, 70% greater average power output and 67% greater peak power output. The force time profile shows the vertical force applied during the press exceeded the bar weight for only 370ms of the 590ms concentric phase. In contrast, force during the throw was above bar weight for 430ms of the 440ms phase, suggesting a greater proportion of time under positive acceleration [2].

B. Muscle Activation Patterns

When throwing the ball as compared to catching it, muscle activity (measured as EMG) was enhanced in all upper body muscles examined (the pectoralis major (19% greater), anterior deltoid (34% greater), triceps brachii (44% greater), biceps brachii (27% greater)). Temporal differences can be seen in the range of motion activation patterns [14].

The activation levels of the anterior deltoid and triceps brachii were significantly heightened from the initial concentric phases of the throw condition. For the first 50-60% of the movement, the pectoralis major had similar activation levels for both conditions, but during the last 40% of the concentric phase, there was much higher pectoralis major activation for the throw. The biceps brachii muscle, which potentially acts as an antagonist and stabilizer, produced greater averaged activity during the throw.

Velocity



Concentric Phase (%)

Fig. 2: Conceptual velocity profiles during the concentric phase, illustrating early velocity peaking and deceleration in the press compared with sustained acceleration in the ballistic throw.

TABLE II: Timing and Position of Peak Events During Press

Throw Conditions

_ The observed kinetic differences were directly reflected in

Peak Event	Condition	Time (ms)*	Position (% Concentric)
Velocity	Press	370 ± 60	60 ± 10
	Throw	430 ± 50	96 ± 8
Force	Press	10 ± 30	0.0 ± 31.9
	Throw	10 ± 30	0.6 ± 31.4
Triceps EMG	Press	280 ± 150	40 ± 31
	Throw	240 ± 140	40 ± 33
Pectoralis EMG	Press	170 ± 150	20 ± 28
	Throw	140 ± 150	30 ± 27

C. Timing of Peak Events in the Concentric Phase

The temporal characteristics of peak velocity, force, and EMG activity revealed fundamental differences in movement strategy between conditions. As shown in Table II, peak velocity during the press occurred significantly earlier in the movement (at 60% of concentric displacement) compared to the throw (at 96%). This earlier peak necessitates a longer

subsequent deceleration period. Similarly, the timing of peak muscle activation for prime movers showed trends toward earlier occurrence in the press condition, though only the triceps brachii reached statistical significance for peak EMG timing. The peak force output during the entire movement showed no significant difference in timing between conditions, suggesting that the initial explosive effort was similar but could not be maintained in the press.

VI. Discussion

A. Mechanical Superiority of Ballistic Loading

The study's findings give a strong indication that ballistic loading enhances dynamic performance metrics better than non-ballistic loading. According to research, however, it is highly likely that a ballistic bench throw would produce greater movement velocities, force outputs, and mechanical power than an explosively intended traditional press with the same submaximal load. The major explanation for this difference in mechanism is the removal of the deceleration phase. In the classic press, a competitor must actively decelerate the bar at the end of the range to bring it to rest. Results of this study showed this deceleration phase accounting for 40% of total concentric movement time during explosive press at 45% 1RM. At this time, the force output plummets rapidly, often dropping below the weight of the bar itself (so the muscles are "unloaded"). However, in the ballast throw, there is a constant requirement for continuing positive acceleration throughout the entire concentric phase, which launches the load. So, force is maintained at a high level until the final moment before release. The neuromuscular system must consistently exert force and power across the full range of motion due to the different mechanical stimulus that it creates.

B. Neuromuscular Activation Implications and

the patterns of muscle activation. Higher integrated EMG for the throw condition across all prime movers indicates a greater overall neural drive was required to execute the ballistic task. More insightful is the temporal analysis of EMG throughout the movement. The earlier and sustained elevation in anterior deltoid and triceps brachii activation during the throw suggests these muscles are recruited more aggressively from the initiation of the concentric phase to facilitate the required acceleration profile. The finding that pectoralis major activation diverged only in the latter half of the movement is particularly telling. It implies that during a traditional press, neural drive to this large prime mover is downregulated in anticipation of the impending deceleration, whereas in a

ballistic action, it is maintained to contribute to terminal acceleration. This neuro-mechanical coupling—where the nervous system modulates activation based on the intended movement outcome—highlights a critical limitation of rapid traditional lifts: the nervous system appears to "prepare" to decelerate the load, thereby limiting the potential for maximal force and velocity development even when the intent is explosive.

C. Neuromuscular Activation Implications

The observed kinetic differences were directly reflected in the patterns of muscle activation. Higher integrated EMG for the throw condition across all prime movers indicates a greater overall neural drive was required to execute the ballistic task [7]. More insightful is the temporal analysis of EMG throughout the movement. The earlier and sustained elevation in anterior deltoid and triceps brachii activation during the throw suggests these muscles are recruited more aggressively from the initiation of the concentric phase to facilitate the required acceleration profile.

The pectoralis major activation only being different in the second half of movement is an interesting finding. This means that with a normal press, the neural drive to this large prime

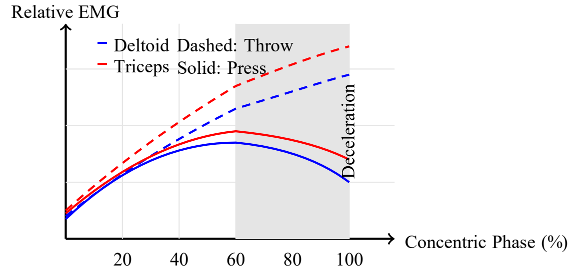
Fig. 3: Conceptual EMG activity profiles for the anterior deltoid and triceps brachii during press and throw conditions. The shaded region denotes the press-specific deceleration phase, where EMG activity decreases.

output indicates the structural limiting factor of normal fast lifts.

D. Practical Applications for Power Development

The findings may prove useful in the practical applications of strength and conditioning, sports medicine, and rehabilitation. The selection of exercises, if the training goal is to enhance an athlete's capacity to express high force at high velocity (i.e. explosive power). Performing traditional resistance exercise such as the bench press with light weight and emphasis on speed may be less than ideal because the exercise will feature an inherent deceleration phase (as it is called in strength training literature) and, as a consequence, a reduction in the neuromuscular loading, especially in the last section of the exercise that is crucial for the sport. Ballistic movements, including bench throws, jump squats and medicine ball throws, offer more specific mechanical and neural stimulation [17]. They promote acceleration across the complete spectrum, strengthen neural drive to the primary movers, and more effectively reproduce the force-velocity characteristics of genuine explosive sports tasks, such as throwing and striking. As a result, ballistic training is fundamentally important to periodised power development blocks [5].

mover is downregulated to prepare for the upcoming deceleration; with a ballistic action, this is maintained to assist with terminal acceleration. This coupling where neural networks control muscle activation according to the required



VIII. Conclusion

This study found that a ballistic upper-body movement (the bench throw) is associated with a significantly greater kinematic velocity that produced increased kinetic force and power output and greater neuromuscular activation than an explosively-performed press with the same submaximal load. The significant difference is that the classic movement has a large phase of deceleration that helps to prematurely reduce force and muscle activation. When one utilizes ballistic load-

VII. Limitations and Future Research

Although this study has powerful comparative data, there are limitations. Because the participants were recreationally trained males, the findings of the study do not necessarily generalize to elite athletes or females or untrained populations. The acute responses were examined in this study, indicating that longitudinal training studies would confirm the superior acute kinetic and EMG profile of ballistic training results in superior adaptations in power output compared to traditional explosive training. In addition, a single-joint, upper-body exercise was examined. Future research should investigate similar comparisons for lower body and multi joint exercises. In the end, the ballistic training's safety and logistical requirements (e.g., special equipment, technical competency) must be considered practically.

ing and requires acceleration throughout the range, there is a fuller and more potent stimulus to the neuromuscular system. The biomechanical and physiological evidence presented here supports the use of ballistic exercises during training for athletes wishing to increase explosive power. One should quantify training adaptations using separate methods in the future work.

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