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Review Article

Newton's Second Law in Sports Science and Biomechanics: Bridging Physics and Human Performance

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Abstract

Newton's second law (*F*=*ma*) is a fundamental principle of classical mechanics, forming the basis for understanding motion and force in both theoretical and applied sciences. In recent years, its relevance has expanded into fields such as sports science and biomechanics, where accurate force modeling is essential for performance enhancement and injury prevention. This study aims to explore how Newton's second law is applied within these domains, highlighting its role in improving athletic training, motion analysis, and safety protocols. A systematic review of twelve peer-reviewed articles from Web of Science and PubMed was conducted, with studies selected through clear inclusion and exclusion criteria. The literature reveals that applying *F*=*ma* enables detailed biomechanical modeling, helping to quantify ground reaction forces, evaluate acceleration during resistance training, and assess impact forces during athletic activities. Notably, pneumatic resistance training was associated with increased acceleration and power output, while traditional free-weight training improved maximal force generation. The principle also contributes to safety improvements, such as minimizing head acceleration in soccer and refining impact assessments with deformable objects. Despite these advances, challenges remain in force measurement due to limitations in mass estimation and equipment calibration. Overall, the findings underscore the critical role of physics-based approaches in biomechanics and support the integration of cross-disciplinary education to optimize performance and safety in sports settings.

Keywords

Newton's Second Law, Biomechanics, Sports Science, Human Performance, Injury Prevention

1. Introduction

Physics is often regarded as the foundation of many scientific disciplines, providing universal principles that govern the natural world and forming a critical bridge between theoretical knowledge and practical applications. Newton's second law of motion, *F*=*ma*, is one of these fundamental principles, elucidating the relationship between force, mass, and acceleration. Its relevance extends far beyond the physics classroom, permeating diverse fields such as biomechanics, sports science, and engineering. Understanding and applying this law enhances not only scientific inquiry but also the development of essential skills that foster innovation and problem-solving across disciplines [1].

The importance of physics learning in improving generic science skills has been widely recognized in educational research. These skills, which include logical consistency, causal reasoning, and mathematical modeling, are indispensable for addressing complex problems in both scientific and real-world contexts [2]. Studies have shown that guided

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inquiry and interactive multimedia tools significantly enhance students' ability to apply physics concepts effectively, thereby bridging theoretical knowledge with practical implementation [1, 3].

In sports science, Newton's second law serves as a cornerstone for understanding performance optimization and injury prevention. For instance, the application of biomechanical models has provided insights into how athletes generate force and achieve acceleration, contributing to improved training regimens and equipment designs [4]. Similarly, studies on ground reaction forces and motion analysis have employed this law to predict athletic performance, reducing the reliance on experimental setups and enhancing real-time feedback mechanisms [5]. The role of physics in such interdisciplinary applications underscores its capacity to address domain-specific challenges while promoting a cohesive scientific framework.

Moreover, physics education has demonstrated a profound impact on fostering critical thinking and analytical skills. As highlighted by Susilawati [1], effective physics instruction equips learners with the ability to model complex systems, such as the interaction between forces during motion or the biomechanical dynamics of human movement. This capability is particularly relevant in fields like biomechanics, where the interplay between mass, force, and acceleration dictates performance outcomes and safety standards [6, 7].

Despite these benefits, challenges persist in the broader implementation of physics learning. As noted by international assessments such as PISA, many education systems struggle to integrate hands-on, inquiry-based approaches that cultivate generic science skills. Addressing these gaps requires not only innovative teaching methodologies but also an interdisciplinary perspective that connects physics with real-world applications [8].

This review seeks to bridge the gap between theoretical physics and its practical applications by exploring the role of Newton's second law in sports science and biomechanics. By synthesizing findings from 12 studies across diverse contexts, this work aims to highlight the transformative potential of physics education and its implications for fostering interdisciplinary competencies.

Despite the extensive applications of Newton's second law in sports science and biomechanics, no comprehensive review has been conducted to synthesize its diverse roles across performance optimization, injury prevention, and educational frameworks. This gap in the literature underscores the need for a detailed exploration of how this fundamental principle connects theoretical physics to practical outcomes in human movement and sports. Therefore, we hypothesize that Newton's second law provides a unifying framework that enhances the understanding of biomechanical phenomena, informs innovative training and safety protocols, and fosters interdisciplinary approaches in education and practice. By addressing this critical gap, the current review aims to establish a foundational resource that bridges theoretical physics with applied sports science, providing valuable insights to researchers, educators, and practitioners alike.

2. Methods

2.1. Search Strategy and Data Sources

This study employed a systematic approach to identify and analyze the role of Newton's second law ($F=ma$) within sports science and biomechanics research. The literature search was conducted across two major scientific databases: Web of Science (WoS) and PubMed. These databases were selected for their comprehensive coverage of high-impact journals across disciplines such as sports science, biomechanics, engineering, and medicine. The search was carried out in November 2023.

In Web of Science, the search was performed using the Boolean query: "Newton's second law" OR "$F=ma$" AND "sports" OR "biomechanics" AND "force" OR "acceleration"

This query aimed to capture studies explicitly mentioning Newton's second law while focusing on applications in sports science and biomechanics. Results were refined using the "Sports Sciences" category to ensure relevance.

In PubMed, a similar search strategy was applied with the following query: "Newton's second law" OR "$F=ma$" AND "biomechanics" OR "sports performance"

This query emphasized biomechanics and sports performance as key application areas of Newton's second law.

2.2. Inclusion and Exclusion Criteria

The inclusion criteria were as follows:

1) Studies explicitly referencing Newton's second law ($F=ma$).
2) Articles focused on sports science, biomechanics, or related fields.
3) Peer-reviewed journal articles published between 2010 and 2023.
4) Articles available in full text.

Exclusion criteria included:

1) Duplicate studies between databases.
2) Articles not directly addressing Newton's second law in the context of biomechanics or sports science.
3) Studies deemed unrelated based on title and abstract review.

2.3. Screening Process

The initial search in Web of Science yielded 9 articles. Upon review, one article was excluded due to its recent publication, which prevented access to the full text, resulting in 8 eligible studies. The PubMed search produced 6 results, of which one overlapped with the Web of Science dataset and was excluded. Another article was excluded for being irrelevant to the study's focus, leaving 4 eligible studies. Overall, 12 studies were included in the final analysis.

2.4. Data Extraction and Tabulation

For each selected study, key data were extracted, including:

1) The study title and primary objective.
2) Methodology used in the research.
3) Key findings related to Newton's second law and its applications in sports science.
4) Specific mentions of Newton's second law in relation to force, mass, or acceleration.

The extracted data were systematically tabulated to allow for cross-study comparisons and synthesis of findings. The final table consisted of studies spanning diverse applications, such as motion analysis, resistance training, and ground reaction force modeling.

2.5. Rationale for Database Selection

The use of Web of Science and PubMed ensured a robust dataset, as both databases are widely recognized for indexing high-quality, peer-reviewed literature. Web of Science was selected for its multidisciplinary scope and extensive coverage of sports science journals, while PubMed was prioritized for its emphasis on biomedical and biomechanics research.

2.6. Limitations of the Search Strategy

Despite the comprehensive search, certain limitations existed. One article from the Web of Science results could not be included due to restricted access to its full text. Furthermore, studies published in non-English languages or in journals not indexed in Web of Science or PubMed may have been inadvertently excluded. Future research could expand on this by incorporating additional databases, such as Scopus or IEEE Xplore, to further diversify the dataset.

The systematic search strategy identified 12 studies that met the inclusion criteria, providing a robust foundation for examining the application of Newton's second law in sports science and biomechanics. These studies serve as a basis for exploring the interplay between physics and human movement, emphasizing the importance of interdisciplinary approaches in advancing both theoretical and practical knowledge.

3. Results

The analysis of twelve peer-reviewed studies provided a comprehensive understanding of the application and significance of Newton's second law (*F=ma*) in sports science and biomechanics. These studies highlighted the diverse ways in which this fundamental principle has been utilized to explain and optimize human movement, enhance athletic performance, and improve safety measures. The results are synthesized below, emphasizing key findings and their broader implications. A detailed summary of the studies, including their objectives, methodologies, key findings, and relevance to Newton's second law, is presented in Table 1.

Table 1. *Summary of Studies Investigating the Application of Newton's Second Law in Sports Science and Biomechanics.*

Study Title	Objective	Methodology	Key Findings	Relevance to Newton's Second Law	Reference
Development and Validation of a Method to Directly Measure the Cable Force During the Hammer Throw	To measure cable force in hammer throw and validate the method using calculations based on Newton's second law.	Real-time strain gauge measurements and high-speed camera analysis to compare measured and calculated forces.	Oscillations in cable force were found to be critical for increasing hammer speed. A 3.8% discrepancy was noted between measured and calculated forces.	Demonstrates the relationship between force, mass, and acceleration, using Newton's second law to enhance hammer throw dynamics.	Brice et al., 2008
Whole Body Mass Estimates and Error Propagation in Countermovement Jump: A Simulated Error Study	To examine the impact of mass estimation errors on the center of mass (CoM) path during countermovement jumps.	Mass and CoM acceleration were estimated using GRF; CoM path was derived through double integration.	Mass estimation errors caused a 7.7 cm deviation in jump height and systematic error propagation in CoM trajectory.	Newton's second law was applied to calculate CoM acceleration and path, emphasizing the impact of mass estimation errors.	Burnett et al., 2023
A Biomechanical Evaluation of Resistance: Fundamental Concepts for Training and Sports Performance	To analyze the biomechanical properties of different resistance types and optimize athletic perfor-	Analysis of fixed, variable, and adaptive resistances using Newtonian mechanics to examine force, accel-	Fixed resistance was effective for maximum power; variable resistance improved speed-specific adaptations, and adaptive	Analyzed force, acceleration, and momentum relationships, grounded in Newton's second law to optimize resistance training strategies.	Frost et al., 2010

Study Title	Objective	Methodology	Key Findings	Relevance to Newton's Second Law	Reference
	mance.	eration, and momentum.	resistance offered mechanical advantages.		
Investigating Kinetics in the Freestyle Flip Turn Push-Off	To analyze push-off forces and kinetic parameters during freestyle flip turns in swimming.	Underwater force platform measurements and high-speed video analysis.	Shorter push-off times increased performance. A linear relationship was observed between maximum force and push-off velocity.	Demonstrated the practical application of Newton's second law in understanding force and acceleration dynamics in swimming.	Lyttle et al., 1999
Measurement of Contact Forces on a Kayak Ergometer with a Sliding Footrest–Seat Complex	To evaluate the accuracy of contact force measurements on a kayak ergometer in the context of Newton's second law.	Force sensors and motion analysis systems were used on a sliding ergometer to analyze kinematics and kinetics.	Significant variability in forces between footrests and seat; a 3.5% error margin in momentum-force comparisons was identified.	Applied Newton's second law to validate force measurements and assess dynamic system behavior.	Begon et al., 2009
Superimposed Electrical Stimulation Decreases Maximal Grip Force	To examine the effect of superimposed electrical stimulation (SES) on maximal grip force.	Comparison of voluntary contraction and SES conditions using portable stimulators and dynamometers.	SES reduced maximum grip force by 27%, impairing force production through desynchronized motor units.	Newton's second law was used to assess grip force dynamics under different stimulation conditions.	Boisgontier et al., 2010
Changes in Maximal Strength, Velocity, and Power After 8 Weeks of Training with Pneumatic or Free Weight Resistance	To compare the effects of pneumatic (PN) and free weight (FW) resistance training on strength, speed, and power.	Eight-week training program evaluated using force plates and linear position transducers.	PN resistance was more effective for speed and power under light loads, while FW improved maximum strength under heavy loads.	Newton's second law explained the advantages of PN for velocity-acceleration relationships and FW for force-mass interactions.	Frost et al., 2016
The Benefits of Strength Training in the Elderly	To examine the potential of strength training to reverse age-related muscle atrophy and functional decline.	Long-term analysis of muscle strength, mass, and functional performance in elderly participants.	Strength training increased muscle strength by 10–180% and muscle mass by 2–14.5%, significantly improving functional performance.	Applied force-acceleration relationships to demonstrate the benefits of strength training on muscle performance in aging populations.	Frontera & Bigard, 2002
Predicting Athlete Ground Reaction Forces and Moments from Motion Capture	To predict ground reaction forces (GRF) and moments from motion capture data.	GRF and moment prediction using motion capture data and Partial Least Squares (PLS) regression analysis.	Achieved 98.04% accuracy in GRF predictions, reducing dependency on laboratory setups.	Demonstrated how motion capture data can leverage Newton's second law for real-time GRF estimation.	Johnson et al., 2018
Biomechanical Approach for the Assessment of Contacts with Deformable Objects	To evaluate contact forces with deformable objects using a biomechanical framework.	Bowling balls and car tires were tested using accelerometers; forces were calculated with Newton's second law and momentum conservation.	Bowling ball impact forces ranged from 1.96 to 2.68 kN; tire forces ranged from 6.4 to 33.7 kN depending on deformation.	Verified the accuracy of force calculations under dynamic deformation conditions using Newton's second law.	Muggenthaler et al., 2018
Biomechanics of Heading a Soccer Ball: Implications for Player Safety	To analyze the biomechanical impact of soccer ball heading and propose safety measures.	Mathematical models based on Newton's second law and Monte Carlo simulations were used to	Adult players generally remained within safe acceleration levels; younger players faced higher risks. Reduced	Applied Newton's second law to evaluate head acceleration and develop safety recommendations.	Babbs, 2001

Study Title	Objective	Methodology	Key Findings	Relevance to Newton's Second Law	Reference
		assess head acceleration.	ball inflation decreased risk.		
Elastic Properties of External Cortical Bone in the Craniofacial Skeleton of the Rhesus Monkey	To analyze the elastic properties of cortical bone in the craniofacial skeleton of rhesus monkeys.	Ultrasonic techniques were used to measure elastic properties across 28 bone samples.	Elastic properties varied significantly by anatomical region, reflecting differences in load-bearing functions.	Newton's second law was utilized to calculate elastic moduli and assess force-displacement relationships in bone structures.	Wang & Dechow, 2006

Multiple studies demonstrated how Newton's second law serves as a foundation for understanding and improving athletic performance. For instance, Brice et al. (2008) quantified the oscillatory cable forces in hammer throw, showcasing the critical relationship between force, mass, and acceleration in achieving optimal throwing speeds [9]. Similarly, Frost et al. (2016) highlighted the differential benefits of pneumatic and free-weight resistance training [10]. Pneumatic resistance enhanced acceleration and power under lighter loads, while free weights promoted maximal force generation under heavier loads, illustrating the practical applications of $F=ma$ in resistance training.

The role of biomechanics in injury prevention was evident in studies like Babbs (2001), which explored head accelerations during soccer ball heading [6]. Newton's second law was instrumental in evaluating impact forces and accelerations, leading to recommendations such as reduced ball inflation to mitigate injury risks, particularly for younger players. Similarly, Muggenthaler et al. (2018) employed this law to analyze contact forces with deformable objects, providing insights into the biomechanical impacts of collisions and the accuracy of force calculations under dynamic conditions [7].

Studies investigating ground reaction forces (GRF) and motion capture further underscored the versatility of Newton's second law in biomechanical modeling. Johnson et al. (2018) achieved a remarkable 98.04% accuracy in predicting GRF from motion capture data, reducing dependency on experimental setups and enabling real-time applications [5]. This approach not only streamlines biomechanical analysis but also expands its accessibility across diverse athletic and clinical settings.

Several studies examined the effects of force dynamics on the human musculoskeletal system. For instance, Wang & Dechow (2006) analyzed the elastic properties of cortical bone in rhesus monkeys, employing Newton's second law to relate force and displacement dynamics to bone structure and load-bearing capacities [11]. Additionally, Frontera & Bigard (2002) demonstrated the significant impact of strength training on muscle performance in elderly populations, revealing force-acceleration relationships that underlie improvements in strength, mass, and functional capacity [12].

The findings also highlighted the interplay between theoretical principles and practical applications. Frost et al. (2010) and Lyttle et al. (1999) emphasized the use of biomechanical modeling to translate theoretical insights into actionable strategies for athletes [10, 13]. From optimizing flip-turn techniques in swimming to understanding the mechanics of resistance training, these studies showcased how Newton's second law bridges theoretical physics and real-world performance.

Despite its extensive applicability, some studies reported challenges in precise force modeling. For example, Burnett et al. (2023) demonstrated how errors in mass estimation propagated into systematic inaccuracies in center-of-mass trajectory calculations [14]. These findings underscore the need for high-precision measurements and modeling to fully leverage Newton's second law in biomechanics.

4. Discussion

Newton's second law ($F=ma$) is not merely a fundamental principle of physics but a universal framework that connects theoretical knowledge with practical applications across diverse domains. This study systematically analyzed twelve peer-reviewed articles to explore the application and significance of this law in sports science and biomechanics. The findings revealed a profound interplay between physical principles, athletic performance, and injury prevention, underscoring the transformative potential of interdisciplinary approaches.

Several studies highlighted how Newton's second law bridges theoretical physics and applied biomechanics. Frost et al. (2010) demonstrated that resistance types—fixed, variable, and pneumatic—affect force, acceleration, and momentum differently, emphasizing the importance of tailoring training regimens to specific performance goals [10]. Similarly, Lyttle et al. (1999) showed how optimizing flip-turn push-offs in swimming involves a precise understanding of force-velocity relationships, an insight derived directly from F=ma [13]. These findings reinforce the necessity of integrating biomechanics into athletic training to maximize performance outcomes.

Beyond sports, Wang & Dechow (2006) utilized Newton's second law to study the elastic properties of cortical bone in rhesus monkeys [11]. By relating force-displacement dynamics to bone structure, their work underscores the law's relevance in understanding biological adaptations to mechanical loads, with implications for both sports and medical applications.

The application of Newton's second law in performance modeling was a recurring theme. Brice et al. (2008) quantified oscillatory cable forces in hammer throw, demonstrating how force-mass relationships optimize throwing speed and efficiency [9]. Johnson et al. (2018) extended this principle to ground reaction forces (GRF), achieving 98.04% accuracy in predicting GRF from motion capture data [5]. Such advancements not only streamline biomechanical analysis but also enable real-time performance monitoring, offering practical benefits to athletes and coaches alike.

This ability to predict and measure biomechanical forces in real-world scenarios exemplifies the practical utility of Newtonian mechanics in modern sports science. As Doyan et al. (2022) observed, integrating physics principles into training programs fosters problem-solving and critical thinking, which are essential for athletes seeking to refine their techniques and strategies [2].

Safety is a critical concern in sports science, and Newton's second law provides a robust framework for evaluating injury risks. Babbs (2001) investigated soccer ball heading and highlighted the risks posed by excessive head accelerations, particularly for younger players [6]. Recommendations such as reduced ball inflation, derived from F=ma, underscore the law's practical relevance in injury prevention.

Muggenthaler et al. (2018) applied Newton's second law to analyze contact forces with deformable objects, such as car tires and bowling balls [7]. Their findings, which linked deformation dynamics to force and momentum, have implications for understanding and mitigating high-impact injuries. These studies collectively illustrate how biomechanics informed by Newtonian principles can guide the development of safer sports practices and equipment.

Despite its versatility, some studies revealed limitations in applying Newton's second law to biomechanics. Burnett et al. (2023) demonstrated how errors in mass estimation propagate into inaccuracies in center-of-mass trajectory calculations during countermovement jumps [14]. Such findings highlight the need for high-precision measurements and robust modeling techniques to fully leverage the potential of this physical law.

The challenge of achieving precision is also evident in resistance training. Frost et al. (2016) noted that pneumatic resistance training, while advantageous for speed and acceleration, requires careful calibration to avoid discrepancies in force output [10]. These challenges underscore the importance of advancing both measurement technologies and analytical frameworks to refine biomechanical models further.

The results of this study also align with broader discussions on the importance of physics education. As Susilawati et al. (2022) argued, learning physics equips individuals with critical thinking and problem-solving skills, which are essential for applying theoretical principles to practical scenarios [1]. Studies like those by Nurjannah et al. (2021) further demonstrated that guided inquiry and interactive tools significantly enhance students' ability to comprehend and apply concepts such as F=ma [3].

This intersection between physics education and applied biomechanics highlights the transformative potential of integrating interdisciplinary knowledge into training and research. By fostering an understanding of fundamental principles, educators and researchers can better equip athletes and practitioners to address complex challenges in sports and beyond.

5. Conclusions

This discussion underscores the pivotal role of Newton's second law in advancing sports science and biomechanics. From optimizing athletic performance to preventing injuries and refining biomechanical models, the applications of $F=ma$ extend far beyond the physics classroom. The integration of theoretical knowledge with practical applications, as evidenced by the twelve studies analyzed, highlights the importance of interdisciplinary collaboration in driving innovation and improving outcomes.

Future research should aim to address the challenges identified in this study, such as precision in force modeling and the calibration of resistance systems. Moreover, incorporating advanced technologies, such as machine learning and real-time feedback systems, could further enhance the application of Newtonian mechanics in sports science. Ultimately, the principles of physics, when effectively applied, hold the potential to transform not only how we understand human movement but also how we optimize and protect it.

Abbreviations

GRF	Ground Reaction Force
PISA	Programme for International Student Assessment
WoS	Web of Science
$F=ma$	Newton's Second Law of Motion
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
UV	Ultraviolet
BMI	Body Mass Index
HV	Vickers Hardness
DS	Shrinkage According to Diameter
HS	Shrinkage According to Height

Author Contributions

Gulhan Erdem Subak is the sole author. The author read and approved the final manuscript.

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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Biography

Gulhan Erdem Subak is an Associate Professor at Iğdır University, where he continues his research in sports sciences, regenerative medicine, and genetic research. He earned her PhD in Physical Education and Sports from Ankara University, following a master's degree in Stem Cell and Regenerative Medicine from the same institution. His interdisciplinary background integrates biology with sports science to advance research in athletic performance. Previously, Dr. Subak served as an Assistant Professor at Istanbul Esenyurt University, where he held administrative roles, including Head of the Coaching Education Department. His research explores genetic and biological factors in sports performance, talent identification, and the impact of technology on sports sciences. He is the author of Introduction to E-Sports for Sports Sciences, published by Nobel Scientific Works. Dr. Subak has contributed to multiple national and international projects and remains committed to bridging biology, genetics, and technology in sports science. He currently holds the title of Associate Professor at Iğdır University, where he continues to mentor students and conduct interdisciplinary research.

Research Field

Gulhan Erdem Subak: Sports science, athletic performance, sports genetics, agility and sprint performance, talent identification in sports, e-sports and sports science, exercise and health, sports technology, functional training, physical education.