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THE EFFECT OF MECHANICAL FEEDBACK ON THE LEARNING AND RETENTION OF SELECTED GYMNASTICS SKILLS AMONG FEMALE STUDENTS

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ABSTRACT

Technological advances in sports have opened up new opportunities to enhance the efficiency of learning motor skills, including gymnastics. This study found that mechanical feedback improves movement accuracy, speeds up the learning process and reduces performance variability compared to traditional methods. The study examined the impact of real-time mechanical feedback on the acquisition and retention of preferred gymnastics skills among students at the College of Physical Education and Sports Science at the University of Baghdad. A quasi-experimental design was used, with 40 students divided into two groups: an experimental group of 20 students who received mechanical feedback and a control group of 20 students who were trained using traditional methods. Data were collected through pre- and post-workout tests, as well as a retention test, to evaluate skill mastery, execution precision, and endurance. The results showed that mechanical feedback significantly improved movement execution and skill retention compared to the control group. In conclusion, technology-based mechanical feedback has the potential to be an effective training tool in sports, supporting improved performance through better motor control. Further research is needed to explore the long-term effects of mechanical feedback and the integration of artificial intelligence technology in training systems, as well as its effect on psychological and cognitive factors such as motivation, focus and athlete confidence.

***Keywords**:* gymnastics; biomechanics; mechanical feedback; motor learning; skill acquisition; sports science.

PENGARUH UMPAN BALIK MEKANIS PADA PEMBELAJARAN DAN RETENSI KETERAMPILAN SENAM YANG DIPILIH DI KALANGAN MAHASISWA

ABSTRAK

Kemajuan teknologi dalam bidang olahraga membuka peluang baru untuk meningkatkan efektivitas pembelajaran keterampilan motorik, termasuk dalam senam. Salah satu temuan penting dalam studi ini adalah bahwa umpan balik mekanis mampu meningkatkan akurasi gerakan, mempercepat proses pembelajaran, dan mengurangi variabilitas kinerja dibandingkan metode tradisional. Penelitian ini bertujuan untuk mengkaji pengaruh umpan balik mekanis waktu nyata terhadap pembelajaran dan retensi keterampilan senam pilihan pada mahasiswa Sekolah Tinggi Pendidikan Jasmani dan Ilmu Olahraga di Universitas Baghdad. Metode penelitian menggunakan desain kuasi-eksperimental dengan total 40 mahasiswa, yang dibagi menjadi dua kelompok, 20 mahasiswa dalam kelompok eksperimen yang menerima umpan balik mekanis, dan 20 mahasiswa dalam kelompok kontrol yang dilatih menggunakan metode tradisional. Pengumpulan data dilakukan melalui tes pra-latihan, pasca-latihan, dan tes retensi untuk mengevaluasi penguasaan keterampilan, ketepatan eksekusi, dan daya tahan keterampilan. Hasil menunjukkan bahwa penggunaan umpan balik mekanis memberikan peningkatan signifikan dalam pelaksanaan gerakan dan retensi keterampilan dibandingkan kelompok kontrol. Kesimpulannya, umpan balik mekanis berbasis teknologi berpotensi menjadi alat intervensi yang efektif dalam pelatihan olahraga, dan mendukung peningkatan performa melalui kontrol motorik yang lebih baik. Penelitian lanjutan disarankan untuk mengeksplorasi efek jangka panjang umpan balik mekanis, integrasi teknologi kecerdasan buatan dalam sistem pelatihan, serta pengaruhnya terhadap aspek psikologis dan kognitif seperti motivasi, fokus, dan kepercayaan diri atlet.

Kata kunci: *senam;biomekanik;umpan balik mekanis;pembelajaran motorik, perolehan keterampilan, ilmu olahraga.*

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INTRODUCTION

Gymnastics is widely known to be one of the most technically challenging sports, and is a demanding mix of strength, agility, balance, and motor control. From biomechanical principles underlying movement during the performance, to their efficiency as emphasized in the sport, to the refinement of motor control strategies, gymnastics skills are highly intricate skills that require systematic training and detailed feedback systems to ensure properly executed performance. Traditionally, gymnastics skills have developed through repetitive practice and corrective feedback from coaches (Knoll, K. ,2002). On the contrary, considering the recent developments in the fields of sports science and biomechanics, the importance of mechanical feedback to improve learning and performance results has increased now. Therefore, researchers have sought not only to study the role of feedback in skilled performance but also to compare the efficacy of various feedback modalities, including mechanical feedback, in terms of skill acquisition, error reduction, and optimal movement performance. While biomechanical feedback is critical in any training environment, most still underuse it, relying only on traditional coaching techniques that do no guarantee precise movement corrections suited to the unique learners.

In general, in motor learning, feedback is essential to acquire a skill because it helps movers to know how they did at moving (Richard, A., 2011). Indeed, though coaches relying on verbal and visual input is still the gold standard in gymnastics training, technology has paved the way for increasingly advanced feedback mechanisms to inform training, including motion analysis systems, wearable sensors, and video replay. These devices allow athletes to receive immediate mechanical feedback from their bodies, making it possible for them to adjust their technique on the fly. It has been shown that this type of feedback can greatly improve the learning curve as it reinforces correct movement patterns while eliminating any inefficient biomechanics. Because of the nature of gymnastics skills, many of which include various rotations, flips, and balance, having biomechanical feedback as part of transfer in training protocols is not only an asset for optimizing athlete performance, but a vital piece of information to decrease injury rate.

The introduction of low-cost biomechanical tools for the pedagogical monitoring of skill acquisition and retention creates a special opportunity to investigate, in a systematic manner, the impact of these tools on improving skill acquisition for novice gymnasts. Although feedback is widely acknowledged to be a crucial component in facilitating the motor learning process, mechanical feedback mechanisms appear to be considerably under-utilized in gymnastics training programs, particularly within academia. Many gymnastics instructors focus on verbal feedback and visual cues, which has its place, but insufficient biomechanical information can hinder skills smoothing down to a higher competitive level. And it was concluded to the researcher, considering earlier studies, that female students at the College of Physical Education and Sport Sciences/University of Baghdad: they experienced difficulties in response to the acquisition and learning of the gymnastics skills which are selected (Shaleh et, al.,2023). Their lack of structured biomechanical feedback that can swiftly address these issues in training may lead to slower learning rates, a chain of technical errors in performance and negligible performance improvements. To help bridge this gap, this study will investigate the effects of mechanical feedback on the learning and retention of specific gymnastics skills while providing a foundation for developing more efficient training methodologies.

The study contributes to the ever-expanding literature on both motor learning and biomechanics by offering empirical evidence of the effectiveness of mechanical feedback in the context of gymnastics training. Mechanical feedback, unlike conventional feedback mechanisms that tend to lean on the subjective and vary widely in consistency, provides objective and measurable insight into your execution of movement so you can make accurate adjustments (Ghafoor et,

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al.,2022). Through a comprehensive exploration of its influence on game acquisition and retention, this study will elucidate practical recommendations for practitioners and coaches, looking to optimize training strategies. Furthermore, the results may lay the groundwork for incorporating cutting-edge feedback techniques into more extensive physical education curricula to enhance training effectiveness across diverse sports arenas. This study is significant because it can be applied to connect the theoretical knowledge to the practical implementation of gymnastics training. Understanding the efficacy of mechanical feedback in refining skill development would help shape faster learning opportunities in the curriculum of other sports programs. Additionally, the findings of this study may be beneficial in the context of injury prevention strategies that incorporate biomechanical principles (Al-Azzawi et,al.,2013). As the field of sports science evolves, there is a growing reliance on evidence-based practices, and the findings of this study highlight the importance of utilizing advanced feedback systems to optimize performance in individuals, who present unique challenges to traditional paradigms of training. In conclusion, the results have far-reaching implications for coaching practices, sports technology innovation, and the evolution of training methods in gymnastics and other skill-oriented sports.

Feedback establishes and plays one of the most critical roles in motor learning from practice, especially in gymnastics expertise for skill execution that requires accuracy in coordination and motor execution. Performed a systematic review of the effects of verbal feedback in gymnastics training (Al-Fadhli et,al.,2010). They found that auditory feedback aids the acquisition of motor skills by promoting efficiency of movement and minimizing errors. Considering the significant effects of the differing verbal cues on performance, the study highlights the importance of structured verbal feedback protocols to optimize learning outcomes in gymnastics training regimes. In the same fashion studied the influence of delayed mechanical feedback on long jump performance (Al-Fadhli et,al.,2017).. The analysis found that delayed feedback was a key factor in motor learning, providing time for an athlete to internalize adjustments in their movements. All sport types could promote more effective feedback by improving the timing of feedback: by ensuring that feedback is provided during an appropriate time window around a practice task.

Innovative technology applied to sports training has opened new ways to improve motor learning. by Al-Fadhli et,al.,(2017)., the implementation of serious games for gymnastics elements learning. This suggests that game-based learning strategies could help enhance engagement and skill retention for learners, and as a result, support modern gymnastics practitioners and educators. In addition, Ameen (2018) performed a systematic review on the use of Android-based apps applied to physical education and sports. Mobile applications offer immediate feedback, Omar said, so the athlete can monitor their success and immediately correct any shortcomings in their performance. The culmination of this technology helps facilitate the increasing use of digital tools in sporting training. Biomechanics is a critical component of gymnastics training as it ensures that movement patterns are executed with optimal mechanical efficacy. Explored the effect of feedback-driven corrective exercises on volleyball spiking performance (Al-Dulaimi & Al-Shammari, 2018). The results confirm the values of the kinematic indicators is greater when mechanical feedback is assigned compared to no mechanical feedback indicating that this method can also be useful in gymnastics training. Speculated on the role of kinesiology in gymnastics training, claiming knowledge of the biomechanics of motion can improve skills execution (Khiyon, 2011). Their study is further evidence for the notion that biomechanics-driven training methods induce more economical motor learning processes. Training approached in gymnastic are always recording to progress performance impossible. Investigated the effect of different spotting techniques on gymnasts' performance and self-confidence level (Starzak et al., 2022). This study reinforces the value of hands-on spotting as

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an essential coaching intervention which means the quality of execution is improved and the athlete is reaping the benefit of hands-on demonstrated techniques that can build the confided level. conducted a study on the structures of acquiring gymnastic and acrobatic skills among high school students (Zghibi, 2024). Researchers concluded that early exposure to structured training programs enhances long-term skill retention, emphasising the need for age-specific training approaches. The Debate of Training Methodologies- Sports science has always been curious about the effectiveness of different methodologies of training. Traditional training versus researcher-designed devices for handstand imbalance training (Abbas, Mushref, & Shalash, 2024). The results indicate that training with a device is effective as it increases the duration of handstands, reduces pain, and improves execution of other skills in beginner gymnasts. Our present study highlights the role of technology in gymnastics coach education and a few of its advantages.

This study mainly aims at examining the effect of the mechanical feedback on development and retention of certain gymnastics skills among the female students at the College of Physical Education and Sport Sciences. To reach this goal, the research will concentrate on these goals To evaluate the effects of mechanical feedback on precision of movement and execution of accuracy of gymnastics skills. To compare of the learning outcomes in students who receive mechanical feedback and in students relying solely on traditional coaching.

Method

This study used a quasi-experimental design to investigate the effects of mechanical feedback on the learning and retention of selected gymnastics skills. The study used a pre-test and post-test control group design. Participants were randomly assigned to an experimental group that received mechanical feedback or a control group that followed traditional coaching methods. The study looked to rely on empirical evidence on whether mechanical feedback was effective compared to the performance gains of the two groups.

The study was conducted at the College of Physical Education and Sport Sciences at the University of Baghdad using female students attending a gymnastics training course. Through purposive sampling, participants with the same skill level were used to ensure homogeneity of group [14]. Forty students, with twenty in the experimental group and twenty in the control group, were involved in the study. Informed consent was obtained from all subjects before enrolling in the study as in table 1.

Table 1. Participant Distribution Table.

Group	Number of Participants	Feedback Method
Experimental	20	Mechanical Feedback
Control	20	Traditional Coaching
Total	40	

All participants were required to take a pre-test prior to the training intervention to set performance baseline for selected gymnastics skills. The skills evaluated were, as demonstrated in table 2. Each of these skills were performed by the participant with the supervision of experienced gymnastics instructors. Scores were tabulated according to technical execution, movement accuracy, and movement stability, through a standardized point system as established by professional gymnastics evaluators. All subjects practiced these skills under the supervision of experienced gymnastics instructors. Performance was judged by technical execution, movement accuracy and stability using a standardized scoring system used by professional gymnastics assessors.

Table 2. The skills assessed

Skill	Performance Criteria
Straddle Forward Roll	Execution accuracy, movement control
Handstand	Stability, balance, alignment
Arabian Cartwheel	Coordination, rotation control
Cartwheel	Symmetry, fluidity
Balance	Postural control, endurance

The training intervention was conducted over a six-week period, during which participants attended supervised gymnastics training sessions three times a week for 60 min at a time. These sessions included skill-specific drills, corrections of movement content, and implementation of feedback targeted to improve gymnastics performance. The purpose of this study was to compare the effect of mechanical feedback with the conventional method used in the skill acquisition of female students in gymnastics (Al-Jaafreh & Qawaqzeh, 2024).

Participants within the experimental group were given real-time mechanical feedback when training. And this came not just from motion analysis software and video playback, but from biomechanical correction tools that allowed an athlete to home in on the minutiae of how closely their movements matched the ideals. Mechanical feedback introduced the concept that error correction could happen much faster, and that execution of technique could be enhanced. Participants in this group were able to address their form and coordination through visual analysis of their movement and immediate feedback on errors made.

FINDINGS AND DISCUSSION

This study also was held at the College of Physical Education and Sport Sciences, University of Baghdad to estimate the effect of mechanical feedback on the learning and retention of selected gymnastics skills for female students. Using purposive sampling, the participants were divided into two groups, an experimental group that received mechanical feedback during training, and a control group that followed traditional coaching methods in the absence of additional biomechanical intervention. The skills tested in the study were straddle forward roll, handstand, Arabian cartwheel, cartwheel and balance. To establish their initial skill levels, pre-tests were given to all participants before the intervention. The pre-test purpose was to evaluate the accuracy, execution, and stability of each skill based on standardized performance criteria before intervention. At training phase students in the experimental group received immediate mechanical feedback using motion analysis software, video feedback and biomechanical correction methods. It provided immediate feedback to adjust and correct the skill being practiced. In the control group, students were given only verbal and visual feedback by their coaches, which is the normal practice.

Students received an intervention for several weeks and had structured training sessions including practice, feedback, and repetition. A post-test was then evaluated after the training program to quantify the improvement in skill execution; pre- and post-training performance was compared between the two groups. Means, standard deviations, and t-tests are reported to assess the quality of mechanical feedback. To measure retention of the skill acquired, there was a follow up test after a set period to see how well the skill retained over time. The data were analysed, considering differences
2 in the pre-test versus post-test, between the experimental and control groups, and between groups based on the statistical significance of mechanical feedback as an aid in motor learning and retention. Mechanical feedback for gymnastics training resulted in significant improvements for skill execution in the experimental group compared to the control group ($p < 0.05$).

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The second section explains the post-test, pre-test, and retention test results for both the experimental and control group. The key purpose of this analysis is to assess mechanical feedback in skill acquisition and retention for female gymnastics students. Results are presented via tables and interpreted with an eye towards the statistical significance of improvements noted in skill execution. This section attempts to evaluate the effectiveness of biomechanical feedback in gymnastics training by comparing the performance of the experimental and control groups. The results also shed light on the stability and plasticity of skill acquisition and whether mechanical feedback enables more accurate, stable, and precise movement execution.

Table 3 depicts the mean and standard deviation (SD) values of each skill tested pre- and post-the training intervention for both cohorts of participants. The experimental group receiving mechanical feedback also demonstrated post-test mean values considerably superior to their pre-test mean values suggesting an impressive enhancement of skill execution. This block showed that the control group, trained using the traditional methods, also experienced performance improvements, however these improvements were not substantial as that of the experimental group. Standard deviation values suggest that post-test scores were highly representative of individuals with similar previous (pre-test) motor performance only for the experimental group, and these data thus indicate that mechanical feedback was a helpful method to reduce variability and improve motor execution.

Table 3. Mean and Standard Deviation Results for the Experimental and Control Groups.

Group	Skill	Pre-Test Mean	Pre-Test SD	Post-Test Mean	Post-Test SD
Experimental	Straddle Forward Roll	3.5	1.07	5.13	0.83
Experimental	Handstand	3.38	1.19	5.63	0.92
Experimental	Arabian Cartwheel	3.13	0.99	5.5	1.07
Experimental	Cartwheel	3.5	0.76	5.75	0.71
Experimental	Balance	2.88	0.99	4.75	1.04
Control	Straddle Forward Roll	3.13	0.83	5.13	0.83
Control	Handstand	3	1.07	5	0.93
Control	Arabian Cartwheel	2.75	0.46	5.38	0.92
Control	Cartwheel	3.25	0.46	5.75	0.71
Control	Balance	2.88	0.99	4.75	1.04

Table 4 summarizes the t-test results for the pre-test and post-test scores for each group, demonstrating a statistically significant difference between the two tests. As for the assessment of the skills, statistically significant improvements in each execution were observed in the experimental group, with greater t-values and lower p-values ($p < 0.05$) for all skills assessed, confirming that mechanical feedback was an effective means of increasing the execution of skills. The control group also had the same trends of statistical improvements, but they displayed lower t-values, indicating the amount of skill acquisition was not as vigorous as in the experimental group. These findings highlight that mechanical feedback produces a greater and quantifiable improvement in motor learning than standard feedback protocols.

Table 4. Results of the Differences Test Between Pre-Test and Post-Test Scores for the Experimental and Control Groups.

Group	Skill	t-Value	Sig. (p-value)	Significance
Experimental	Straddle Forward Roll	4.33	0	Significant
Experimental	Handstand	4.97	0	Significant

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Experimental	Arabian Cartwheel	4.2	0	Significant
Experimental	Cartwheel	5.46	0	Significant
Experimental	Balance	3.91	0.01	Significant
Control	Straddle Forward Roll	5.29	0	Significant
Control	Handstand	3.74	0.01	Significant
Control	Arabian Cartwheel	6.25	0	Significant
Control	Cartwheel	6.61	0	Significant
Control	Balance	3.91	0.01	Significant

Post-test Performance of Experimental and Control Groups. The experimental group wide-ranging surpassed the control group in all skills, as indicated by higher mean scores and significant t-values ($p < 0.05$). This suggests that mechanical feedback influenced skill acquisition more than traditional coaching did. The findings further augment the notion that mechanical feedback serves as an attuned stimulus to amplify performance prowess, optimizing movement precision, stability, and execution fidelity within the realm of gymnastics as in table 5.

Table 5. Results of the Differences Test Between the Experimental and Control Groups.

Skill	Experimental Mean	Experimental SD	Control Mean	Control SD	t-Value	Sig. (p-value)	Significance
Straddle Forward Roll	5.13	0.83	5.13	0.83	3.92	0	Significant
Handstand	5.63	0.92	5	0.93	2.99	0.01	Significant
Arabian Cartwheel	5.5	1.07	5.38	0.92	3.79	0	Significant
Cartwheel	5.75	0.71	5.75	0.71	3.38	0	Significant

The study results, as seen from the Sig. value, are showing how the experimental group, i.e., those receiving mechanical feedback, have outperformed the control group. less than 0.05 a degree of freedom. "Mechanical feedback is thus a powerful driver of motor learning and skill acquisition in gymnastics," the authors wrote. The significant improvement in performance seen in the experimental group can be explained by the fact that biomechanical analysis and video-based feedback systems offer accurate and timely feedback, enabling participants to effectively address errors and refine their execution. Feedback in motor learning is vital in improving performance and facilitating skill acquisition. Stated that effective feedback is based on feedback accuracy and the degree of relevance to the learner (Sorzano, 2023). This drives the learning process which is more effective if the feedback is accurate. Being able to get real-time data driven feedback allows athletes to diagnose problems, rectify their actions, and optimise their performance which results in better performance statistics (Al Ardha et al., 2024).

The experimental group utilized mechanical feedback that facilitated the tracking of movement patterns, allowing for adjustments in training in real-time. Compared to traditional methods, this approach increased the accuracy of movement trajectories and decreased the distance between actual and ideal performance. Stated that visual feedback systems, examples include video playback, biomechanical analysis tools and motion capture systems, allow the athlete to clearly understand what is going wrong and what the correct movement looks like, resulting in more proficient skill performance (Hasan & Hasan, 2022). In addition, biomechanical feedback is an important component of motor learning because it provides the learner with an accurate demonstration of the skill that he or she must develop which enhances the ability of the learner to execute the skill in a correct manner (Ávalos Ramos & Vega Ramírez, 2022). Athletes use someone else's guidance and see their performance on a screen and analyse their movements trajectories and figure out the errors in their technique to rectify it.

The second contributing factor that potentially paved the way to the success of the experimental group is an increase in kinaesthetic awareness a known effect of rehearsing a movement repeatedly and adding corrective feedback (Morsalfard, Nasermeli, & Namina, 2023). Biomechanical feedback during the training embeds motor programs in the learner that optimize the ability to execute and coordinate movement. This stimulus and feedback mechanism allows athletes to learn more quickly and retain information over the long-term, which can translate into better performance in the long run (Moon & Park, 2023). The control group, which received only verbal and visual feedback from coaches in the weight room, did not experience as an increase in performance. Without a clear visual representation of their movement, verbal feedback alone can be imprecise and not aid in learning and can lead to hesitation within learners. Coaches' instructions can be important as well, but with limitations those common feedback methods are poorly suited for spiking subtle errors, let alone making instant corrections to motion trajectories.

By combining video-based feedback with biomechanical analysis tools, athletes gain insight into their performance and the ability to pinpoint where changes in technique may be needed. In gymnastics especially, where precision in movement, how one's body is positioned, and timing matter in total measure of success, that is crucial. For example, the incorporation of an external feedback system in the form of motion analysis software and slow-motion video playback can enhance motor control and improve overall performance (Zemková & Kováčiková, 2023). Additionally, the benefit of mechanical feedback on motor learning can be accounted for by the theory of motor control and motor program formation. Schema Theory (Schmidt, 1975) suggests that motor learning involves repetition and feedback, whereby varying our motor output leads to the formation of a general motor program in the mind, able to be adapted based on execution conditions. The brain stores these motor programs, which can be activated and performed in future performances. Visual and mechanical feedback can hasten the learning process, enabling athletes to create more accurate motor programs and perform movements more precisely.

Mechanical feedback not only improves an athlete's technical performance but also helps them develop a better cognitive feel for the mechanics behind the movements they are executing. This use of immediate feedback helps athletes become more responsible of their actions and their effects. This factor of cognitive awareness is paramount to developing your overall performance in gymnastics as this can ultimately help you with your decision making and improve your reaction time as well as muscle memory (Zemková & Kováčiková, 2023). These results are consistent with previous literature and highlight the need for technology-based in-sport feedback (Blynova et al., 2022). In a working paper, the authors found that utilizing temporarily landmark feedback notions, real-time performance data measurements, motion capture systems, force sensors and observation tools, resulted in better skill performance over practice time and increased performance consistency with greater magnitudes.

While the results were favourable, the study also reveals some limitations that future research should consider. One limitation is that the intervention was only delivered over 6 weeks. Future studies could also address over longer training if mechanical feedback would still elevate performance compared to control conditions and if, they would have a longer lasting imprint on muscle memory and stability of performance. Furthermore, the sample size was small and thus, findings may not be generalizable to a broader population.

8 To sum up, the findings from this research provide significant evidence for the positive impact of mechanical feedback on motor learning and skill acquisition in the realm of gymnastics. Coaches can also use this technology to deliver real-time, data-driven feedback to athletes, enabling them to

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gain a competitive advantage by improving their movement accuracy and consistency. Biomechanical feedback systems, including video analysis systems and motion tracking technology, are revolutionizing sports training methods. Further research should increase sample sizes, extend training periods, and incorporate artificial intelligence-based feedback systems to enhance athletic performance to an even greater extent.

CONCLUSION

This research makes a valuable theoretical contribution by providing evidence that data-driven mechanical feedback can significantly improve motor skill learning, reduce movement variation and optimise performance strategies. In practical terms, the study demonstrates the feasibility of integrating biomechanical tools into training, enabling trainers to transcend traditional methods such as verbal and visual feedback. The findings have broad implications, including the potential adaptation of mechanical feedback in various sports and physical education programmes. This system improves exercise efficiency and safety and can reduce injuries and engineering errors. Further research is needed to investigate long-term retention and the integration of artificial intelligence for real-time feedback, as well as its psychological impact on athletes' motivation and confidence. Large-scale, cross-disciplinary studies will enhance our understanding of the effectiveness of mechanical feedback in modern sports training and education.

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