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Innovation of Artistic Gymnastics Equipment in Limited Space

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Abstract. This study was motivated by the limited space for men's artistic gymnastics in Central Java, which generally uses a small and unrepresentative school arena, so the arrangement of equipment such as uneven bars, parallel bars, rings and saddle horses is not optimal. The aim of this study is to develop innovative multifunctional artistic gymnastics equipment in a limited space to optimise the gross motor development of junior male artistic gymnasts and to improve the effectiveness and efficiency of training. The research method uses a research and development approach with quantitative data from expert questionnaires, athletes and coaches, as well as analysis of equipment innovation based on Computer Aided Design (CAD) technology. The results of the analysis showed the maximum stress on the developed equipment, namely single bars 45.7 MPa, parallel bars 72.6 MPa, straps 29.48 MPa and saddles 92.9 MPa, which are located at the ends near the pivot point. The results of the analysis showed that the Innovation products are safe to use. The conclusion the conclusion of this research is the creation of artistic gymnastics equipment innovation in a limited space that is feasible to use.

Keywords: artistic gymnastics; sports biomechanics; training tool; training equipment for gymnastics

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1. Introduction

Artistic Gymnastics is a sport that requires special equipment with strict international standards [1], [2], [3]. Equipment such as single bars, parallel bars, bracelets and saddles play a vital role in supporting the training and performance of athletes, particularly in the development of young athletes [4], [5]. In Central Java, the main challenge for men's artistic gymnastics training is limited practice space, often in unrepresentative school gyms. This has an impact on the arrangement of equipment, which is sub-optimal, often outside the building and exposed to external factors such as the weather. This condition disrupts the training process and has the potential to inhibit the gross motor development of the athletes, especially at the stage of learning the movement, getting the idea of the movement and fixation. The innovation and development of multifunctional gymnastics equipment in confined spaces is an important solution to improve the quality of training and support the gross motor growth of young

athletes. The development of modern sports science and technology presents a number of new in science and technology in meeting various sports facilities by integrating multi-functional space. [6], [7], [8]. The science and technology of sports engineering focuses on the development of equipment for sports that are multifunctional, complex and constant. In order to determine the constant sports equipment, computer aided design software is needed, which is part of the multidisciplinary study of sports engineering and as a fulfilment of the composition of the requirements in the code of points of artistic gymnastics. [9], [10]. Sports engineering is a field of science that determines the conceptual design of construction integrating high performance and sustainable gymnastics equipment [11].

Artistic gymnastics equipment requires a good design because the equipment is expected not to change position when the tool is used, so that the gymnast's movement technique is stable during training or competition [12], [13]. Innovation of appropriate sports equipment will have an impact on users and motor learning stages consisting cognitive stage, associative stage and autonomous stage [14], [15]. Growth and development stages of learning motion according to Gentile " s divide into 2 stages, namely getting the idea of the movement and fixation. Getting the idea of the movement Focusing on learning movement needs to identify relevant and irrelevant stimuli in relation to skills and movement patterns that are appropriate to achieve effective skill goals, while fixation relates to what is required by each type of skill in the movement patterns that must be produced to achieve the goal.

Optimising the idea of movement and fixing it requires innovation in sports techniques that produce technical products and tactical functions, such as different times, different spaces and different positions according to the needs of the sport. These needs include the development of sports facilities and infrastructure among all the innovations of sports gymnasiums and the need for energy sources for gymnasts in the process of artistic gymnastics training [16], [17].

Along with the development of science and technology, the field of sports engineering has facilitated various innovations in the world of sport, including the development of multifunctional and high-performance equipment. Sports engineering focuses on the development and design of complex yet effective sports equipment that can best support the training needs of different sports. Research into Computer Aided Design (CAD) as part of sports engineering has been widely applied to ensure that sports equipment meets the requirements of the Artistic Gymnastics Code of Points, particularly in terms of safety, stability and performance [4], [18].

The existing literature indicates that the stability and quality of the construction of gymnastic equipment is of great importance. Unstable equipment can cause disturbances in the athlete's movement technique, affect the stability of movements and impede the process of motor learning. On the other hand, the stages of movement learning according to Gentile's theory of stages of learning emphasise the importance of getting the idea of the movement and fixation in mastering effective movement skills. Understanding and applying innovations in sports equipment that support this movement learning process is essential to accelerate and optimise the mastery of athletic skills.

Previous research on the development of artistic gymnastics equipment has focused more on improving the standards and safety of the apparatus in a wide and ideal environment [19], [20]. However, there are gaps in research investigating the innovation of artistic gymnastics equipment in confined spaces, particularly those designed to support the gross motor development of young athletes with limited facilities. This study attempted to fill this gap by integrating several gymnastic tools, such as single bars, parallel bars, wrist bands and saddle horses, into a multi-functional tool suitable for small training spaces. This innovation is expected to support the exercise programme without interference from external factors and to meet the standards of the artistic gymnastics points code.

Based on the observation, the use of artistic gymnastics equipment in Central Java on average with a school arena that is not representative as a means of exercise, especially on a single bar, parallel bars, bracelets and saddle horses in the arrangement is still outside the building, which has not been adapted to the needs of gross motor development gymnasts, it has an impact, this situation resulted in the ineffectiveness of the implementation of the exercise program due to external factors, one of which is the weather factor. To overcome these problems, researchers need to explore the innovation of artistic

gymnastics equipment in a limited space as the optimisation of gross motor growth, getting the idea of movement and fixation in accordance with the anthropometric needs of junior men's artistic gymnasts by integrating single bars, parallel bars, bracelets and saddle horses designed into one tool, as a means of mastering gymnasts ' movement skills to meet the composition of the artistic gymnastics code of points. This study aims to develop innovative artistic gymnastics equipment in a limited space in order to optimise the gross motor development of junior male artistic gymnasts. This innovation integrates several gymnastic tools into a safe, efficient and effective multifunctional equipment, which is able to improve the gymnasts' movement skills and meet the composition of the artistic gymnastics code of points.

2. Methods

This study uses research and Development methods, with quantitative and qualitative approaches to develop multifunctional artistic gymnastics equipment that fits the needs of limited space [21], [22], [23]. The study participants consisted of 20 people, namely 5 experts, 10 athletes and 5 coaches, selected by purposive sampling. The research design includes several stages: initial data collection through questionnaires and interviews, development of tool design using computer aided design (CAD) technology, validation of the tools by experts and users, and field trials [24]. Data measurement was carried out using questionnaires to measure user perceptions of the functionality, safety and effectiveness of the space, and interviews to explore the user experience. Data analysis was quantitative using descriptive statistics and qualitative using thematic analysis. The research process includes needs identification, data collection, tool design, validation, testing and analysis of the results to provide recommendations for improving the tool.

Table 1. Questionnaire of gymnasts and technologists

No	Criteria	Rating Indicators	Expert Assessment Results			
			1	2	3	4
1	Aspects Of Originality	Is the result of the findings of researchers.				
		There is a distinguishing aspect with existing sports technology.				
2	Aspects Of Innovation Excellence	Has advantages in innovative tool design.				
3	Aspects Of Usefulness	Has the power to use a multifunctional tool as an effort to develop artistic gymnastics achievements in Central Java.				
4	Economic Aspects	Have a positive impact in the application of cutting-edge technology CAD, in designing products development of multi-purpose exercise equipment artistic gymnastics on a limited space				
		Has commercialization potential and market reach				
5	Security Aspects	Have a good level of security for artistic gymnasts				
6	Comfort Aspects	Has a good comfort level for artistic Gymnastics athletes				
7	Aspects Of Completeness Of Supporting Data	Has a description in the use of multi-purpose exercise equipment development of Artistic Gymnastics in a limited space				

3. Results and discussion

The results of the evaluation questionnaires carried out by gymnasts and technical experts on the innovation of the multipurpose apparatus for artistic gymnastics show that this apparatus receives a positive response in various aspects, such as originality, excellence of innovation, usefulness, economy, safety, comfort and completeness of the supporting data. The results of the expert questionnaire are presented in Tables 2 and 3.

Tabel 2. Results of filling out questionnaires gymnasts and technologists

No	Criteria	Rating Indicators	Expert Assessment Results			
			1	2	3	4
1	Aspects Of Originality	Is the result of the findings of researchers.	3	4	4	3
		There is a distinguishing aspect with existing sports technology.	3	3	4	3
2	Aspects Of Innovation Excellence	Has advantages in innovative tool design.	4	3	4	3
3	Aspects Of Usefulness	Has the power to use a multifunctional tool as an effort to develop artistic gymnastics achievements in Central Java.	4	4	3	4
4	Economic Aspects	Have a positive impact in the application of cutting-edge technology CAD, in designing products development of multi-purpose exercise equipment artistic gymnastics on a limited space	4	3	3	4
		Has commercialization potential and market reach	3	3	3	3
5	Security Aspects	Have a good level of security for artistic gymnasts	3	3	3	4
6	Comfort Aspects	Has a good comfort level for artistic Gymnastics athletes	4	3	3	3
7	Aspects Of Completeness Of Supporting Data	Has a description in the use of multi-purpose exercise equipment development of Artistic Gymnastics in a limited space	4	4	3	4

Tabel 3. Percentage assessment of gymnasts and technologists

NO	Criteria	Rating Indicators	Percentage
1	Aspects Of Originality	Is the result of the findings of researchers.	87,5 %
		There is a distinguishing aspect with existing sports technology.	81,25 %
2	Aspects Of Innovation Excellence	Has advantages in innovative tool design.	87,5 %
3	Aspects Of Usefulness	Has the power to use a multifunctional tool as an effort to develop artistic gymnastics achievements in Central Java.	93,75 %
4	Economic Aspects	Have a positive impact in the application of cutting-edge technology CAD, in designing products development of multi-purpose exercise equipment artistic gymnastics on a limited space	87,5 %
		Has commercialization potential and market reach	75 %
5	Security Aspects	Have a good level of security for artistic gymnasts	81,25 %
6	Comfort Aspects	Has a good comfort level for artistic Gymnastics athletes	81,25 %
7	Aspects Of Completeness Of Supporting Data	Has a description in the use of multi-purpose exercise equipment development of Artistic Gymnastics in a limited space	93,75 %

The results of the questionnaire assessment Table 1, in general, the results show that this tool has advantages in originality, innovative design, as well as high usefulness, especially in coaching artistic gymnastics achievements, although there are some variations in the assessment, especially in the aspect of convenience and commercialisation potential. Table 2, where the usefulness and completeness of

supporting data received the highest score (93.75%), while the commercialisation aspect received a lower percentage (75%). The aspects of originality, innovation, economy, safety and comfort are also considered to be quite high with percentages above 80%. Overall, the tool is considered to have strong potential in various aspects, but the potential for commercialisation and comfort can still be improved. Here's a picture of the initial design of the Artıstık gym equipment in a limited space.

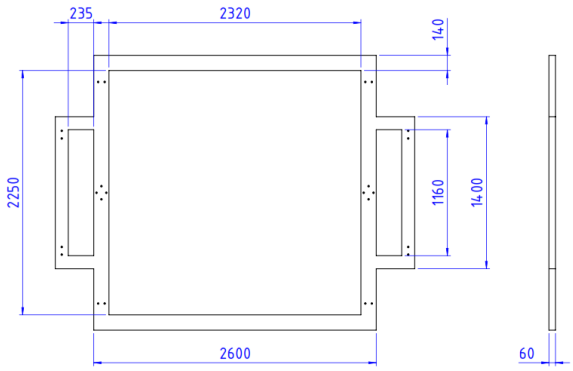

Figure 1. Specification Of Single Cross

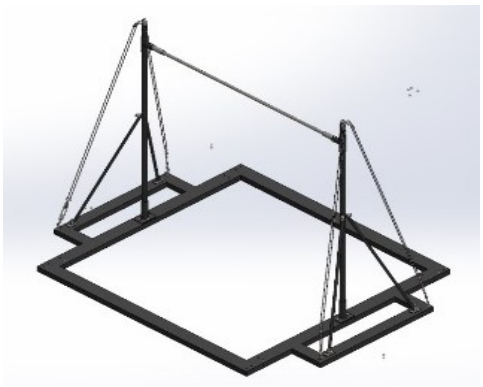

Figure 2. Single Crossbar Design

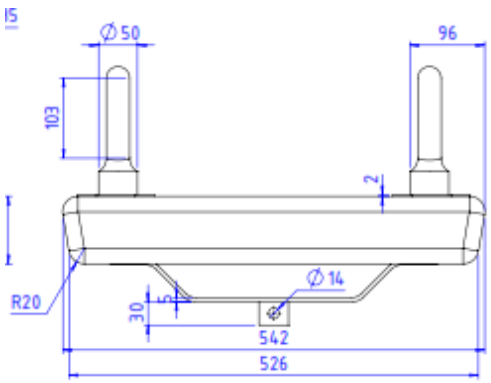

Figure 3. Specification Of Horse Saddle Stage 1

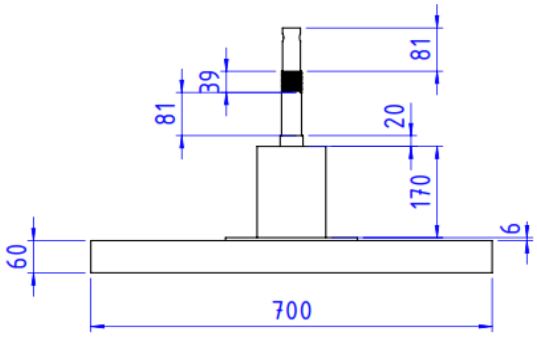

Figure 4. Specification Of Horse Saddle Stage 2

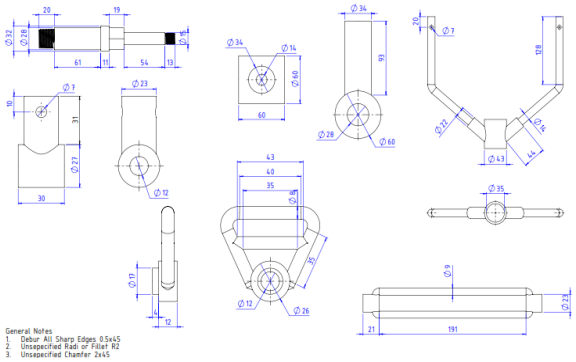

Figure 5. Specification Of Horse Saddle Stage 3

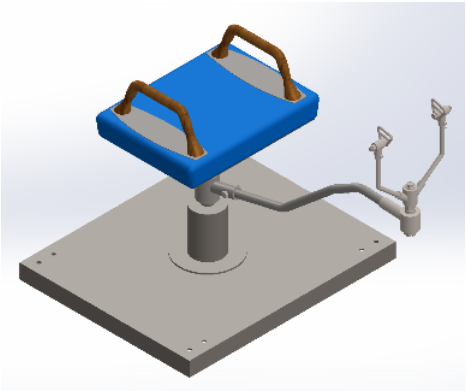

Figure 6. Saddle Horse Design

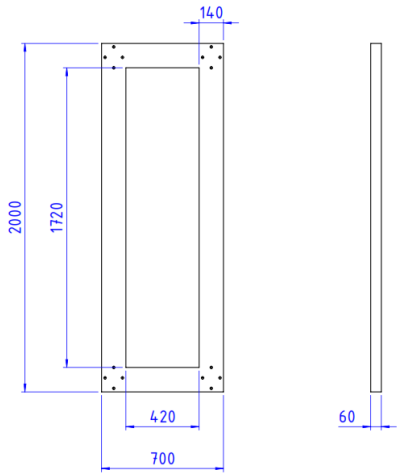

Figure 7. Specification Of Parallel Bars

Figure 8. Parallel Bars Design

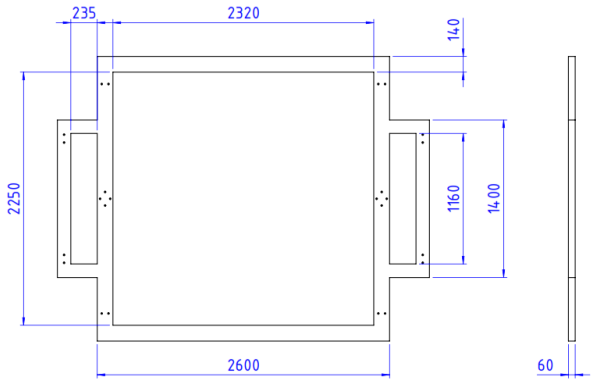

Figure 9. Specification of bracelets Stage 1

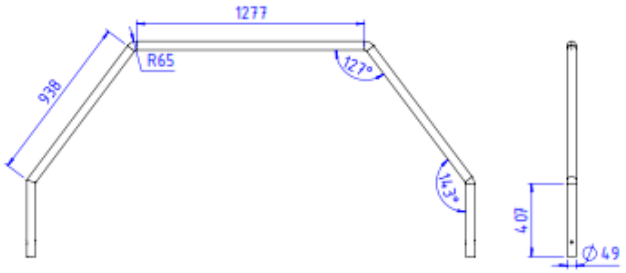

Figure 10. Specification of bracelets Stage 2

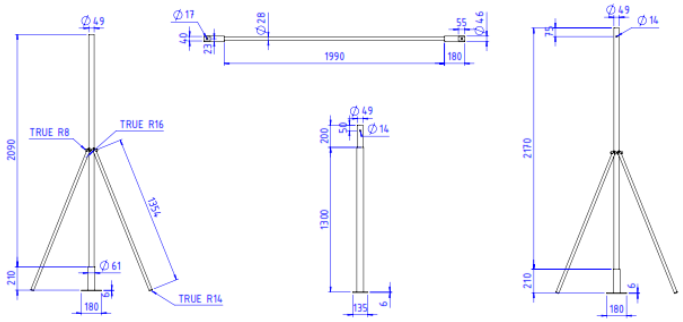

Figure 11. Specification of bracelets Stag

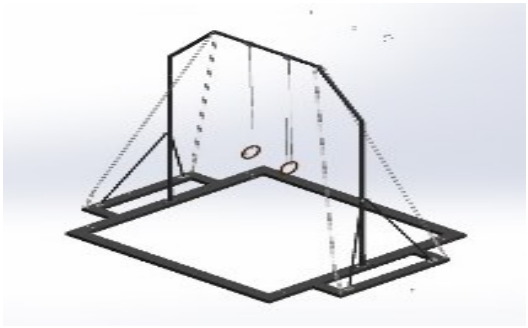

Figure 12. Design bracelets

Product design analysis of artistic gymnastics equipment innovation in limited space using computer aided design. Stages of the simulation process carried out on the assembly of a single bar tool, parallel bars, saddle horses and wristbands on the structure of the assembled parts will be simulated separately, and each reaction force that occurs due to loading on the first component will be used as input parameters for the simulation of the second component, and so on. The simulation to be carried out is a simulation used to describe or take into account the effects that occur on the components due to loading. The load applied in this simulation is 700 Newtons. This value is obtained by estimating that the weight of the user is 70 kg. The results of the tool section that has been analysed, obtaining the maximum stress on the single cross section 45.7M.Pa, parallel bars of 72.6 MPa, bracelets of 29.48 MPa saddle horses of 92.9 MPa, which are located on the end parts near the fulcrum in the developed tool. Based on the results of the computer aided design analysis, the products used can be used safely.

Disscussion

The identification of artistic gymnastic talent in Central Java is still based on a traditional approach that does not differentiate the quality of prospective gymnasts. Proper anthropometric composition is considered important to support performance. However, the majority of gymnastics organisations still

use cramped school gyms, which means that the arrangement of equipment is not optimal and is affected by the weather. Equipment innovation involves collaboration between engineering, sports medicine and equipment manufacturers to develop products that meet the needs of athletes. The development of facilities and infrastructure is necessary to meet the standards of artistic gymnastics and to support the mastery of movement skills in accordance with the anthropometry and mechanics of gymnastic movements [25], [26], [27].

Gross motor development in young artistic gymnasts is essential to ensure optimal physical growth. Gross motor skills involve the movement of large muscles and must be developed early so that the gymnast can master basic techniques such as vaulting and tumbling. This exercise also promotes coordination and balance, which are essential for performing complex movements on gymnastic apparatus. [28], [29], [30].

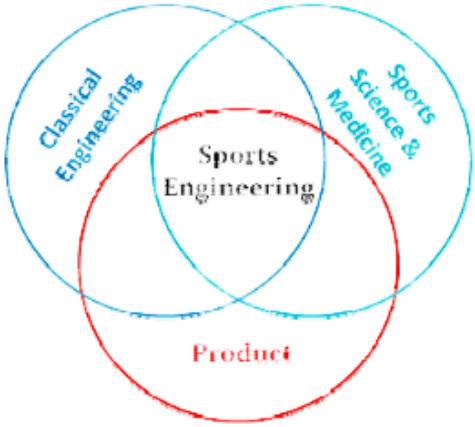

Figure 13. The interrelation of classical engineering, science, sports medicine and sports equipment

Anthropometry plays an important role in monitoring the athlete's physical growth, including muscle mass and changes in posture. Between the ages of 8-13 years, the focus of training is on basic motor development and muscle stability, while heavy weight training must be avoided to prevent injury [31], [32], [33]. Between the ages of 14 and 18, muscle mass growth can be further enhanced by planned training. Anthropometric monitoring in athletes under the age of 17 is important to ensure that height growth and body composition are in balance with muscle strength [34], [35].

The rapid growth in posture, particularly during adolescence, affects performance. Biomechanics also plays a role in understanding the movement and strength required for gymnastic apparatus such as uneven bars and parallel bars, where body proportions and muscle strength must be adapted to the developmental stage of the young athlete. Structured training in line with physical development and regular monitoring are necessary to optimise performance and avoid injury [21], [36], [37].

Research on parallel bars has shown that skills such as huge backward swings require special technique.

Especially as the apparatus has height limitations that affect movement. There are significant differences between parallel bars and horizontal bars in terms of joint torsion and mechanical work, particularly on the shoulder and hip joints. Coaches need to understand these differences in order to train gymnasts effectively.

In addition, tools such as wrist bands and saddle horses also require strong muscle control, especially in young gymnasts under the age of 17 who are still in the growth phase. The biomechanics of this apparatus are influenced by anthropometrics such as arm length and body proportions. Saddle horses, require core muscle strength and flexibility, where different body proportions can affect balance and performance [38], [39], [40].

An understanding of biomechanics and anthropometry is essential to help young gymnasts adapt to their physical development. Exercises adapted to the growing body of young athletes can optimise their performance and prevent injuries, while improving their ability to master movements on various gymnastic apparatus.

The single bar has been designed with good construction and appropriate materials to ensure safety during use. The simulation results show that the safety factor is in the good category and the elasticity of the bars meets the standards of the Artistic Gymnastics Code of Points. This ensures that the equipment can be used safely during training sessions. The elasticity of rail bars allows for efficient energy storage and recovery. However, studies show that gymnasts sometimes release the bar when they jump, which can reduce the effectiveness of the technique. Gymnasts can use this elasticity to determine the right time to perform a skill, based on the tension felt in the hands when using rail bars [41], [42], [43].

To increase flexibility, single bar products are fitted with springs that have a positive effect on the elasticity of the rail bars. Flexibility and the use of springs help to minimise the impact between components, supporting flexibility during use. According to the Federation Internationale de Gymnastics, individual bars act as linear springs, with a linear relationship between the load applied and the tension on the bars. The tension of the wires that stabilise the uprights also affects the stiffness of the bars, which can affect a gymnast's technique [44]. Research shows that bar displacements are calibrated with forces ranging from 100N to 4000N, with three levels of cable tension reflecting the variations commonly used.

The use of AIDS with an electric motor drive in the circular movements of artistic gymnasts on the saddle horse apparatus. Research shows that the location of the suspension (knee or ankle) affects the kinematics and kinetics of the movement. Assisted knee movement is more similar to unassisted movement than ankle suspension, indicating an increase in the diameter of ankle movement. Suspension in the knees reduces the moment of inertia and results in a shorter duration of movement [17], [45].

These aids also help to correct the amplitude of movement by reducing body flexion and increasing shoulder extension, regardless of the point of suspension. Suspension at the ankle provides greater vertical movement and maintains a higher position, thus optimising the gymnast's movement skills. In addition, AIDS, with its elastic bearing components, helps the junior gymnast develop gross motor skills. Although the hip joint moment is lower in the knee suspension, there is no significant difference in the front suspension between the knee and ankle [46], [47].

Application of biomechanical principles to optimise the performance of gymnasts on parallel bars, particularly for junior male artistic gymnasts. Mastering gymnastic elements on parallel bars involves the development of an elastic apparatus as well as kinematic and dynamic analysis of the gymnast's movements. Factors such as height, leg length, knee and shoulder joints are important to consider.

Research has shown that the kinetic energy lost during a swing can be compensated for by the use of the hip and shoulder joints. On parallel bars, hip and shoulder extension torques are required to lift the body, and the regulation of these torques is more complex than on horizontal bars. The torsional effort on the Pralel bars is greater, especially in the shoulder joint, which requires a longer and more intense effort to reach the handstand position.

Mastering artistic gymnastics movements on the horizontal bar requires the constant involvement of concentric and eccentric muscles due to the instability of the apparatus, which moves in all directions. This has implications for technique, particularly in movements such as kip, swing, swing to handstand, strength elements and hold elements. Coaches and gymnasts should develop technique and strength at the same time, especially in the preparatory phase.

Angular momentum and moment of inertia play an important role in the rotation of the body that occurs when the gymnast performs spins in the air on apparatus such as single bars, parallel bars and rings. Friction, air resistance and load torque affect the speed and control of the rotation. The elasticity of the apparatus also allows energy to be stored and recovered, which helps in certain movements, although it must be used precisely to avoid negative effects.

Static and dynamic balance are very important in gymnastics, with the gymnast's ability to control angular momentum when performing movements such as handstands. Meanwhile, dismount ability relies on conservation of momentum, where the gymnast uses torque to control rotation and take-off speed.

An important new finding in the study is the emphasis on developing training tools that match the physical development of junior gymnasts. The study adds a new dimension by introducing innovative tools that can be adapted to gymnasts' anthropometry and confined training spaces, which have not been extensively addressed in previous studies. The study also introduces the effect of equipment elasticity on joint torsion, which can be used by trainers to improve gymnasts' technique, particularly in dynamic and static movements.

The main implication of this study is to improve the effectiveness of the training of young artistic gymnasts by developing equipment that is more adaptable to anthropometric changes. This can help gymnasts optimise their physical development and reduce the risk of injury, especially during the period of rapid growth at puberty, this can help gymnasts optimize their physical development and reduce the risk of injury, which in terms of gravity, torque, and joint extension play an important role in movement control and injury prevention. Product innovation of artistic gymnastics equipment in limited space on single bars, parallel bars and bracelets is a tool that requires high strength and coordination because gymnasts perform various acrobatic movements, the influence of gravity on the developed product is very significant in the release and landing phases, while in the saddle horse tool, gymnasts perform simultaneous and repetitive 360-degree circuits using balance and body momentum with aids that are emphasized on the ankles as mastery of gymnast movements in joint extension and rotation of leg movements during circuits.

In addition, the innovation of this tool provides opportunities for gymnastics coaches and organisations to create a safer and more effective training environment, regardless of space and weather constraints. Potential product innovation of artistic gymnastics equipment in limited space has commercial viability in the market reach economically with estimated product manufacturing costs more efficient by integrating the equipment 4 tools into one tool and can be used practically by coaches and gymnasts.

Trials of this innovative equipment need to be conducted over a longer period of time to truly understand its impact on the overall performance of gymnasts. In addition, further research is needed to test the effectiveness of this equipment in different age groups and skill levels, particularly in senior gymnasts who have different biomechanical challenges to junior gymnasts. Overall, this research adds to the understanding of how anthropometric and biomechanical factors can be optimised through gymnastic equipment innovation, which is relevant to improving gymnast performance and safety.

4. Conclusions

Product innovation artistic gymnastics equipment in a limited space is specifically used as an alternative means of exercise to optimize the implementation of the exercise program as the optimization of gross motor development artistic gymnasts junior men to improve the skills of athletes on a single crossbar, parallel bars, bracelets and saddle horses without interference external factors. Gymnast models include anthropometric segments in determining the correct training programme and require upper body strength and stability as well as the ability to coordinate core muscle movements. Longer and less stable postures in young athletes can be a challenge in maintaining balance when performing jumps and rebounds on the single bar, the parallel bars of the saddle horse. From an anthropometric point of view, body proportions such as arm length and height greatly influence the effectiveness of repulsion and swing movements. Biomechanics also takes into account the moment of force resulting from the gymnast's movement to flex/lengthen the joint and increase the gymnast's mechanical energy to support performance.

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References

[1] S. Tayne, L. Bejarano-Pineda, and M. R. Hutchinson, "Gymnastics (Artistic, Rhythmic, Trampoline)," 2021, *Springer International Publishing*. doi: 10.1007/978-3-030-66321-6_5.

[2] G. Cervin, "Ringing the Changes: How the Relationship between the International Gymnastics Federation and the International Olympic Committee Has Shaped Gymnastics Policy," 2020, *Human Kinetics*. doi: 10.1123/shr.2019-0041.

[3] J. Weber, "DEMANDS PROFILE IN WHEEL GYMNASTICS," 2022, *University of Ljubljana*. doi: 10.52165/sgj.14.1.119-130.

[4] E. R. Sukamti and A. Chrisnanda, "Developing Basic Techniques of Artistic Gymnastics Book: Gymnastics on Motion," 2019, *SCITEPRESS - Science and Technology Publications*. doi: 10.5220/0009303901760179.

[5] S. Linge, O. Hallingstad, and F. Solberg, "Modelling the parallel bars in Men's Artistic Gymnastics," *Hum Mov Sci*, vol. 25, no. 2, pp. 221–237, 2006, doi: https://doi.org/10.1016/j.humov.2005.11.008.

[6] H. Zhang, J. Chai, and C. Li, "On innovative strategies of youth sports teaching and training based on the internet of things and artificial intelligence technology from the perspective of humanism," *Learn Motiv*, vol. 86, p. 101969, 2024, doi: https://doi.org/10.1016/j.lmot.2024.101969.

[7] Z. Chen and X. Dai, "Utilizing AI and IoT technologies for identifying risk factors in sports," *Heliyon*, vol. 10, no. 11, p. e32477, 2024, doi: https://doi.org/10.1016/j.heliyon.2024.e32477.

[8] Y. Qi, S. M. Sajadi, S. Baghaei, R. Rezaei, and W. Li, "Digital technologies in sports: Opportunities, challenges, and strategies for safeguarding athlete wellbeing and competitive integrity in the digital era," *Technol Soc*, vol. 77, p. 102496, 2024, doi: https://doi.org/10.1016/j.techsoc.2024.102496.

[9] F. Wang, T. Zhang, Q. Zhou, and Y. Lu, "Comparison of the morphological accuracy of automatic crowns designed by multiple computer-aided design software programs with different levels of dentition information acquisition," *J Prosthet Dent*, vol. 132, no. 2, pp. 441–452, 2024, doi: https://doi.org/10.1016/j.prosdent.2023.01.024.

[10] L. Pelliccia, M. Bojko, R. Prielipp, and R. Riedel, "Applicability of 3D-factory simulation software for computer-aided participatory design for industrial workplaces and processes," *Procedia CIRP*, vol. 99, pp. 122–126, 2021, doi: https://doi.org/10.1016/j.procir.2021.03.019.

[11] C. Yuza, M. Asmawi, and W. widiastuti, "Model Latihan Gerak Dasar Senam Lantai B-Gym Untuk Pemula (Usia 9-12 Tahun)," *Jurnal Segar*, vol. 7, no. 2, pp. 1–11, Sep. 2019, doi: 10.21009/segar/0702.01.

[12] B. Mkaouer, S. Amara, R. Bouguezzi, A. Ben Abderrahmen, and H. Chaabene, "Validity of a new sport-specific endurance test in artistic gymnastics," *Front Sports Act Living*, vol. 5, p. 1159807, Sep. 2023, doi: 10.3389/fspor.2023.1159807.

[13] R. B. Aji-Putra, T. Rahayu, W. Kasmini, and Sulaiman, "The software instrument for gymnast posture analysis," *Journal of Human Sport and Exercise*, vol. 17, no. 2, Sep. 2020, doi: 10.14198/jhse.2022.172.20.

[14] H. Aliriad, S. Soegiyanto, H. Setijono, and S. Sulaiman, "Effect of the Project-based Learning Model, Age, and Motor Educability on Fundamental Motor Skills in Early Children," *Health*

Education and Health Promotion, vol. 11, no. 1, pp. 125–131, 2023, doi: http://dx.doi.org/10.58209/hehp.11.1.125.

[15] H. Aliriad, S. Adi, J. G. Manullang, I. B. Endrawan, and M. H. Satria, "Improvement of Motor Skills and Motivation to Learn Physical Education Through the Use of Traditional Games," *Physical Education Theory and Methodology*, vol. 24, no. 1, pp. 32–40, 2024, doi: https://doi.org/10.17309/tmfv.2024.1.04.

[16] C. Schärer, L. Reinhart, and K. Hübner, "Age-Related Differences between Maximum Flight Height of Basic Skills on Floor, Beam and Vault and Physical Condition of Youth Female Artistic Gymnasts," *Sports*, vol. 11, no. 5, p. 100, Sep. 2023, doi: 10.3390/sports11050100.

[17] S. Kaufmann *et al.*, "Energetics of Floor Gymnastics: Aerobic and Anaerobic Share in Male and Female Sub-elite Gymnasts," *Sports Med Open*, vol. 8, no. 1, p. 3, Sep. 2022, doi: 10.1186/s40798-021-00396-6.

[18] N. Barker-Ruchti, R. Kerr, A. Schubring, G. Cervin, and M. Nunomura, "'Gymnasts Are Like Wine, They Get Better With Age': Becoming and Developing Adult Women's Artistic Gymnasts," 2016, *Informa UK Limited*. doi: 10.1080/00336297.2016.1230504.

[19] Chandra and Y. Jutalo, "Pengembangan Prototipe Alat Tumble Track Trampoline Pada Cabang Olahraga Senam Trampoline Dki Jakarta," *Jurnal Segar*, vol. 10, no. 2, pp. 95–97, Sep. 2022, doi: 10.21009/segar/1002.06.

[20] chandra and H. J. Yansen, "Pengembangan Prototipe Alat Double Mini Trampoline (DMT) Pada Cabang Olahraga Senam Trampoline DKI Jakarta," *Jurnal Segar*, vol. 11, no. 2, pp. 47–54, Sep. 2023, doi: 10.21009/segar/1102.01.

[21] T. M. Barbosa *et al.*, "The role of the biomechanics analyst in swimming training and competition analysis," *Sports Biomech*, vol. 22, no. 12, pp. 1734–1751, Apr. 2021, doi: 10.1080/14763141.2021.1960417.

[22] M. Kamal, "RESEARCH AND DEVELOPMENT (R&D)," *Al-Afkar: Manajemen pendidikan Islam*, vol. 7, no. 2, pp. 1–22, 2019.

[23] G. P. Ahmadan, Nasuka, and H. Pramono, "Development of Target Basket Tools for Set-Up and Receive Serve Precise Practice in Volleyball Games," *Journal of Physical Education and Sports*, vol. 7, no. 2, pp. 185–192, 2018.

[24] M. Mulyadi, "Buku Ajar CAD/CAM (Computer Aided Design / Computer Aided Manufacturing)," 2018, *Umsida Press*. doi: 10.21070/2018/978-602-5914-10-2.

[25] C. Pinheiro and N. Pimenta, "A figurational approach to women's artistic gymnastics," 2020, *Routledge*. doi: 10.4324/9781003007005-13.

[26] M. Kalichkova, "INNOVATION OF THE SUBJECT OF ARTISTIC GYMNASTICS AT UNIVERSITIES WITH A SPORTS FOCUS - SAFE GYMNASTICS 4ALL (Erasmus+ project)," 2024, *University of Ljubljana*. doi: 10.52165/sgj.16.1.160-162.

[27] I. V. Ivanova, "SPORTS PROFILE OF ELITE ATHLETES IN RHYTHMIC GYMNASTICS," 2022, *University of Ljubljana*. doi: 10.52165/sgj.14.1.73-88.

[28] Suharti, Nurhasan, and O. Wiriawan, "The Influence of Physical Fitness Gymnastics 2017 and Indonesian Jaya Gymnastics toward Flexibility and Endurance," 2019, *Africa Health Research Organization*. doi: 10.36295/asro.2019.221119.

[29] F. J. Cleophas and U. T. Visser, "ROOTS, ORIGINS AND DEVELOPMENT OF RHYTHMIC GYMNASTICS: A HISTORICAL INSIGHT," 2024, *University of Ljubljana*. doi: 10.52165/sgj.16.1.67-76.

[30] M. Benzie, "ACHILLES RUPTURES AND RETURN TO SPORT IN GYMNASTICS: AN OVERVIEW," 2024, *University of Ljubljana*. doi: 10.52165/sgj.16.1.29-41.

[31] E. Nyman, "Biomechanics of Gymnastics," 2019, *Springer International Publishing*. doi: 10.1007/978-3-030-26288-4_3.

[32] B. Risby and A. Palouda, "Fantastic Gymnastics," 2021, *Routledge*. doi: 10.4324/9781003236290-1.

[33] J. L. Shapiro, M. L. Bartlett, and L. E. Lomonte, “Psychological Aspects of Injury in Gymnastics,” 2019, *Springer International Publishing*. doi: 10.1007/978-3-030-26288-4_5.
[34] W. A. Sands, G. C. Bogdanis, G. Penitente, and O. Donti, “ASSESSING INTEREST IN ARTISTIC GYMNASTICS,” 2021, *University of Ljubljana*. doi: 10.52165/sgj.13.1.5-18.
[35] D. Bento-Soares and L. M. Schiavon, “GYMNASTICS FOR ALL: DIFFERENT CULTURES, DIFFERENT PERSPECTIVES,” 2020, *University of Ljubljana*. doi: 10.52165/sgj.12.1.5-18.
[36] D. R. Hidayanto, A. Kristiyanto, and S. K. Purnama, “Development Model of Basic Skills Training Shot Put O’Brien Style Techniques Based on Biomechanical Studies,” in *International Seminar on Public Health and Education 2018 (ISPHE 2018)*, Atlantis Press, 2018, pp. 72–76.
[37] V. Panoutsakopoulos and I. A. Kollias, “Reliability of a Pendulum Apparatus for the Execution of Plyometric Rebound Exercises and the Comparison of Their Biomechanical Parameters with Load-Matching Vertical Drop Jumps,” 2023, *MDPI AG*. doi: 10.3390/biomechanics3020018.
[38] A. Lamošová, O. Kyselovičová, and P. Tomková, “ANTHROPOMETRIC AND MOTOR CHANGES AFTER ONE-YEAR AEROBIC GYMNASTICS TRAINING IN YOUNG GYMNASTS,” 2021, *University of Ljubljana*. doi: 10.52165/sgj.13.2.243-251.
[39] M. Rico-González, L. P. Ardigò, A. P. Ramírez-Arroyo, and C. D. Gómez-Carmona, “Anthropometric Influence on Preschool Children’s Physical Fitness and Motor Skills: A Systematic Review,” 2024. doi: 10.3390/jfmk9020095.
[40] M. R. Islam *et al.*, “Accelerometer-Measured Physical Activity, Fitness and Indicators of Cardiometabolic Risk among Rural Adolescents: A Cross-Sectional Study at 15-Year Follow-up of the MINIMat Cohort,” 2024. doi: 10.1007/s44197-024-00245-1.
[41] L. K. Ritchie, N. Ronshaugen, and J. Sygo, “Growth and Development in Gymnastics,” 2019, *Springer International Publishing*. doi: 10.1007/978-3-030-26288-4_4.
[42] A. Batista, R. Garganta, and L. Ávila-Carvalho, “BODY DIFFICULTIES IN RHYTHMIC GYMNASTICS ROUTINES,” 2023, *University of Ljubljana*. doi: 10.52165/sgj.11.1.37-55.
[43] T. Haigis and K. Schlegel, “THE REGULATORY INFLUENCE OF THE VISUAL SYSTEM: AN EXPLORATORY STUDY IN GYMNASTICS VAULTING,” 2020, *University of Ljubljana*. doi: 10.52165/sgj.12.1.61-73.
[44] M. Azaza, A. Eskilsson, and F. Wallin, “Energy flow mapping and key performance indicators for energy efficiency support: a case study a sports facility,” *Energy Procedia*, vol. 158, pp. 4350–4356, 2019, doi: https://doi.org/10.1016/j.egypro.2019.01.785.
[45] O. Kyselovičová, E. Zemková, K. Péliová, and L. Matejová, “Isokinetic leg muscle strength relationship to dynamic balance reflects gymnast-specific differences in adolescent females,” *Front Physiol*, vol. 13, p. 1084019, Sep. 2023, doi: 10.3389/fphys.2022.1084019.
[46] P. Peláez-Gorrea *et al.*, “Biomechanical evaluation of chondral lesions in sheep model treated with hyaline cartilage suspended in plasma rich in growth factors and prgf intraarticular injection (CN-Biomatrix) by force platform. preliminary results,” *Osteoarthritis Cartilage*, vol. 29, pp. S69–S70, 2021, doi: https://doi.org/10.1016/j.joca.2021.02.099.
[47] L. Huang, Z. Yang, R. Wang, and L. Xie, “Physiological and biomechanical effects on the human musculoskeletal system while carrying a suspended-load backpack,” *J Biomech*, vol. 108, p. 109894, 2020, doi: https://doi.org/10.1016/j.jbiomech.2020.109894.