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Article

Practical application research of biomechanical theory in physical education training and teaching

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Abstract: Biomechanics is referred to as the study of mechanical aspects of living organisms and plays a significant role in human movement analysis. In sports training and physical education (PE), biomechanical principles help to improve techniques, and performance, and prevent injury risks. Conventional PE programs often lack a scientific approach to movement analysis, leading to inefficient training strategies and an increased risk of injury. This research investigates the application of biomechanical theory in PE training, to improve skill acquisition, and athletic performance, reduce injury risk, and create personalized training programs. The data were collected based on motion analysis, performance metrics, and surveys on training methods, physiological assessments, and participant feedback during PE training sessions and classes. The collected data was split into two different categories an experimental group (EG) trained using plyometric training (PMT) and a control group (CG) who participated in standard PE activities. Biomechanical assessments were conducted on both groups using motion capture technology (MoCap) and force plates (FP) to analyze joint angles, movement patterns, and force generation. The training interventions based on biomechanical principles were implemented over 12 weeks. Statistical analysis was performed to evaluate the significance of pre- and post-intervention performance metrics. The findings demonstrated significant improvements in movement efficiency, technique precision, and performance outcomes among participants in the EG receiving PMT compared to the CG. The study highlights the importance of combining biomechanical theory into PE and sports training. It helps in enhancing athletic performance, prevents injuries, and creates personalized training strategies.

Keywords: physical education; plyometric training (PMT); biomechanical; sports; force plates; motion capture technology

1. Introduction

Plyometric exercises are those that make a muscle generate its maximal force in a certain length of time. Athletes enhance their talents by doing a range of explosive movements during plyometric training (PMT). Several researches have indicated that engaging in plyometric activity can have a good impact on athletes' general health [1]. These exercises incorporate activities namely leaping, skipping, and hopping. The objective of these plyometric exercises is to optimize the muscle's neuro-mechanical performance during the stretch-shortening cycle (SSC) [2]. Especially, in sports, SSC is a component of most quick, reflexive actions that consists of an active muscle tendon element rapidly stretching before shortened contraction. By performing these workouts, you can enhance the force and power that your muscles can produce. By increasing the transition between the succeeding shortening and the lengthening phase, PMT sessions can improve the muscle's power, force acquisition, and rate of force development (RFD) [3].

The neuromuscular, physiological, mechanical, and biomechanical aspects of learning should be taken into account by physical education (PE) coaches, who should also provide pertinent motor learning resources that impact students' overall performance [4]. Advanced technical advancements have made it possible to include real-time biomechanical input into training routines. Sensors and software are used by biomechanical feedback systems to provide real-time data on an athlete's performance, including force production, muscle activation, and movement precision. Because it allows for quick modifications and procedures, the knowledge gained can assist maximize performance and prevent injury [5]. Important sport-specific characteristics are measured using contemporary technology to improve athlete performance and coaches' capacity for informed decision-making. Thus, athletes are now able to execute physical, tactical, and technical activities efficiently [6].

Motion capture (MoCap) technology, also known as motion capture imaging, is the computerized tracking and recording of an object's movements in space. To capture motion, various technologies and methods have been created in recent years. There are also systems for tracking the movements of expressed structures that depend on potentiometers, electromagnetic fields (EMF), and inertial sensors [7]. Hybrid systems eliminate camera occlusions and increase precision by combining various MoCap technologies. Understanding and controlling musculoskeletal and neuromuscular effects with force plates (FP) requires evaluating the dynamics and control of human movement [8]. Contrarily, FP saves a lot of time during experiment setup because they are simple to use and require less apparatus on the body. They also assist in documenting the irregularities in lower body segment mobility during particular exercises. Nevertheless, these issues are found to be unsolved, and several difficulties with highly skilled specialists in the fields of PE and sports receiving instruction in mathematics and statistics [9].

1.1. Paper objective

The intention of the suggested study is to analyze the improvement in PE teaching and learning of students by implementing PMT as part of their PE class. Initially, the data is collected and then categorized into two different groups namely CG and EG. Here, CG students were provided with a traditional teaching approach while the PMT group was involved in training sessions. MoCap and FP were implemented to assess movement patterns, force generation, and joint angles. Finally, analysis was executed to identify, which type of training sessions obtained improved knowledge on performing physical activities.

1.2. Paper organization

The paper is organized as follows. Literature studies that are relevant to the analysis of PE performance among various sports categories that involve PMT as a training method in section 2. Processes implemented in the analysis are explained in section 3 to provide clear knowledge of the methods used for teaching and learning PE activities. Then, detailed deliberation on results procured by analyzing the outcomes of two groups was presented in section 4. Discussion on the results acquired and the conclusion of the study is provided in sections 5 and 6.

2. Related works

Among primary school girls, the research involved recognition of impacts when PMT was integrated into PE sessions [10]. The students were categorized into two groups control and PMT group. The analysis was based on the flexibility, balance, and strength of the girls before and after nine weeks of training. Students who received PMT in addition to regular PE programs produced improvements. To examine and characterize university student's PT in the field of PE as a vocation was the main concept of the study [11]. Without the help of a personal trainer, university students worked out by themselves and designed their daily schedules. The results procured have consequences for both students and teachers. It was analyzed that students must learn to adjust to the rhythm of plyometric exercises to stay fit, and teachers must consider in providing adequate training.

Article concentrated on analyzing how plyometric exercise influenced both physical fitness (PF) and gross motor coordination (GMC) groups [12]. Further, findings implied that physical therapy enhanced certain aspects of health-related PF and GMC. Investigation on determining the impacts of adding eight weeks of twice-weekly upper limb-loaded plyometric exercise was carried out in [13]. By using elastic bands, handball player's in-season training was scheduled. Ball throwing velocity in three types of throwing methods, cycle ergometer force-velocity tests were the measurements taken both before and after the intervention. From the results, it was shown that the EG procured improvements in relative and absolute muscle power. The goal of the research was to create a PMT model that was efficient and reliable [14]. The average vertical leap test resulted in a 67% average with the improved category in the effectiveness test. Therefore, it could be said that the PMT model for students were implemented in legitimate, useful, and efficient categories to the lectures in Physical, Health, and Recreation Education. Therefore, it was identified that the PMT model could be implemented in a legitimate, useful, and efficient way for lectures for students studying PE, health education, and recreation education.

The impacts of several training, such as PMT or suspension training (ST)were compared based on strength and power measurements in healthy, and untrained youngsters [15]. At baseline intervention, measurements were taken for the ball throw, standing long jump, countermovement leap, and 20-meter sprint (Sp20m). After examination, PMT outperformed sprint training groups. It was found that in healthy, uneducated youngsters, ST or PMT was useful in improving power and strength-related characteristics. These could be used in school-based programs as substitutes for conventional exercise patterns. Article assessed how PMT influences the shot-putt raining [16]. Its objective was to strengthen foundation for the creation of power-related indicators, including endurance of strength, speed of acceleration, and explosive force. The effects of the training program using plyometrics on the shot-put techniques were found to have improved outcomes.

Article examined how sprint and change-of-direction skills were affected by a six-week PMT regimen [17]. The change-of-direction ability was assessed using the

Illinois Agility Test (IAT), while the sprint was assessed using the Sp20m. ANOVA (Analysis of Variance) with repeated measures and effect size (ES) were applied and results indicated that the EG had more favorable benefits than the control group. Further, to help young basketball players develop certain athletic abilities, physical therapy was advised. Analysis of how young basketball player's vertical leap was affected by PMT was determined and exhibited by the study [18]. Jump height was measured from flying duration using the jump application. According to the results, the squat jump and its movement were significantly improved by both groups. The impact of a 10-week scheduled program that included upper as well as lower limb PMT (ULLPMT) on physical performance mechanisms in players was investigated [19]. Changes in ball throwing, change of direction (CoD), and 30-meter sprint times along with four jumping tests were evaluated through two-way analyses of performance based on group and time.

Research gaps

Despite extensive research on PMT across different sports activities, several gaps remain that require further investigation. Most research focuses on short-term interventions, however, the long-term effects and retention of gains in athletic performance, flexibility, and injury prevention from PMT are rarely examined. Exploring how PMT can be tailored to different sports would offer more comprehensive insights into its applicability. Current studies emphasize group-based PMT interventions, often lacking adaptive or individualized training models. Further research could develop personalized PMT programs based on biomechanical data to optimize performance for each participant. While Mocap and FPare used, integrating these advanced biomechanical tools could offer deeper insights into muscle activation patterns and movement mechanics during PMT sessions. Addressing these gaps would expand the knowledge based on PMT and its application across diverse populations and settings, providing more effective and inclusive training strategies. Hence, the suggested study implemented PMT and traditional training sessions and analysis was performed by using MoCap and force plates. This method helps in improving the training and learning strategies of physical activities and enhances the decision-making process.

3. Methodology

This section delivers the methods involved in this present study such as data collection, training methods, evaluation variables, and statistical analysis methods.

3.1. Data collection

The data comprises of 200 sports participants of both genders which was collected from students based on motion analysis, performance metrics, and surveys on training methods, physiological assessments, and participant feedback during PE training sessions and classes. The training interventions based on biomechanical principles were implemented over 12 weeks. The collected data was split into two groups. Initially, EG contained 100 students while CG of 100 students. EG participants were trained by implementing PMT as part of their PE class and CG students received standard PE training. Prior to the collection of data, a familiarization session was provided to every student. All of the information on the protocols and exercises was shown to the students during this session. **Table 1** shows the details about the participants.

Table 1. Description of demographic details of students participated.

Categories	Demographic Details
Age (15–25 years)	
15–18 years	93 (46.5%)
19–21 years	55 (27.5%)
22–25 years	38 (19%)
Physiological Assessment (BMI)	
Underweight	65 (32.5%)
Normal weight	68 (34%)
Obese/Overweight	67 (33.5%)
Frequency of Physical Activities	
Daily	84 (42%)
Intermediate	81 (40.5%)
Low	35 (17.5%)
Previous Exposure to Plyometric Training	
Yes	131 (65.5%)
No	75 (37.5%)

Based on the above-mentioned details, the students were indulged in the PE training sessions. This demographic information comprises detailed aspects that provide insight into the participant's past engagement in physical activities.

3.2. Questionnaire design

A total 10 questionnaires were dispersed across many departments and programs of the pre- and post-intervention performance metrics for evaluation. The first stage in this approach is to create a questionnaire with seven basic elements,

1) Rate of force development (RFD): The section included two questions for assessing explosive strength and that quickly an athlete can generate force.
2) Ground reaction force (GRF): The section considered of two questions that effects on the body motions and training loads.
3) Balance score: The section demonstrated two questions an evaluating stability and control during various movements.
4) Vertical jump height: The section included two questions a key measure of lower body power and explosiveness.
5) Sprint time: The final section considered two questions that evaluating speed and acceleration.

Internal consistency measures were used to verify the questionnaire's dependability and make sure the feedback data was reliable and consistent. By comparing the questionnaire's answers with objective performance metrics, the construct validity of the survey was examined.

3.3. Two training methods

The paper analysis of physical education training and teaching for explains the two training methods such as PMT, and standard.

Plyometric training (PMT): The majority of athletic performances depend heavily on PMT, which has helped trainers, athletes, and coaches in a variety of sports. Plyometrics is a key component in determining the extent of athletic development and is hence incorporated into the training programs conducted by coaches. Numerous studies have tried to determine how effective PMT is at enhancing performance due to its increasing popularity. PMT has been demonstrated to enhance an athlete's jumping, bone density, kicking, throwing, change of direction speed, balance, power, speed, and strength among other attributes.

Standard: The PE programs employ exercise based on physical movements, to educate participants effectively. It is a type of analysis on movement of body parts.

3.4. Motion capture technology

By offering thorough feedback on motion data, MoCap technology is essential for improving athletes' strategies, abilities, and methods. Sports-related scientific research and technological advancements have emerged due to the need for efficient training methods, peak performance, and injury avoidance. MoCap has become an essential tool for comprehending, evaluating, and improving athletic performance among the many instruments and techniques used in sports science. In the past few decades, enhancements in both software as well as hardware raised to upgraded levels and apply its purposes in a several sectors namely, sports training, human movement biomechanics, and other training. **Figure 1** denotes illustration of using MoCap in PE.

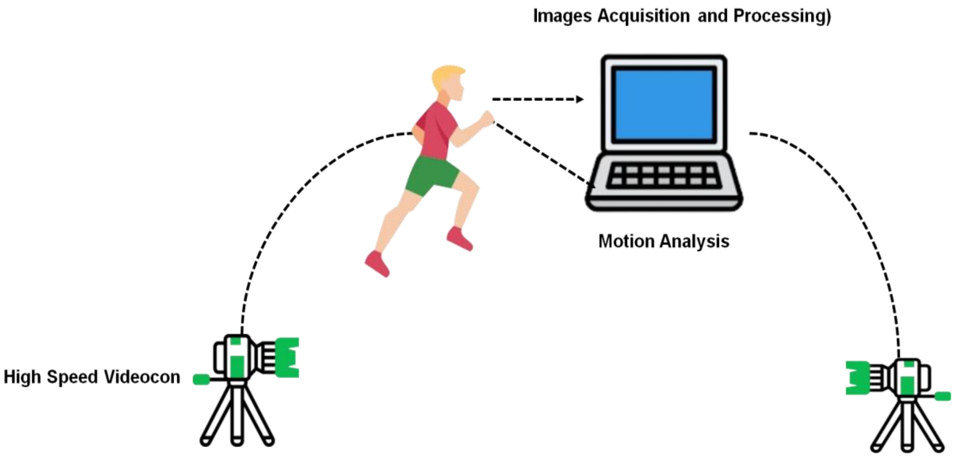

Figure 1. Illustration of motion capture technology.

MoCap combines techniques and ideas from biomechanics, physiology, and anatomy, to examine the configuration as well as process of the movements in human. It helps researchers gain better knowledge of the intricate interactions between the joints, bone marrow, nervous system, and muscles during athletic performance by supplying elaborate kinetic and kinematic data. Due to its capacity to deliver unbiased, measurable data, coaches have been able to improve training regimens, avoid injuries, and raise the overall performance of athletes.

The Vicon motion capture system, which has 12 cameras that capture at 200 Hz, was used in the study to improve the accuracy and dependability of biomechanical assessments. Important anatomical landmarks were marked using reflective markers, and a 3D calibration frame was used to calibrate the system prior to each session.

3.5. Force plates (FP)

The majority of PE assessment involves force platforms often referred to as FP, as a key tool for enhanced athlete monitoring, screening, rehabilitation, and profiling. FP testing, which uses standardized motions meant to accurately assess the neuromuscular condition in place of sports-specific movements, becomes particularly helpful in leagues with erratic and crowded competing schedules as a method to assess player preparation. External ground reaction forces (GRFs) in three planes such as medial-lateral, vertical, and anterior-posterior can be measured simultaneously by several FPs. An athlete's connection with the ground is depicted in detail by these metrics. **Figure 2** represents the purpose of FP in training physical exercise.

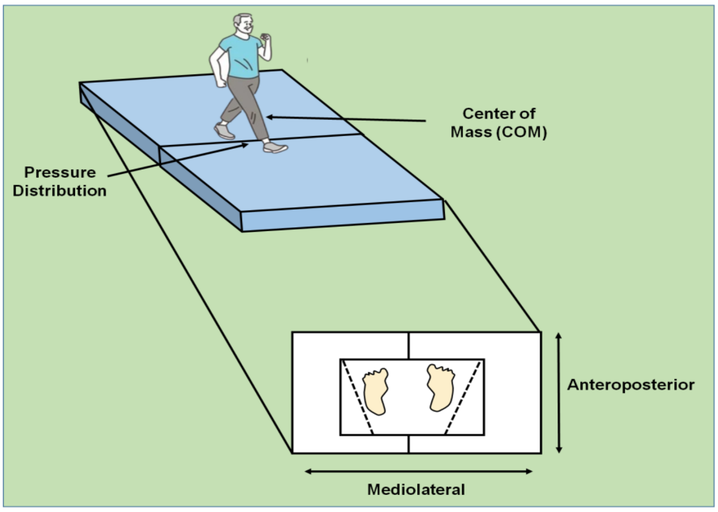

Figure 2. Force plates in physical education session.

Sprint performance, one maximum repetition back squat, agility, and other performance metrics have all been demonstrated to have reasonable associations with GRFs and other variables generated. The three laws of motion invented by Newton provide a better knowledge and understanding of ground-based propulsion. Four cells positioned in each corner of the FP make it possible to calculate the center of force, pressure, and axes from each cell's placement on the FP. Ground reaction forces were measured using advanced mechanical technology (AMTI) FPs with sampling frequency at 1000 Hz that were calibrated with known weights. Vicon Nexus software was used for combined kinematic and kinetic analysis to synchronize the MoCap and FP data.

3.6. Evaluation variables

Certain variables are used for the analysis of participants' performance indulged in both PMT and standard training sessions. Based on the FP plates the variables such as RFD, perceived exertion, balance score, and GRF were derived. With MoCap technology as base, agility score, sprint time, and vertical jump height variables were extracted. These variables are derived from the assessment methods such as MoCap technology and force plates. A detailed description of each variable is as follows.

- Rate of force development (RFD): RFD is the measure of how quickly an individual can produce a force that reflects the explosive strength of a muscle group. It is essential in sports requiring quick and powerful movements. High RFD is associated with better athletic performance and can be measured FP during dynamic movements.
- Ground reaction force: It is exhibited asthe force applied by a body on the ground in contact with it, which can be measured using FPs. Understanding GRF is vital for assessing loading patterns, developing injury prevention strategies, and analyzing movement mechanics.
- Perceived exertion: It is defined as the evaluation of how an athlete experiences complexity during physical activity. It supports understanding the perspective of an athlete's response to training intensity and can aid in regulating workout intensity to increase performance.
- Balance score: The balance score quantifies an athlete's talent to withstand their center of mass over the base of support in FP. These are usually assessed through dynamic or static balance tests. An optimized balance score is important for overall athletic performance, thus decreasing the chances of obtaining risk of injuries, and is particularly important in sports that require coordination and stability.
- Sprint time: It is signified as the measure of how long it takes an athlete to complete a specified distance while sprinting. The performance is an indicator of overall athletic ability in terms of speed and a lower sprint time exhibits better acceleration, which are essential for performance in various sports activities.

3.7. Statistical analysis

In this suggested study, a statistical package for social science (SPSS) was used to derive the present study's dependability. Two types of data analysis were applied to compute such as the ANOVA Test, and Regression Analysis. Two types of statistical analysis have been used to assess which type of training approach provides a comprehensive understanding of an athlete's physical capabilities. The following are the methods involved in this study.

- Regression analysis: In sports science, especially in movement analysis, it is regarded as a potent statistical method for analyzing correlations between various variables. Recognize the ways in which different elements impact athletic performance and how this approach determines physical actions. Finding the ways that changes in the independent variables impact the dependent variables is one of its benefits.
- ANOVA (analysis of variance): This statistical technique is used to calculate differences between group means and the processes that go along with them. ANOVA is especially helpful in sports and movement studies when comparing the results of various training regimens. It enables coaches to compare the means of the two groups to assess whether performance outcomes and performance

metrics vary statistically significantly. Trainers can create more successful tactics that are suited to the individual demands of athletes by comprehending the ways in which different factors impact athletic performance.

4. Results and discussion

The results obtained by the present study involved assessing, which method of training is effective for improving athlete's performance in PE.

4.1. Performance analysis

By applying two different analysis methods, the results obtained are discussed elaborately. Seven different variables are used to assess which type of coaching is effective among athletes. **Table 2** shows the outcomes of pre- and post-intervention results. It reflects changes in physical performance metrics across two groups such as CG, and an EG, both measured pre- and post- intervention. The variables such as the RFD, GRF, balance score, vertical jump height, and sprint time that improvements in both groups post-intervention, the experimental group demonstrates a more increase, especially in balance, vertical jump, and sprint time, indicating that the intervention significantly improved the EG's physical performance in comparison to the CG.

Table 2. Outcomes of pre- and post-intervention results.

Variables	Pre-intervention (CG)	Post-intervention (CG)	Pre-intervention (EG)	Post-intervention (EG)
Rate of force development (RFD)	150	155	148	180
Ground reaction force (GRF)	2450	2600	2410	351
Balance score	6.0	6.6	5.7	8.4
Vertical jump	33	35	27	39
Sprint time	5.2	4.8	5.0	4.7

The results produced by applying the regression analysis in CG groups' method are shown in **Table 3**. A number of variables are included in the study, such as sprint time, vertical jump height, balance score, RFD, and GRF. With related standard errors, t-values, and p-values that demonstrate their statistical significance, each predictor exhibits varying degrees of effect, as represented by their coefficient (β). The models overall explanatory ability is indicated by the R-squared and modified R-squared values that provide a decent fit to the information. The results produced by applying the regression analysis in EG are shown in **Table 4**.

The results produced by applying the outcome of ANOVA are shown in **Table 5**. The results of study demonstrate substantial difference in the groups, and a high F-value suggests the difference is unlikely to result of change. The associated $P - value$ is lower than 0.05, a statistically significant difference in the groups is suggested. The F-value of 12.53 and the p-value of 0.001 show there is a statistically significant difference between the EG and CG. The tests overall significance is increased by the decreased within-group variance that increases overall variation. The suggests that, across all groups, the independent variable significantly affects the dependent variable.

Table 3. Outcomes of CG regression analysis groups.

Predictor variable	Coefficient (β)	Standard error	*t*-value	*p*-value	R^2	Adjusted R^2
RFD	0.05	0.02	2.50	0.025	0.45	0.40
GRF	0.01	0.005	2.00	0.058	-	-
Balance score	0.20	0.10	2.00	0.058	-	-
Vertical jump height	0.15	0.07	2.14	0.043	-	-
Sprint time	−0.32	0.12	−3.06	0.006	-	-

Table 4. Results produced by regression analysis in EG.

Variables	Coefficient (β)	Standard error	t −value	P −value	R^2	Adjusted R^2
RFD	0.08	0.03	5.02	0.005	0.56	0.55
GRF	0.04	0.007	7.06	0.001	-	-
Balance score	0.21	0.09	3.62	0.014	-	-
Vertical jump height	0.19	0.08	3.42	0.002	-	-
Sprint time	−0.40	0.09	−3.25	0.0005	-	-

Table 5. Outcomes of ANOVA.

Source of variation	Sum of squares (SS)	Degrees of freedom	Mean square (MS)	$F - value$	$P - value$
Between groups	154.00	1	154.00	12.53	0.001
Within groups	321.00	37	8.84	-	-
Total	475.00	38	-	-	-

4.2. Discussion

The study employed two statistical methods, to compare the effectiveness of EG and CG among athletes. Across the analysis performance variables, a showed superior result in RFD, vertical jump height, GRF, and balance scores. The EG also exhibited lower perceived exertion scores, suggesting that athletes experienced less fatigue during training, a crucial indicator of efficient workload management. The physical educator provides hands-on examples of proper posture, running in the field, smashing a shuttle, and kicking a ball. It allows the children to learn firsthand information and later engage in autonomous physical activity and sports. To foster the development of motor skills, knowledge, and behaviors necessary for physical exercise and fitness, physical education offers cognitive content and instruction. Giving schools the support, they need to implement daily PE provide participants with the self-assurance and skills they require to stay active physically forever. The higher training benefits of PMT were demonstrated by some variables, such as Vertical Jump Height and Agility Score in CG, which approached non-significance. Thus, the results of this study demonstrate how adding biomechanical concepts to PE programs especially through PMT has several advantages. This strategy has the potential to lower the risk of injury while simultaneously enhancing athletic performance.

5. Conclusion

The suggested study explores the ways in which biomechanical concepts can be used to improve athletic performance, and injury prevention. Motion analysis, performance measurements, and participant comments were used to gather information to evaluate the impact of PMT in comparison to traditional PE exercises. Advanced biomechanical evaluations, such as FPs and MoCap, were utilized to examine joint angles, force production, and movement patterns in two groups of participants. To forecast the importance of the intervention performance metrics, statistical methods including regression tests, and ANOVA were used. The study's findings showed that, in comparison to CG, EG (PMT) had significantly improved. Coaches can provide more effective individualized instruction by incorporating biomechanical theory into physical education. The study should include more training interventions to achieve greater results, even though it achieved sufficient gains. A particular group of people participated in the study, and the results' generalizability may be limited by the small sample size (38 participants). To overcome the limitations of the study and investigate the psychological components, long-term impacts, and a wider range of training methods, more research will be necessary. A number of other sophisticated assessment techniques could be used to enhance the study in the future.

Conflict of interest: The authors declare no conflict of interest.

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