BMC Sports Sci Med Rehabil

https://doi.org/10.1186/s13102-026-01830-6

Article in Press

Multisensory feedback in gymnastics education: a kinematic study on skill acquisition in youth athletes

Received: 29 April 2026

Accepted: 23 June 2026

Published online: 29 June 2026

Cite this article as: Güler V.Ş., Turan M.B., Pepe O. *et al.* Multisensory feedback in gymnastics education: a kinematic study on skill acquisition in youth athletes. *BMC Sports Sci Med Rehabil* (2026). https://doi.org/10.1186/s13102-026-01830-6

Vesile Şahiner Güler, Mehmet Behzat Turan, Osman Pepe, Doğukan Batur Alp Gülşen, Mehmet Soyal & Mevlüt Yıldız

Multisensory Feedback in Gymnastics Education: A Kinematic Study on Skill Acquisition in Youth Athletes

Vesile Şahiner Güler[1], Mehmet Behzat Turan[2*] Osman Pepe[3], Doğukan Batur Alp Gülşen[4], Mehmet Soyal[5], Mevlüt Yıldız[6],

[1]Department of Physical Education and Sports, Health Sciences Institute, Erciyes University, Kayseri, Turkey

[2]Department of Recreation, Faculty of Sports Sciences, Erciyes University, Kayseri, Turkey

[3]Department of Sports Management, Faculty of Sports Sciences, Suleyman Demirel University, Isparta, Turkey

[4]Department of Recreation, Faculty of Sport Science, Aydın Adnan Menderes University, Aydın, Turkey

[5]Department of Coaching Education, Faculty of Sport Science, İstanbul Gelisim University, İstanbul, Turkey

[6]Department of Coaching Education, Faculty of Sports Sciences, Mugla Sitki Kocman University, Mugla, Turkey

Corresponding Author: Mehmet Behzat Turan (behzatturan@erciyes.edu.tr).

Abstract

Background: Feedback is considered a fundamental component of motor skill learning, yet evidence comparing the effectiveness of visual, verbal, and combined feedback modalities in youth gymnastics remains limited. This study examined the effects of mixed (visual + verbal), visual, and verbal feedback on the acquisition of selected gymnastics skills using two-dimensional kinematic analysis**.** **Methods:** Sixty female gymnasts aged 7–11 years were randomly assigned to mixed feedback (n = 20), visual feedback (n = 20), or verbal feedback (n = 20) groups. Participants completed an 8-week gymnastics training program. Performance in the Front Scale, Back Scale (Knee–Knee), Back Scale (Shoulder–Knee), and Split Jump was assessed at pre-test, mid-test, and post-test using Kinovea-based kinematic analysis. A mixed-design ANOVA was conducted to evaluate the effects of feedback modality, time, and the Group × Time interaction. Bonferroni-adjusted post hoc comparisons were performed where appropriate.

Results: Significant Group × Time interactions were observed for the Back Scale (Knee–Knee) ($F = 3.375$, $p = .020$, $\eta^2 = .106$), Back Scale (Shoulder–Knee) ($F = 32.662$, $p < .001$, $\eta^2 = .534$), and Split Jump ($F = 3.510$, $p = .023$, $\eta^2 = .110$), indicating that performance improvements differed across feedback conditions. Mixed feedback generally led to greater improvement than visual or verbal feedback for these skills. In contrast, although Front Scale performance improved over time, the Group × Time interaction was not statistically significant ($F = 1.680$, $p = .160$), suggesting that improvement patterns did not differ significantly among feedback modalities for this skill. Across all analyses, verbal feedback alone tended to produce smaller improvements than mixed or visual feedback. **Conclusion:** The findings indicate that the effectiveness of feedback modalities may depend on the specific gymnastics skill being learned. Mixed feedback appears particularly advantageous for skills requiring greater coordination and postural control, whereas no clear superiority of any feedback modality was observed for Front Scale performance. Integrating visual demonstrations with verbal instruction may therefore represent an effective strategy for enhancing motor skill acquisition in youth gymnastics.

Trial registration: ClinicalTrials.gov (NCT07082647). Registered retrospectively on July 15, 2025.

Keywords: motor learning, augmented feedback, youth gymnastics, kinematic analysis, skill acquisition.

Introduction

In recent years, studies on the role of feedback in motor skill learning have advanced the identification of effective teaching strategies, particularly for young athletes. Research examining visual, verbal, and mixed (visual + verbal) feedback has revealed that each technique supports different learning processes. Meta-analyses and systematic reviews indicate that augmented feedback combining visual and verbal modalities accelerates skill acquisition and retention, whereas visual-only or verbal-only feedback produces moderate effects (Sigrist et al., 2013; Wulf & Lewthwaite, 2016; Han, Ali, & Ji, 2022; Zhou, Shao, & Wang, 2021). Verbal feedback is particularly effective in increasing attentional focus and promptly correcting technical errors, while blended feedback enhances intrinsic motivation and learning retention through the synergy of both modalities (Tzetzis et al., 2008; Wulf et al., 2010; Chiviacowsky & Wulf, 2007).

Despite these findings, existing studies are generally limited to single movements or short-term practice, and their kinematic effects on multiple technical elements in children's gymnastics (aged 7–11) have received limited attention. Moreover, recent reviews indicate that few experimental studies directly compare multiple feedback modalities (e.g., visual, verbal, mixed) within the same research design (Petancevski et al., 2022; Starzak et al., 2022). These studies also highlight inconsistent methodologies, heterogeneous outcome measures, and a lack of standardized kinematic evidence supporting such comparisons. In addition, most kinematic investigations in gymnastics have focused on single elements or older/elite athletes rather than on several technical elements in preadolescent children (Mkaouer et al., 2023). Therefore, the current study aims to fill this gap by examining the kinematic effects of mixed, visual, and verbal feedback on several gymnastics elements in this age group (Bouzid et al., 2025).

Recent evidence further suggests that the effectiveness of augmented feedback may vary across developmental stages and task complexity. For example, younger learners tend to benefit more from visually enriched feedback because observational learning mechanisms are highly active during childhood, whereas older or more experienced performers may rely more effectively on verbal and self-regulated feedback strategies (Petancevski et al., 2022; Starzak et al., 2022). Furthermore, studies conducted in artistic gymnastics, physical education, and motor skill learning contexts have reported that multimodal feedback may enhance movement accuracy, coordination, and retention more effectively than single-modality feedback, although findings remain inconsistent across age groups and movement tasks (Han et al., 2022; Mödinger et al., 2022; Zhou et al., 2021). These inconsistencies highlight the need for further experimental studies directly comparing multiple feedback modalities within the same developmental population.

Performance improvement is a fundamental goal in sports biomechanics. Effective movement relies on neuromuscular coordination, anatomical factors, cognitive abilities, and physiological capacities. Biomechanics experts play a key role in enhancing performance in technique-dominant skills (Knudson, 2007). Kinematics allows quantitative analysis of positions, angles, velocities, and accelerations of body parts, providing essential insight into angular motions, which are crucial in most human movements (Medved, 2000; McGinnis, 2013).

Gymnastics skills require integrating high-level mental and physical skills. Basic gymnastics training is vital in children because it positively affects motor development and fosters a sense of accomplishment (Mitchell et al., 2002; Holfelder & Schott, 2014). Motor skill is defined as voluntary movement of one or more body parts directed toward a learned goal (Gallahue et al., 2014), and all skills, no matter how simple, must be learned technically and systematically (Özer & Özer, 2007). For this reason, teaching methods that shorten skill acquisition time, such as visual demonstrations or video feedback, have been increasingly emphasized (Rucci & Tomporowski, 2010; Özer & Özer, 2007).

Instructors' feedback during the learning process is a critical tool for ensuring skill acquisition (Koruç et al., 2012). It can be internal, derived from sensory information about one's own movements, or external, provided through verbal instructions, visual demonstrations, scoreboards, or video recordings (Wuest & Bucher, 2003; Schmidt & Wrisberg, 2008; Magill & Anderson, 2017). Combining verbal and visual feedback is thought to maximize learning by reinforcing understanding through demonstration and explanation (Kızılörs, 2022). However, despite its widespread use in sports pedagogy, there remains limited comparative evidence on the relative effectiveness of these multisensory feedback types, particularly in teaching fundamental gymnastics skills. In addition, the need for objective kinematic verification of performance improvements has been emphasized, as traditional observational assessments may not fully capture the nuanced motor patterns associated with skill development.

The present study specifically investigates the effects of mixed, visual, and verbal feedback on the technical development of fundamental gymnastics elements in children aged 7–11. The research question is: To what extent and in what order are mixed feedback (verbal + visual), visual feedback, and verbal feedback effective in teaching the front scale, back scale (knee-to-knee and shoulder-to-knee), and split jump elements in gymnastics education? The findings aim to provide further evidence regarding this question and advance theoretical understanding of feedback-mediated motor skill learning in young athletes.

Beyond its empirical contribution, the present study has both theoretical and practical significance. Theoretically, it provides an opportunity to examine how different feedback modalities influence motor learning within the frameworks of Social Cognitive Theory and the OPTIMAL theory of motor learning. In practice, the study offers evidence-based guidance for coaches and physical education practitioners on selecting feedback strategies during skill instruction. In addition, the use of objective kinematic measurements enables a more precise evaluation of performance changes than traditional observational assessments, thereby contributing to the growing integration of biomechanics and motor learning research.

The present study is grounded in well-established theoretical frameworks of motor learning, particularly the Social Cognitive Theory (SCT) and the OPTIMAL theory of motor learning. According to Social Cognitive Theory, observational learning and self-efficacy play central roles in skill acquisition, suggesting that visual feedback enhances performance through modeling processes. In contrast, verbal feedback contributes to cognitive reinforcement (Bandura, 1997).

Social Cognitive Theory further emphasizes the reciprocal interaction among behavioral, cognitive, and environmental factors during learning processes. Within sport settings, learners acquire new skills not only through direct practice but also by observing models, evaluating their own performance, and developing self-efficacy beliefs regarding task execution (Bandura, 1997). Visual feedback, therefore, represents a mechanism through which athletes can compare their performance with an external model and modify movement patterns accordingly.

Similarly, the OPTIMAL theory of motor learning highlights the importance of enhanced expectancies, autonomy support, and an external focus of attention in promoting motor learning and performance. According to this framework, feedback is most effective when it facilitates attention toward movement outcomes while simultaneously supporting learner motivation and confidence (Wulf & Lewthwaite, 2016). Consequently, multimodal feedback may represent a particularly effective instructional strategy because it combines informational and motivational functions within a single learning environment.

Drawing on Social Cognitive Theory (Bandura, 1997), observational learning processes suggest that visual feedback may facilitate skill acquisition by providing learners with accurate movement models. Similarly, the OPTIMAL theory proposes that motor learning is enhanced when attentional and motivational mechanisms are simultaneously activated (Wulf & Lewthwaite, 2016). Because mixed feedback combines visual modeling with verbal reinforcement, it may provide complementary sources of information that facilitate both cognitive processing and movement execution. Accordingly, the following hypotheses were developed based on these theoretical perspectives.

Study Hypotheses

H_1: When gymnasts receive different types of feedback (visual, verbal, and mixed), each feedback modality will have a significant effect on kinematic performance.

$H_{1.1}$: The mixed feedback method (visual + verbal) will generally result in greater performance improvements than the other feedback modalities, particularly in complex gymnastics skills.

$H_{1.2}$: In the split jump element, the visual feedback method will lead to the highest kinematic performance compared to other feedback types.

$H_{1.3}$: The verbal feedback method is expected to result in lower performance improvements than mixed feedback, particularly in complex gymnastics skills.

$H_{1.4}$: A significant improvement in the kinematic measurements of exercises performed with the feedback type will be observed over time. For example, the differences between baseline and post-feedback measurements will be significant.

Methods

Determination of Sample Size

An a priori power analysis was conducted to ensure that the study was adequately powered to detect the primary effect of interest, namely the Group × Time interaction in a 3 (Group: mixed, visual, verbal) × 3 (Time: pre, mid, post) repeated-measures mixed design. Given that this interaction reflects both between-subjects and within-subjects variability, the analysis was performed using the MANOVA: Repeated Measures, Within–Between Interaction procedure in G*Power 3.1 (Faul et al., 2007), which is recommended for multivariate repeated-measures designs, particularly when sphericity assumptions may be violated.

Pillai's trace (V) was selected as the multivariate test statistic due to its robustness to violations of normality and covariance homogeneity. The analysis was conducted using an effect size of $f(V) = 0.35$ (medium-to-large), an alpha level of .05, a desired statistical power of .85, three groups, and three repeated measurements.

The analysis yielded a noncentrality parameter of $\lambda = 14.21$, a critical F value of 2.45, numerator degrees of freedom of 4, denominator degrees of freedom of 110, an estimated Pillai's V of 0.218, and an achieved power of 0.8555. These results indicated that a minimum sample size of 58 participants was required to detect the expected interaction effect reliably.

Given that the present study included 60 participants, the sample size exceeded the minimum requirement, confirming that the study was sufficiently powered to detect meaningful Group × Time effects and supporting the statistical adequacy of the research design.

Participants

The study employed a randomized controlled experimental design. Athletes from an amateur gymnastics club were recruited using a purposive sampling method. Participants were randomly assigned to groups using a computer-generated randomization sequence, and allocation was implemented through sequentially numbered, opaque, sealed envelopes prepared by an independent researcher who was not involved in data collection or analysis. This procedure ensured allocation concealment and minimized potential selection bias (Schulz et al., 2010), thereby enhancing the study's internal validity and allowing a more accurate comparison of performance differences across groups over time (pre-, mid-, and post-training).

Parental informed consent was obtained from all participants prior to data collection, and the relevant institutional ethics committee approved the study protocol. The study population consisted of female gymnasts aged 7 to 11 who were training at facilities affiliated with the Talas Youth and Sports District Directorate of the Ministry of Youth and Sports.

All participants had at least one year of organized gymnastics experience and were actively involved in regular club-based training. Athletes participated in gymnastics training approximately two to three times per week and competed at the local or regional amateur level. Participants were recruited from the same training environment, which helped ensure a relatively homogeneous level of technical experience and exposure to coaching practices.

Following a brief familiarization with the selected gymnastics skills (Front Scale, Back Scale, and Split Jump), participants were randomly assigned to one of three groups. The first group (Mixed Feedback Group, n = 20) received both visual (video-based) and verbal feedback; the second group (Visual Feedback Group, n = 20) received only visual feedback; and the third group (Verbal Feedback Group, n = 20) received only verbal feedback.

Inclusion criteria were as follows: being female, aged 7-11 years, actively participating in gymnastics training, and medically fit to train (all participants held valid athlete licenses requiring health clearance). Given that all participants were amateur athletes undergoing similar training programs and possessed basic gymnastics knowledge, no additional skill-level criteria were applied.

Exclusion criteria included being male, not participating in gymnastics training, having a medical condition that could limit physical activity, or falling outside the specified age range.

The reporting of this randomized controlled trial follows the CONSORT (Consolidated Standards of Reporting Trials) guidelines to ensure transparency and completeness. All randomized participants completed the study, and no attrition occurred during the intervention period. The randomization sequence was generated by an independent researcher using a computer-based random number generator. This researcher had no role in participant recruitment, outcome assessment, or statistical analysis.

Participant enrollment, randomization, group allocation, and repeated measurement time points are illustrated in the CONSORT flow diagram (Figure 1).

Clinical trial registration was completed after the intervention and data collection procedures had been concluded. The study was registered at ClinicalTrials.gov on July 15, 2025 (Identifier: NCT07082647). Therefore, the trial should be considered retrospectively registered. The registration was undertaken to improve research transparency, facilitate public access to the study protocol, and ensure compliance with current reporting recommendations for intervention studies.

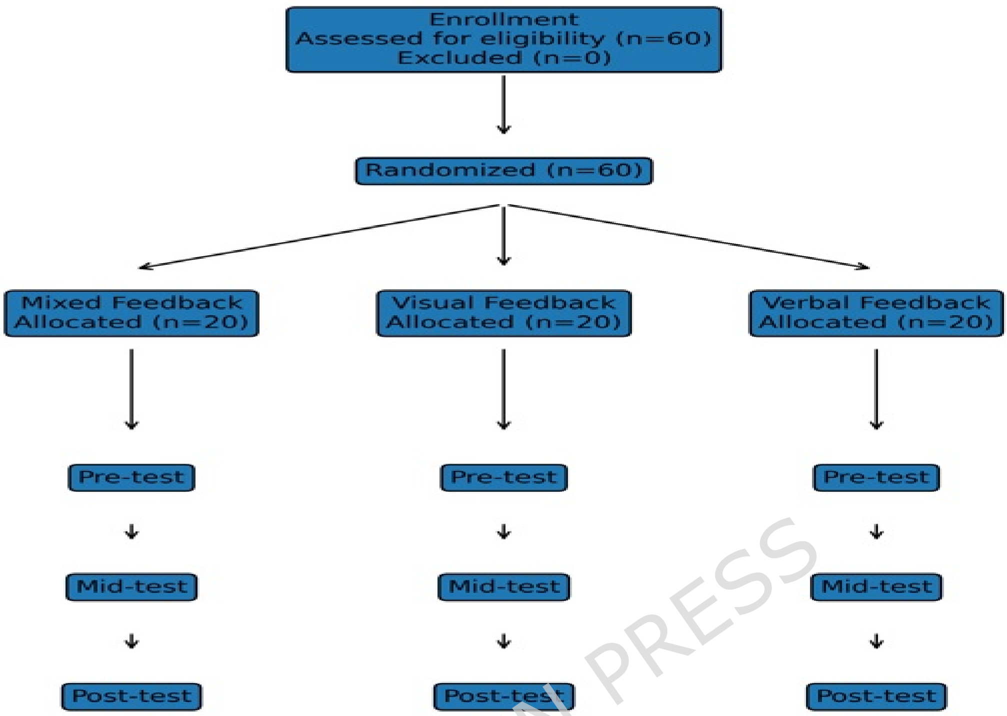

Figure 1. CONSORT flow diagram illustrating participant enrollment, group allocation, and repeated measurement points (pre-test, mid-test, and post-test) in the randomized controlled trial.

Measures

Body Weight Measurement

The participants' body weights were measured using a Xiaomi electronic scale with an accuracy of ±0.1 kg (Toprak, 2019). Height was measured using a stadiometer, and BMI was calculated as body mass (kg)/height (m^2), following standard anthropometric procedures (WHO, 2000; Lohman et al., 1988).

Height Measurement

Participants' heights and leg lengths were measured using a Fisco brand tape measure with an accuracy of ±0.1 cm, following standard anthropometric procedures (Hayta, 2019; Lohman et al., 1988; Stewart et al., 2011).

Front Scale

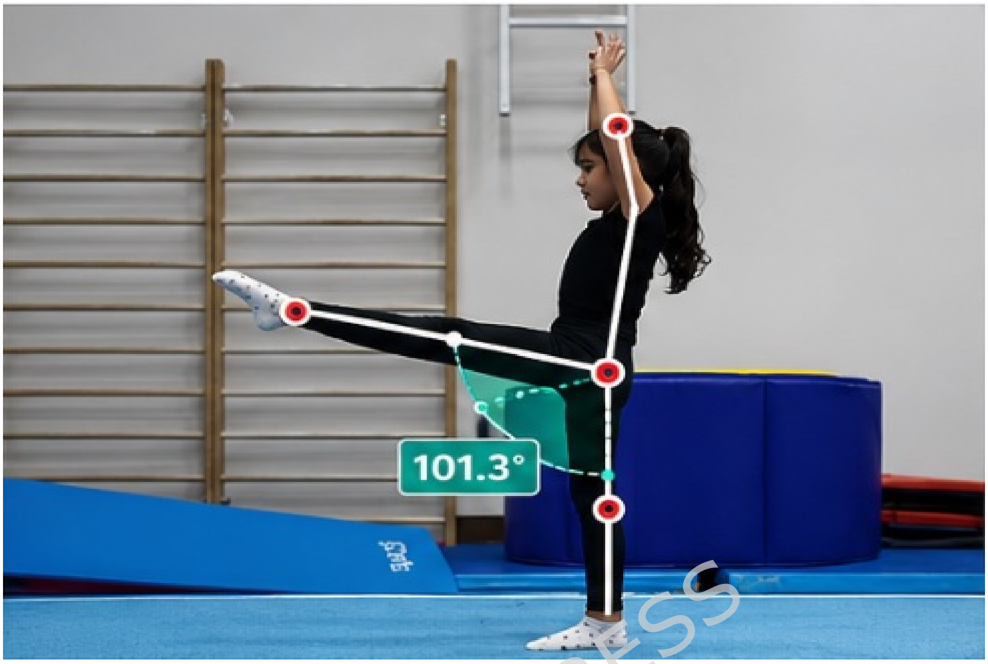

Figure 2. Front scale**.**

In Figure 2, the basic posture begins with position and posture. With the arms up and one foot stretched above 90 degrees, the other foot at the bottom is raised to the toes and held steadily for 2 seconds (Kılınç, 2021).

Back Scale

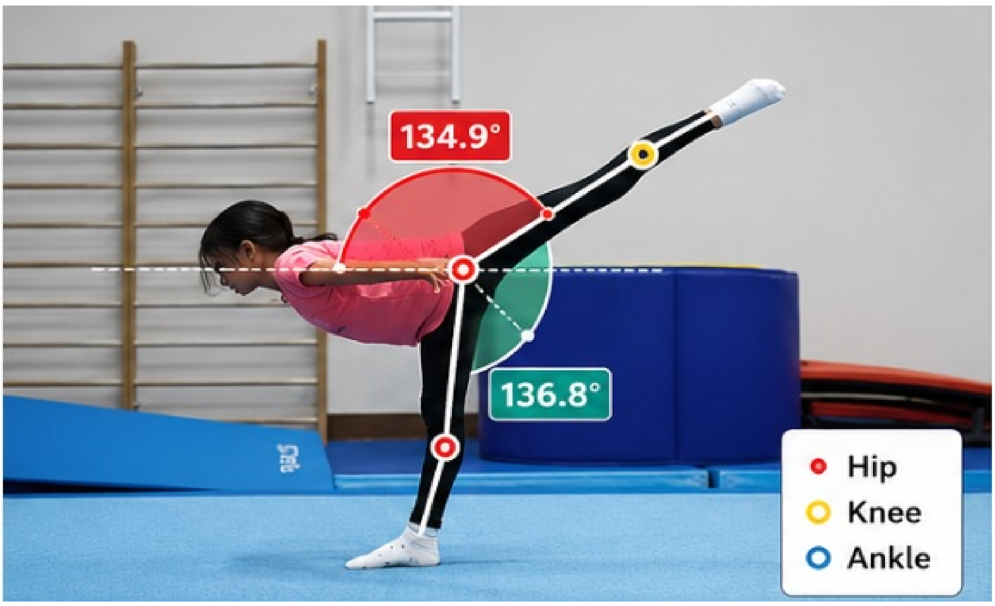

Figure 3. Back scale.

In Figure 3, the movement begins with a standing and basic posture. In gymnastics, it is a posture in which one of the feet is on the ground, and the body weight is on one leg. In the scale pose, the other leg is raised while maintaining full extension. The arms are open at the sides and at shoulder level. The body and arms are parallel to the ground (Kılınç, 2021).

Split Jump

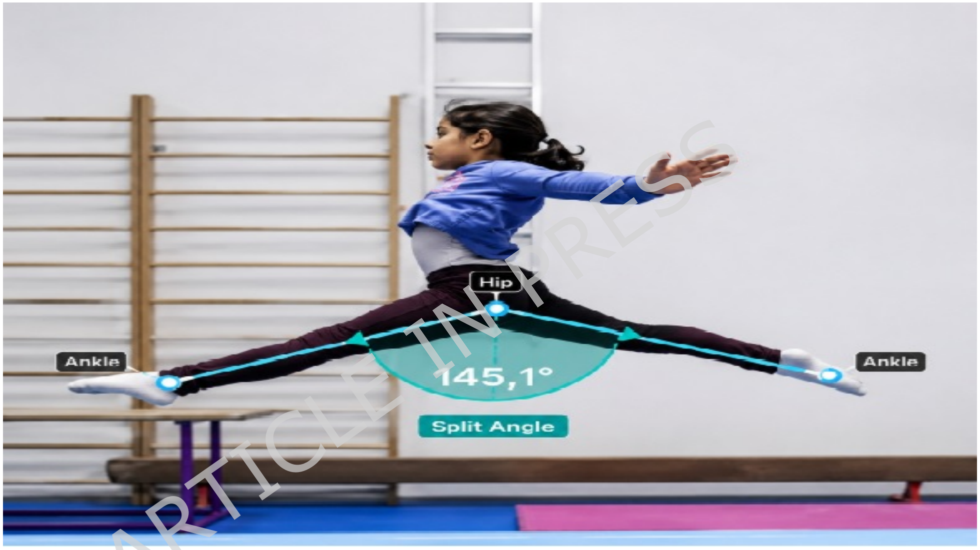

Figure 4. Split jump.

In Figure 4, during the split jump, the arms are positioned above, and the legs are opened forward and back, creating a 180-degree angle (Kılınç, 2021).

Participants performed three trials for each gymnastics element during every testing session. To reduce the influence of random performance fluctuations, the mean value obtained from the three trials was used for statistical analysis. All trials were recorded under identical testing conditions and analyzed using the same measurement procedures.

Kinovea Video Analysis

Kinematic analyses were performed using Kinovea software (version 0.9.5), a validated open-source motion analysis tool widely used in sports biomechanics. Video recordings were obtained using a Redmi Note 11 smartphone positioned 3 m from the participant and perpendicular to the primary plane of motion. All videos were recorded at a frame rate of 60 frames per second (fps) and a resolution of 1920 × 1080 pixels. These recording settings were selected to ensure sufficient temporal and spatial resolution for kinematic analysis of gymnastics movements.

The device was mounted on a tripod to ensure recording stability throughout data collection. Recordings were analyzed frame by frame to determine joint angles during Front Scale, Back Scale (Knee–Knee), Back Scale (Shoulder–Knee), and Split Jump performances. Previous studies have demonstrated excellent validity and reliability of Kinovea for angular measurements in human movement analysis (Balsalobre-Fernández et al., 2014; Puig-Diví et al., 2019). For each gymnastics element, the frame corresponding to the maximal performance position was selected for analysis. Specifically, the highest leg position was analyzed for Front Scale, the maximal angular displacement was analyzed for both Back Scale conditions, and the frame corresponding to the highest jump position was selected for Split Jump assessment.

Figure 5 presents a representative example of the angle analysis procedure performed using Kinovea software.

Figure 5. Kinovea analysis.

Kinematic analyses were conducted using two-dimensional (2D) video recordings, which enabled assessment of movement patterns within the primary plane of motion.

Calibration Procedures

Before each data collection session, the recording setup was calibrated to ensure accurate pixel-to-metric conversion. A calibration object of known dimensions was positioned within the measurement plane at the same height and orientation as the movements being performed. This calibration procedure was repeated at the beginning of every session to establish spatial scaling and minimize parallax and perspective-related errors frequently encountered in two-dimensional motion analysis (Borghese et al., 2001).

Rater Blinding and Measurement Workflow

To reduce potential bias, all kinematic measurements were performed independently by two trained raters who were blinded to participant group assignments and measurement time points. Blinding was achieved by assigning randomized identification codes to video files and removing identifiable metadata. The order of video analyses was randomized, and all raters followed a standardized measurement protocol to ensure consistency and reproducibility across repeated assessments (Lopes et al., 2018).

Reliability Analysis (3×3 Mixed-Model Design)

A 3×3 mixed-model design was used to determine the reliability of the kinematic measurements. Each rater performed three repeated measurements, allowing assessment of both interrater and intrarater reliability. Because the same raters were treated as fixed effects and participants as random effects, reliability was estimated using a two-way mixed-effects intraclass correlation coefficient (ICC) model. ICC(3,1) (single measures) and ICC(3,k) (average measures), based on absolute agreement, were calculated in line with established methodological recommendations (Koo & Li, 2016). All ICC values were reported with corresponding 95% confidence intervals.

Measurement error was quantified using the standard error of measurement (SEM), calculated as SEM = SD × √(1 − ICC), and the minimum detectable change at the 95% confidence level (MDC95) was computed as MDC95 = SEM × 1.96 × √2.

All reliability analyses were conducted and reported in accordance with GRRAS guidelines (Kottner et al., 2011). This mixed-model ICC approach offers an appropriate estimation of reliability in contexts where the same raters are expected to conduct future evaluations (Weir, 2005).

Interrater reliability was excellent across all kinematic variables, with ICC(3,k) values ranging from .92 to .98. Intrarater reliability coefficients ranged between .90 and .97. SEM values varied between 1.12° and 2.34°, whereas MDC95 values ranged from 3.10° to 6.49°. These findings indicate excellent measurement consistency and support the reliability of the kinematic assessment procedures.

Front Scale Analysis

The highest angular distance between the knee joints and the two legs was measured on the front scale (stance over 90 degrees with the leg forward).

Back Scale Analysis (Knee-Knee) And (Shoulder-Knee)

The maximum angular distance between the knee joints of the hind leg and lower leg (knee-knee) and between the shoulder and hind leg (shoulder-knee) was recorded during the scale movement. Although the backscale (knee-knee) and backscale (shoulder-knee) elements were tested in the same movement, their angular values were recorded and evaluated independently.

Note: A decrease in the shoulder-knee angle indicates increased flexibility.

Split Jump Analysis

When the split jump was performed, the angle between the knee points was recorded at the highest value achievable between the legs.

Table 1. Educational program.

Weeks	Lesson 1	Lesson 2
1	Running, Animal Walks, Forward Roll, Front Scale, Back Scale, Split Jump, Bridge, Middle Split, Front Splits	Running, Animal Walks, Forward Roll, Backward Roll, Front Scale, Back Scale, Split Jump, Balance (static) Exercises, Bridge, Middle Split, Front Splits
2	Running, Animal Walks, Forward Roll, Backward Roll, Front Scale, Back Scale, Split Jump, Static Strength Exercises, Bridge, Middle Split, Front Splits	Running, Animal Walks, Roll Exercises, Cartwheel, Front Scale, Back Scale, Split Jump, Staircase Exercise, Bridge, Middle Split, Front Splits
3	Running, Stretching Exercises, Animal Walks, Roll Exercises, Cartwheel, Front Scale, Back Scale, Split Jump, Plyometric Exercises, Bridge, Middle Split, Front Splits	Running, Animal Walks, Cartwheel, Front Scale, Back Scale, Split Jump, Balance (static) Exercise, Bridge, Middle Split, Front Splits
4	Running, Animal Walks, Cartwheel, Front Scale, Back Scale, Split Jump, Dynamic Strength Exercises, Bridge, Middle Split, Front Splits	Running, Animal Walks, Cartwheel, Handstand Exercise, Front Scale, Back Scale, Split Jump, Stretching Exercise, Bridge, Middle Split, Front Splits
5	Running, Stretching, Animal Walks, Roll Exercises, Cartwheel, Handstand, Front Scale, Back Scale, Split Jump, Static Strength Exercises, Bridge, Middle Split, Front Splits	Running, Stretching, Animal Walks, Roll Exercises, Cartwheel, Handstand, Front Scale, Back Scale, Split Jump, Staircase Exercises, Bridge, Middle Split, Front Splits
6	Running, Stretching, Animal Walks, Cartwheel, Handstand, Front Scale, Back Scale, Split Jump, Plyometric Exercises, Bridge, Middle Split, Front Splits	Running, Animal Walks, Cartwheel, Handstand, Front Scale, Back Scale, Split Jump, Bridge, Middle Split, Front Splits
7	Running, Stretching, Animal Walks, Cartwheel, Handstand, Front Scale, Back Scale, Split Jump, Dynamic Strength Exercises, Bridge, Middle Split, Front Splits	Stretching, Animal Walks, Cartwheel, Handstand, Front Scale, Back Scale, Split Jump, Running Exercise, Bridge, Middle Split, Front Splits
8	Running, Stretching, Animal Walks, Cartwheel, Handstand, Front Scale, Back Scale, Split Jump, Static Strength Exercises, Bridge, Middle Split, Front Splits	Running, Stretching, Animal Walks, An overview, Back Scale, Split Jump, Bridge, Middle Split, Front Splits

Table 1 provides details of the gymnastics training program implemented for participants, two days a week, for eight weeks. Each session lasted 40 minutes. Each participant completed their training for the same amount of time. The week of the lesson and the movements applied in the training program are indicated in the table.

Feedback Intervention Procedures

All intervention sessions were conducted by the same gymnastics coach, who had more than five years of experience working with youth gymnasts. To ensure consistency across groups, the coach followed a standardized intervention protocol throughout the study.

Participants attended two training sessions per week for eight weeks. Each session lasted approximately 40 minutes. Feedback was provided immediately following each performance trial of the target gymnastics skills (Front Scale, Back Scale, and Split Jump).

In the Visual Feedback group, participants viewed video recordings of their own performances together with a model demonstration performed by an experienced gymnast. Videos were displayed on a tablet computer immediately after each trial. Participants were allowed to review the recordings twice before performing the next attempt.

In the Verbal Feedback group, participants received standardized verbal instructions focusing on body alignment, posture, balance, flexibility, and movement execution. Feedback statements were delivered using a predetermined instructional script to ensure consistency across participants and sessions.

In the Mixed Feedback group, participants received both visual and verbal feedback simultaneously. Following each trial, participants first reviewed the video recording of their performance and then received standardized verbal explanations highlighting strengths, movement errors, and corrective strategies. This combined approach was designed to provide both observational and instructional information during the learning process.

To minimize instructor-related bias, the same coach delivered all feedback sessions, and identical training content was implemented across groups. The only difference between groups was the type of feedback provided.

Analysis Of Data

The data were analyzed using SPSS version 27. The normality of the data distribution was assessed using the Shapiro–Wilk test. Descriptive statistics, including frequency analysis, were used to summarize participants' demographic characteristics.

Given that the data met parametric assumptions, one-way analysis of variance (ANOVA) was conducted to examine between-group differences, while repeated-measures ANOVA was used to assess within-group changes over time. Baseline group comparisons were examined using one-way ANOVA. The primary analyses were conducted using mixed-design ANOVA to evaluate the effects of Group, Time, and Group × Time interactions on gymnastics performance. When significant effects were identified, Bonferroni post hoc tests were applied to determine the source of differences. Changes in performance over time were primarily interpreted in terms of interactions between group and time.

In addition to statistical significance testing, effect sizes were interpreted to assess the magnitude of differences, following conventional thresholds (small = 0.01, medium = 0.06, large = 0.14) (Cohen, 1988). Partial eta squared (η^2) values were reported for all ANOVA results to provide a more comprehensive evaluation of practical significance. Assumptions of sphericity were tested using Mauchly's test, and Greenhouse–Geisser corrections were applied where necessary. Bonferroni adjustments were used to control for Type I error inflation in multiple comparisons (Field, 2018; Tabachnick & Fidell, 2019). To complement null-hypothesis significance testing, 95% confidence intervals (95% CIs) were calculated and reported for all primary outcome variables. Confidence intervals were used to provide additional information regarding the precision and stability of estimated effects and to facilitate interpretation of the practical significance of observed performance changes.

RESULTS

Table 2. Descriptive statistics for the mixed, visual, and verbal feedback groups.

Group	N		Age	Height	Weight	BMI	Leg length (cm)	Thigh length (cm)	Calf length (cm)
Mixed feedback	20	Min	7	121	22.4	14	61	31	27
		Max	10	143	35.8	19	81	46	35
		X	8.05	129	27.15	16.50	68.15	36.75	31.45
		SD	0.94	5.43	3.71	1.43	5.23	3.68	2.28
Visual feedback	20	Min	7	121	22	14	61	31	27
		Max	10	143	36	20	81	46	36
		X	8.10	128.70	27.00	16.70	68.70	36.85	31.40
		SD	0.85	4.81	3.69	1.63	5.47	3.77	2.52
Verbal feedback	20	Min	7	121	22	14	61	31	29
		Max	10	143	36	20	81	46	36
		X	8.45	128.8	27.15	16.80	69.20	37.35	31.75

	SD	0.83	4.72	3.86	1.57	5.20	3.65	2.12

Min=Minimum, Max = Maximum.

Table 2 presents the demographic and anthropometric characteristics of participants in the Mixed Feedback, Visual Feedback, and Verbal Feedback groups. The groups exhibited highly similar distributions across age, height, body weight, body mass index (BMI), leg length, thigh length, and calf length. Mean age ranged from 8.05 to 8.45 years, while mean BMI values ranged from 16.50 to 16.80 kg/m² across groups. Likewise, anthropometric measurements demonstrated only minor variations between groups. These descriptive findings suggest that the groups exhibited broadly similar demographic and anthropometric characteristics prior to the intervention.

Table 3. Pre-test comparisons of the groups based on the dominant feedback method applied.

Elements	**Group**	$\bar{x}$	**SD**	**p**
Front scale	Mixed Group[1]	99.01	17.16	0.13
	Visual Group[2]	105.29	11.40	
	Verbal Group[3]	106.93	8.64	
Back scale (knee-knee)	Mixed Group[1]	108.49	17.27	0.11
	Visual Group[2]	120.74	17.20	
	Verbal Group[3]	119.93	25.44	
Back scale (shoulder-knee)	Mixed Group[1]	157.60	3.34	0.16
	Visual Group[2]	158.36	3.38	
	Verbal Group[3]	156.40	2.91	
Split jump	Mixed Group[1]	115.46	8.84	0.15
	Visual Group[2]	99.95	37.78	
	Verbal Group[3]	109.33	18.78	

1=Mixed Group, 2= Visual Group, 3= Verbal Group.

As presented in Table 3, no statistically significant differences were observed among the mixed, visual, and verbal feedback groups across any of the pre-test performance measures ($p > .05$). Although non-significant findings do not establish true equivalence between groups, they indicate that no measurable baseline differences were detected prior to the intervention. Consequently, the observed post-intervention changes are less likely to be attributable to substantial pre-existing performance differences among the groups. Baseline comparison of gymnastics performance scores across feedback groups is shown in Figure 6.

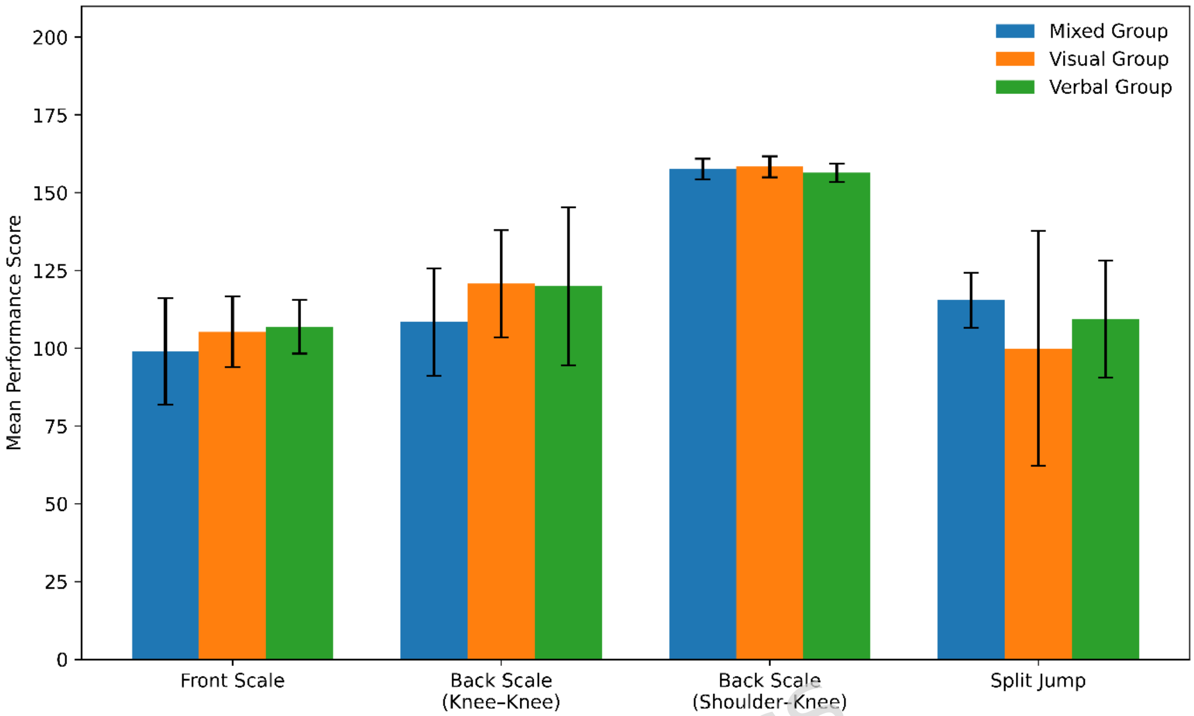

Figure 6. Baseline comparison of gymnastics performance scores across feedback groups. Error bars represent standard deviations

Table 4. Mixed-design ANOVA results and Bonferroni comparisons for Front Scale performance.

Effect	**F**	**p**	**Partial η²**	**Significant Comparisons**
Group	(2,57) = 6.872	.003*	.266	-
Time	(2,114) = 6.291	.003*	.100	-
Group × Time	(4,114) = 1.680	.160	-	-
Group	**Pre-test Mean ± SD**	**Mid-test Mean ± SD**	**Post-test Mean ± SD**	**Bonferroni Comparisons**
Mixed Feedback	99.01 ± 17.16	107.49 ± 11.09	111.08 ± 5.96	Pre < Post*
Visual Feedback	105.29 ± 11.40	105.88 ± 12.17	107.71 ± 22.23	No significant difference
Verbal Feedback	106.93 ± 8.64	108.12 ± 5.22	111.07 ± 4.21	Pre < Post*, Mid < Post*

*p<0.05

Table 4 shows the mixed-design ANOVA results for Front Scale performance. Significant main effects of Group ($F(2,57) = 6.872$, $p = .003$, $\eta^2 = .266$) and Time ($F(2,114) = 6.291$, $p = .003$, $\eta^2 = .100$) were observed, indicating that Front Scale performance differed across feedback modalities and improved throughout the intervention period. However, the Group × Time interaction was not statistically significant ($F(4,114) = 1.680$, $p = .160$), suggesting that the pattern of improvement did not differ significantly among the feedback groups. Bonferroni post hoc comparisons revealed significant improvements from pre-test to post-test in the Mixed Feedback and Verbal Feedback groups. Additionally, the Verbal Feedback group demonstrated a significant improvement from mid-test to post-test, whereas no significant pairwise differences were observed in the Visual Feedback group. The comparison of pre-test, mid-test, and post-test scores for the front-scale element across groups is shown in Figure 7.

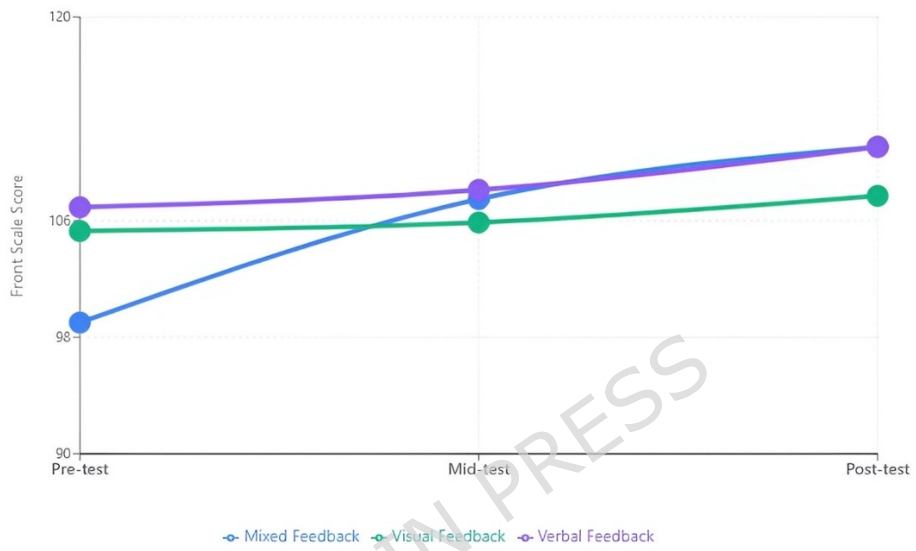

Figure 7. Comparison of front scale pre-test, mid-test, and post-test scores across groups

Table 5. Mixed-design ANOVA results and Bonferroni comparisons for Back Scale (Knee–Knee) performance.

Effect	**F**	**p**	**Partial η²**	**Significant Comparisons**
Group	(2,57) = 20.299	.001	.517	-
Time	(2,114) = 13.652	.001	.193	-
Group × Time	(4,114) = 3.375	.020	.106	Significant interaction
Group	**Pre-test Mean ± SD**	**Mid-test Mean ± SD**	**Post-test Mean ± SD**	**Bonferroni Comparisons**
Mixed Feedback	108.49 ± 17.27	121.50 ± 12.52	130.61 ± 7.66	Pre < Post*
Visual Feedback	120.74 ± 17.20	123.51 ± 15.87	127.30 ± 7.25	No significant difference
Verbal Feedback	119.93 ± 25.44	122.62 ± 9.69	124.75 ± 6.71	Pre < Post*, Mid < Post*

*p<0.05

Table 5 shows the mixed-design ANOVA results for Back Scale (Knee–Knee) performance. Significant main effects of Group (F (2,57) = 20.299, p < .001, η^2 = .517) and Time (F (2,114)

= 13.652, $p < .001$, $\eta^2 = .193$) were identified, indicating differences among feedback modalities and improvements over time. Furthermore, the significant Group × Time interaction effect ($F(4,114) = 3.375$, $p = .020$, $\eta^2 = .106$) indicated that changes in performance varied according to the type of feedback received. Bonferroni post hoc analyses indicated significant improvements from pre-test to post-test in the Mixed Feedback group. Similarly, the Verbal Feedback group showed significant improvements between pre-test and post-test and between mid-test and post-test. Although the Visual Feedback group exhibited increases in mean scores over time, these changes were not statistically significant. The comparison of the pre-test, mid-test, and post-test scores on the Back Scale (Knee-Knee) across groups is shown in Figure 8.

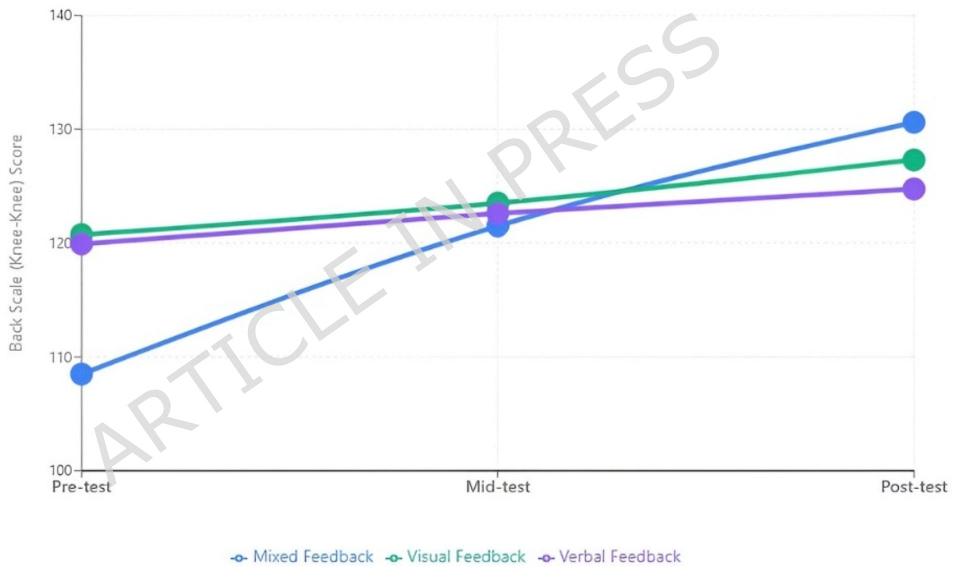

Figure 8. Comparison of pre-test, mid-test, and post-test scores for the back scale (knee-knee) by group.

Table 6. Mixed-design ANOVA results and Bonferroni comparisons for Back Scale (Shoulder–Knee) performance.

Effect	F	p	Partial η²	Significant Comparisons
Group	(2,57) = 155.803	.001	.891	-
Time	(2,114) = 304.544	.001	.842	-
Group × Time	(4,114) = 32.662	.001	.534	Significant interaction
Group	**Pre-test Mean ± SD**	**Mid-test Mean ± SD**	**Post-test Mean ± SD**	**Bonferroni Comparisons**
Mixed Feedback	157.60 ± 3.34	151.24 ± 5.56	142.90 ± 4.97	Pre > Mid*, Pre > Post*, Mid > Post*

Visual Feedback	158.36 ± 3.38	154.39 ± 4.29	151.35 ± 4.77	Pre > Mid*, Pre > Post*, Mid > Post*
Verbal Feedback	156.40 ± 2.91	153.18 ± 2.66	151.10 ± 2.69	Pre > Mid*, Pre > Post*, Mid > Post*

*p<0.05

Table 6 shows the mixed-design ANOVA results for Back Scale (Shoulder–Knee) performance. Significant main effects of Group ($F(2,57) = 155.803$, $p < .001$, $\eta^2 = .891$) and Time ($F(2,114) = 304.544$, $p < .001$, $\eta^2 = .842$) were observed. In addition, a significant Group × Time interaction effect was found ($F(4,114) = 32.662$, $p < .001$, $\eta^2 = .534$), indicating that the magnitude of change differed among the feedback groups. Bonferroni post hoc comparisons demonstrated significant differences between all measurement occasions in all three groups (Pre-test > Mid-test > Post-test). Considering that lower shoulder–knee angle values indicate improved flexibility and technical execution, these findings demonstrate progressive performance improvements throughout the intervention period across all feedback modalities, with the largest improvement observed in the Mixed Feedback group. The comparison of the pre-test, mid-test, and post-test scores on the Back Scale (Shoulder-Knee) across groups is shown in Figure 9.

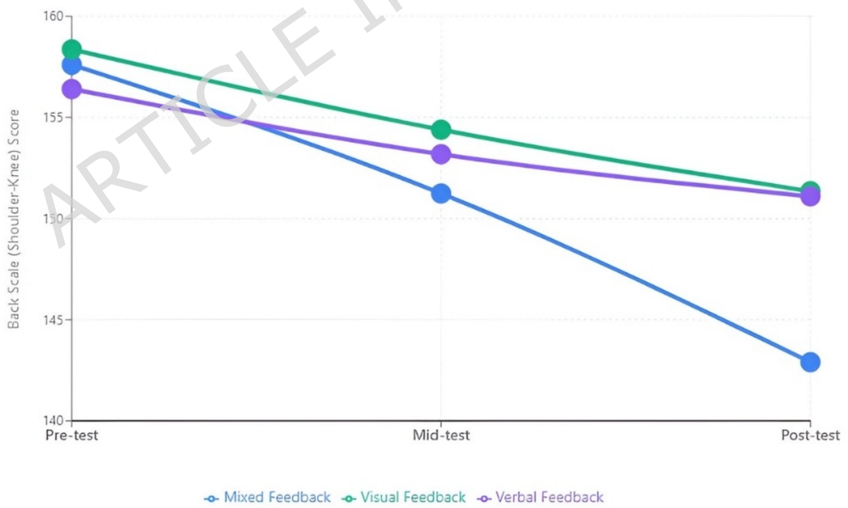

Figure 9. Comparison of pre-test, mid-test, and post-test scores for the back scale (shoulder-knee) by group.

Table 7. Mixed-design ANOVA results and Bonferroni comparisons for Split Jump performance.

Effect	F	p	Partial η²	Significant Comparisons
Group	(2,57) = 28.921	.001	.604	-

Time	(2,114) = 14.274	.001	.200	-
Group × Time	(4,114) = 3.510	.023	.110	Significant interaction
Group	**Pre-test Mean ± SD**	**Mid-test Mean ± SD**	**Post-test Mean ± SD**	**Bonferroni Comparisons**
Mixed Feedback	115.46 ± 8.84	122.70 ± 7.25	125.10 ± 8.18	Pre < Post*, Mid < Post*
Visual Feedback	99.95 ± 37.78	114.47 ± 15.24	123.40 ± 12.91	Pre < Post*, Mid < Post*
Verbal Feedback	109.33 ± 18.78	112.55 ± 11.98	112.13 ± 11.07	No significant difference

*p<0.05

Table 7 shows the mixed-design ANOVA results for Split Jump performance. Significant main effects of Group ($F(2,57) = 28.921$, $p < .001$, $\eta^2 = .604$) and Time ($F(2,114) = 14.274$, $p < .001$, $\eta^2 = .200$) were identified, indicating differences among feedback modalities and overall improvements across the intervention period. Moreover, the significant Group × Time interaction effect ($F(4,114) = 3.510$, $p = .023$, $\eta^2 = .110$) indicated that the pattern of improvement differed across feedback types. Bonferroni post hoc analyses revealed significant improvements from pre-test to post-test and from mid-test to post-test in both the Mixed Feedback and Visual Feedback groups. In contrast, no statistically significant changes were observed in the Verbal Feedback group. These findings indicate that visual information, either alone or combined with verbal feedback, may be particularly beneficial for improving Split Jump performance. The comparison of the pre-test, mid-test, and post-test scores for the Split Jump across groups is shown in Figure 10.

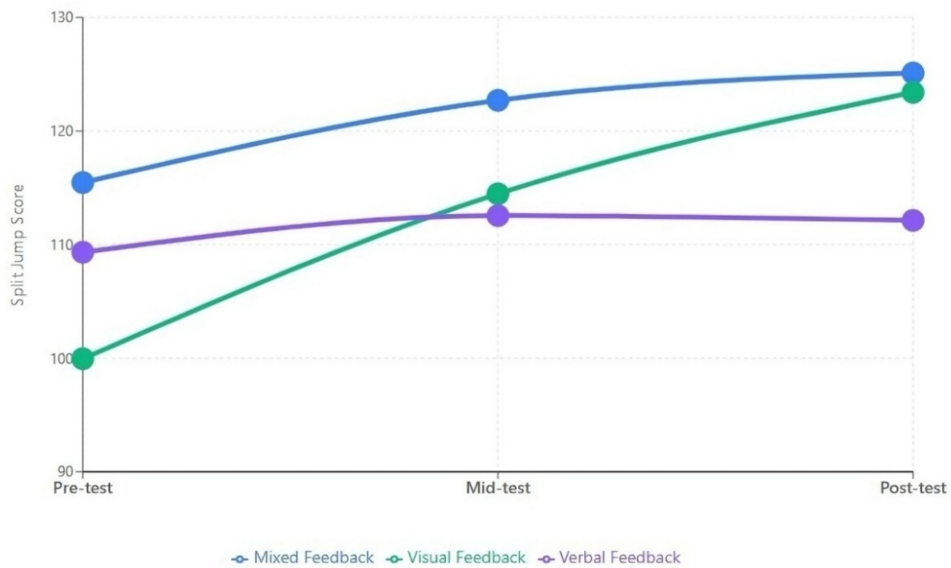

Figure 10. Comparison of split jump scores across feedback groups: pre-test, mid-test, and post-test results.

DISCUSSION

An important finding of the present study is that the effectiveness of feedback modalities varied across gymnastics skills. Although mixed feedback generally produced the largest performance improvements, its superiority was not consistently observed across all movement tasks. This finding supports previous motor learning research suggesting that the effectiveness of augmented feedback depends on task complexity, movement characteristics, and learner-related factors rather than representing a universally superior instructional strategy (Sigrist et al., 2013; Wulf & Lewthwaite, 2016). Consequently, the selection of feedback modalities should be aligned with the specific motor demands of the skill being learned.

The present findings can be interpreted within the frameworks of Social Cognitive Theory and the OPTIMAL theory of motor learning. Social Cognitive Theory proposes that individuals acquire new motor behaviors through observation, imitation, and self-evaluative processes (Bandura, 1997). In contrast, the OPTIMAL theory emphasizes the importance of attentional focus and motivational processes in facilitating motor learning and performance (Wulf & Lewthwaite, 2016). From this perspective, mixed feedback may offer a learning advantage by combining observational information with corrective verbal guidance, thereby supporting both movement understanding and performance refinement.

Regarding Front Scale performance, all groups improved throughout the intervention period. However, the absence of a significant Group × Time interaction indicates that none of the feedback modalities produced statistically superior improvements. This finding suggests that Front Scale acquisition may be relatively less dependent on the specific type of augmented feedback. It may instead benefit from repeated practice opportunities regardless of feedback modality. Such an interpretation is consistent with previous research indicating that simpler balance-oriented skills may be acquired effectively through multiple instructional approaches when learners are provided with sufficient practice and performance information (Moinuddin, Goel, & Sethi, 2021).

In contrast, the findings for both Back Scale conditions suggest that feedback modality becomes increasingly important as movement complexity increases. These skills require greater levels of balance control, flexibility, body awareness, and postural regulation than Front Scale performance. The superior outcomes observed in the mixed feedback condition may therefore reflect the complementary benefits of visual and verbal information during complex motor skill acquisition. Visual demonstrations allow learners to observe movement patterns and body positioning, whereas verbal feedback facilitates error correction and reinforces critical technical components. Similar mechanisms have been proposed in previous studies examining the acquisition of technically demanding motor skills in gymnastics and physical education contexts (Sigrist et al., 2013; Han et al., 2022; Mödinger et al., 2022; Petancevski et al., 2022).

The findings related to Split Jump performance further highlight the importance of visual information during motor learning. Unlike static balance-based tasks, Split Jump requires precise timing, dynamic coordination, and spatial awareness. Consequently, visual demonstrations may provide learners with more accessible, immediately interpretable information about movement execution than verbal explanations alone. The strong improvements observed in both the visual and mixed feedback groups support previous evidence indicating that video-based and observational feedback can enhance movement timing, coordination, and technical execution in dynamic motor tasks (Mödinger, Woll, & Wagner, 2021).

However, not all studies have reported clear advantages of visual or multimodal feedback. Some investigations have suggested that the effectiveness of feedback may diminish when learners become overly dependent on external information, potentially limiting the development of intrinsic error-detection mechanisms (Wulf et al., 2010). Therefore, the effectiveness of feedback strategies may depend not only on the modality employed but also on task characteristics, learner experience, and instructional context.

The developmental characteristics of the participants may also help explain the effectiveness of visual feedback observed in the present study. Children between 7 and 11 years of age experience substantial development in perceptual-motor integration, observational learning, and movement representation processes. During this period, learners frequently rely on visual observation and imitation when acquiring new motor skills, whereas the processing of complex verbal information is still developing (Gallahue et al., 2014; Bandura, 1997). Accordingly, the strong performance gains observed in the visual and mixed feedback groups may partly reflect age-related learning characteristics rather than feedback effects alone. This developmental perspective provides an important explanation for why visual information appeared particularly effective within the present sample.

Another noteworthy aspect of the findings is that verbal feedback alone generally produced smaller performance improvements than visual or mixed feedback. Although verbal instruction remains an important component of skill acquisition, young learners may struggle to translate verbal descriptions into accurate movement patterns without accompanying visual information. This interpretation is consistent with the developmental motor learning literature, which, suggests that children often benefit more from concrete demonstrations than from abstract verbal explanations when learning unfamiliar movement skills (Gallahue et al., 2014).

A major strength of the present study is the integration of objective kinematic analysis within a randomized controlled experimental design. Whereas many previous studies have relied primarily on subjective performance evaluations, the present study employed quantitative kinematic measurements to assess movement quality across multiple gymnastics skills. This approach provides a more objective evaluation of feedback effectiveness and contributes to the growing body of research examining motor learning processes through biomechanical assessment methods.

Overall, the findings suggest that the effectiveness of feedback modalities is skill-dependent rather than universally applicable across all gymnastics elements. Mixed feedback appears particularly beneficial for complex skills requiring substantial balance control, flexibility, and movement coordination. In contrast, visual feedback may be especially effective for dynamic skills that rely heavily on movement observation and spatial awareness. These findings support the growing literature emphasizing the value of multimodal learning environments and provide practical guidance for coaches and physical educators seeking to optimize motor skill acquisition in young athletes.

CONCLUSION

The present findings indicate that all feedback modalities contributed to improvements in gymnastics performance over time. However, the relative effectiveness of feedback varied according to the skill being performed. Mixed feedback demonstrated advantages for the Back Scale (Knee–Knee), Back Scale (Shoulder–Knee), and Split Jump, whereas no statistically significant superiority was observed for Front Scale performance. These results suggest that combining visual demonstrations with verbal instruction may be particularly beneficial for complex gymnastics skills requiring high levels of coordination and body control. Coaches and physical education practitioners should therefore consider selecting feedback strategies according to the specific characteristics of the skill being taught rather than assuming that a single feedback modality is universally superior.

LIMITATIONS

This study has several methodological limitations that should be considered when interpreting the findings. First, the kinematic analyses were based on two-dimensional (2D) video recordings, which inherently limit the assessment of movement outside the primary plane of motion. Although 2D methods are practical and widely used, they are susceptible to errors associated with out-of-plane motion, perspective distortion, and participant alignment (Munro et al., 2012; McLean et al., 2005). Consequently, compared with three-dimensional (3D) motion capture systems, 2D approaches provide lower measurement precision and less detailed biomechanical information.

Second, despite standardized calibration procedures and fixed camera configurations, factors such as camera alignment, lighting conditions, frame rate, and image resolution may have affected landmark visibility and measurement accuracy. Even minor variations in these parameters can introduce systematic or random error in video-based motion analysis (Windolf et al., 2008). Furthermore, the measurement procedure relied on manual identification of anatomical landmarks, which may introduce rater-dependent variability despite the implementation of trained raters, blinding procedures, and a mixed-model reliability design (Koo & Li, 2016; Lopes et al., 2018).

Third, the findings should be interpreted within the context of the study sample. The relatively small sample size, the exclusive inclusion of female gymnasts, and recruitment from a single training setting may limit the generalizability of the results to other populations, including male athletes, different age groups, and athletes with varying levels of expertise. In addition, individual characteristics such as physical activity level, anthropometric features, and motor skill proficiency may have influenced the observed kinematic outcomes.

In addition, biological maturation was not directly assessed using indicators such as peak height velocity (PHV) or Tanner stage. Although participants were recruited from a relatively narrow age range and demonstrated comparable anthropometric characteristics, individual differences in biological maturation may have influenced motor performance and responsiveness to feedback interventions. Future studies should incorporate maturation-related measures to better account for developmental variability during childhood and early adolescence.

Finally, the intervention period was limited to eight weeks and therefore may not fully reflect the long-term retention of motor learning. Moreover, the study was conducted under relatively controlled conditions that may not adequately represent the variability encountered in real-world sport environments, such as fatigue, changing surfaces, competitive pressure, or sport-specific demands. In addition, although objective kinematic measurements were employed, the study focused on a relatively small sample of female gymnasts recruited from a single training center. Therefore, caution should be exercised when generalizing the findings to male athletes, different age groups, elite-level gymnasts, or athletes from different training contexts. Future studies should employ larger and more diverse samples, utilize advanced motion-capture technologies, and examine the long-term retention effects of different feedback modalities in ecologically valid training settings.

Theoretical Implications

From a theoretical perspective, the present findings contribute to the motor learning literature by reinforcing the effectiveness of multimodal augmented feedback in technical skill acquisition. Consistent with prior evidence, multimodal feedback appears to be processed more efficiently and retained longer than unimodal forms (Moinuddin, Goel & Sethi, 2021). The superior performance observed in the mixed feedback condition in this study supports the notion that combining visual and auditory inputs enhances the encoding, consolidation, and retrieval of motor patterns.

These findings can also be interpreted within the framework of contemporary motor learning theories. Specifically, the OPTIMAL theory of motor learning suggests that enhanced expectancies, attentional focus, and motivational processes facilitate performance and learning (Wulf & Lewthwaite, 2016). The superior outcomes observed in the mixed feedback condition may therefore reflect the complementary influence of visual demonstrations and verbal guidance on attentional engagement and movement execution. By simultaneously providing observational and corrective information, mixed feedback may facilitate more efficient motor learning processes than reliance on a single source of feedback.

Furthermore, the findings provide indirect support for Social Cognitive Theory by demonstrating the potential value of observational learning processes during childhood motor skill acquisition. The superior outcomes observed in the visual and mixed feedback conditions suggest that learners may benefit from opportunities to observe movement models and compare their own performance with external references, thereby strengthening self-evaluative and self-regulatory learning processes (Bandura, 1997). This interpretation is particularly relevant in the context of youth sport, where observational learning mechanisms play an important role in the acquisition of new movement patterns and technical skills.

Overall, the findings support the growing consensus that motor learning is optimized when multiple sensory channels are engaged and that feedback effectiveness is closely linked to its ability to facilitate cognitive, motivational, and perceptual-motor integration. Consequently, the present study extends existing theoretical perspectives by providing kinematic-based evidence supporting the value of multimodal feedback during skill acquisition in young gymnasts.

Practical Implications

From a practical standpoint, the results provide clear and actionable guidance for coaches, trainers, and physical education practitioners. The findings indicate that combining visual demonstrations with verbal explanations is more effective than relying on a single feedback modality, particularly for complex and technically demanding gymnastics skills. This supports existing evidence from physical education research demonstrating that video-based visual feedback is more effective than verbal-only feedback in improving motor performance (Mödinger, Woll & Wagner, 2021).

Accordingly, coaches should prioritize structured feedback strategies that integrate modeling, demonstration, and verbal instruction throughout the learning process. Combining video playback with targeted verbal cues may help athletes identify movement errors more accurately, improve body awareness, and accelerate technical refinement. Such approaches may be especially valuable in gymnastics, where successful performance depends on precise body positioning, timing, balance, flexibility, and coordination.

The present findings also suggest that feedback strategies should be adapted to the specific characteristics of the skill being taught. While mixed feedback appears particularly beneficial for skills requiring high levels of postural control and movement coordination, visual feedback alone may represent an effective alternative for dynamic skills in which observational learning plays a central role. In contrast, verbal feedback alone may be less effective for young learners during the early stages of motor skill acquisition, when visual representations of movement are especially important.

From a developmental perspective, the effectiveness of visual and mixed feedback observed in the present study highlights the importance of age-appropriate instructional strategies. Given that children between 7 and 11 years of age frequently rely on observation and imitation when learning new motor skills, coaches may achieve better learning outcomes by providing frequent opportunities for movement observation, video review, and guided performance analysis.

Finally, ongoing developments in digital technology offer new opportunities for enhancing feedback delivery in sport settings. The integration of video analysis systems, mobile applications, wearable sensors, and immersive feedback technologies may further improve learning efficiency by providing immediate, individualized, and objective performance information. Therefore, future training programs should consider combining technology-assisted feedback systems with traditional coaching practices to maximize motor learning and long-term skill development in young athletes.

Ethics approval and consent to participate

The Declaration of Helsinki was followed in the study, which was approved by the Erciyes University Health Sciences Institute Social and Human Sciences Ethics Committee (Approval No: 322; approval date: 29 August 2023). Since the study was conducted with trainee athletes of the Talas Youth and Sports District Directorate affiliated with the Ministry of Youth and Sports, institutional permission was obtained from the Ministry of Youth and Sports, General Directorate of Education, Research, and Coordination (Decision No: 6372632; date: 12 December 2023). Written informed consent was obtained from all participants, and for participants under 18, it was additionally obtained from their parents or legal guardians prior to participation.

Consent for Publication

Written informed consent for publication was obtained from the participants shown in Figures 1, 2, 3, and 4, as well as from their parents or legal guardians.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests

We have no competing interests.

Funding Statement

This research received no external funding.

Author Contributions

For Conceptualization, MBT, OP, and MY; methodology, VSG and DBAG; software, OP; validation, MS, MBT, and DBAG; formal analysis, VSG; investigation, MBT and OP; resources, MY; data curation, MBT; writing original draft preparation, VSG, and MS; writing review and editing, OP and MS; visualization, VSG; supervision, MY and OP; project administration, MBT; all authors have read and agreed to the published version of the manuscript.

REFERENCES

Balsalobre-Fernández C, et al. The concurrent validity and reliability of a low-cost, high-speed camera-based method for measuring the flight time of vertical jumps. J Strength Cond Res. 2014;28(2):528–33. Doi: 10.1519/JSC.0b013e318299a52e

Bandura A. Self-efficacy: The exercise of control. New York: Freeman; 1997. ISBN-13: 978-0-7167-2850-4

Borghese NA, Cerveri P, Rigiroli P. A fast method for calibrating video-based motion analysers using only a rigid bar. Med Biol Eng Comput. 2001;39(1):76-81. Doi: 10.1007/BF02345269

Bouzid MS, Melki H, Ben Romdhane M, Hammoudi S, Khalfallah W, Rezgani Y, Racil G, Padulo J. The impact of video feedback on motor skills and motivation in acrobatic gymnastics through the use of digital tools in physical education. J Hum Sport Exerc. 2025;20(4):1277-1292. https://doi.org/10.55860/pbyv8s24

Chiviacowsky S, Wulf G. Feedback after good trials enhances learning. Res Q Exerc Sport. 2007;78(2):40-7. Doi: 10.1080/02701367.2007.10599402

Cohen J. Statistical power analysis for the behavioral sciences*. New York: Routledge; 1988. https://doi.org/10.4324/9780203771587

Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39(2):175-91. Doi: 10.3758/bf03193146

Field A. Discovering statistics using IBM SPSS statistics. 5th ed. London: Sage; 2018. ISBN-13: 978 1 5264 1952 1

Gallahue D, et al. Motor gelişimi anlamak: Bebekler, çocuklar, ergenler, yetişkinler. Nobel, 2014. ISBN: 978-605-133-532-2

Guzmán-Valdivia CH, et al. Therapeutic motion analysis of lower limbs using Kinovea. Int J Soft Comput Eng. 2013;3(2):2231–307. ISSN: 2231-2307

Han Y, Ali SKB, Ji L. Feedback for promoting motor skill learning in physical education: A trial sequential meta-analysis. Int J Environ Res Public Health. 2022;19(22):15361. Doi: 10.3390/ijerph192215361

Hayta Ü. Genç hentbolcularda endokrin parametrelerinin kas hipertrofisine etkisi. Master's thesis. Sağlık Bilimleri Enstitüsü; 2019. https://tez.yok.gov.tr/UlusalTezMerkezi/

Holfelder B, Schott N. Relationship of fundamental movement skills and physical activity in children and adolescents: A systematic review. Psychol Sport Exerc. 2014;15(4):382-91. https://doi.org/10.1016/j.psychsport.2014.03.005

Kılınç Ö. Orff eğitiminin 7-8 yaş kız sporcularda artistik cimnastik temel hareketler üzerine etkisi. PhD thesis. Ankara Yıldırım Beyazıt Üniversitesi Sağlık Bilimleri Enstitüsü; 2021. https://tez.yok.gov.tr/UlusalTezMerkezi/

Kızılörs G. Görsel, sözel ve karma geri bildirim yöntemlerinin yüzme öğrenme becerileri üzerine etkileri. Master's thesis. Sinop Üniversitesi; 2022. https://tez.yok.gov.tr/UlusalTezMerkezi/

Knudson D. Fundamentals of biomechanics. Springer; 2007. ISBN-10: 0387493115

Koo TK, Li MY. A guideline for selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15(2):155–63. Doi: 10.1016/j.jcm.2016.02.012

Koruç Z, Arsan N, Kağan S. Motor öğrenme ve performans. 2012.ISBN: 9786054434800

Kottner J, Audigé L, Brorson S, Donner A, Gajewski BJ, Hróbjartsson A, Streiner DL, et al. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. Int J Nurs Stud. 2011;48(6):661-71. Doi: 10.1016/j.jclinepi.2010.03.002

Lohman TG, Roche AF, Martorell R. Anthropometric standardization reference manual. Champaign (IL): Human Kinetics; 1988. ISBN: 0-87322-121-4

Lopes TJA, Ferrari D, Ioannidis J, Simic M, Mícolis de Azevedo F, Pappas E. Reliability and validity of frontal plane kinematics of the trunk and lower extremity measured with 2-dimensional cameras during athletic tasks: a systematic review with meta-analysis. J Orthop Sports Phys Ther. 2018;48(10):812-22. https://doi.org/10.2519/jospt.2018.8006

Magill RA, Anderson D. Motor learning and control: Concepts and applications. 11th ed. McGraw-Hill Education; 2017. ISBN-10-1259823997

McGinnis PM. Biomechanics of sport and exercise. Human Kinetics; 2013. ISBN-10-1492592331

McLean SG, Walker KB, van den Bogert AJ. Effect of gender on lower extremity kinematics during rapid direction changes: an integrated analysis of three sports movements. J Sci Med Sport. 2005;8(4):411-22. Doi: 10.1016/s1440-2440(05)80056-8

Medved V. Measurement of human locomotion. CRC Press; 2000. https://doi.org/10.1201/9781420036985

Mitchell D, Davis B, Lopez R. Teaching fundamental gymnastics skills. Human Kinetics; 2002. ISBN-10: 0736001247

Mkaouer B, Akkari-Ghazouani H, Amara S, Bouguezzi R, Jemni M, Chaabene H. Kinetic and kinematic analysis of landing during standing back somersault using three technical arm swings in artistic gymnastics. J Funct Morphol Kinesiol. 2023;8(1):10. https://doi.org/10.3390/jfmk8010010

Moinuddin A, Goel A, Sethi Y. The role of augmented feedback on motor learning: A systematic review. Cureus. 2021;13(11):e19695. Doi: 10.7759/cureus.19695

Mödinger M, Woll A, Wagner I. Video-based visual feedback to enhance motor learning in physical education: A systematic review. Ger J Exerc Sport Res. 2022;52(3):447–460. Doi:10.1007/s12662-021-00782-y

Munro A, Herrington L, Carolan M. Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. J Sport Rehabil. 2012;21(1):7-11. Doi: 10.1123/jsr.21.1.7

Özer SD, Özer K. Çocuklarda motor gelişim. Nobel Yayın Dağıtım Ltd. Şti; 2007. ISBN 978-605-133-377-9

Petancevski EL, Inns J, Fransen J, Impellizzeri FM. The effect of augmented feedback on the performance and learning of gross motor and sport-specific skills: A systematic review. Psychol Sport Exerc. 2022;63:102277. Doi:10.1016/j.psychsport.2022.102277

Puig-Diví A, Escalona-Marfil C, Padullés-Riu JM, Busquets A, Padullés-Chando X, Marcos-Ruiz D. Validity and reliability of the Kinovea program in obtaining angles and distances using coordinates in 4 perspectives. PLoS One. 2019;14(6):e0216448. Doi: 10.1371/journal.pone.0216448

Rucci J, Tomporowski P. Three types of kinematic feedback and the execution of the hang power clean. J Strength Cond Res. 2010;24(3):771–8. Doi: 10.1519/JSC.0b013e3181cbab96

Schmidt R, Wrisberg C. Motor learning and performance: A situation-based learning approach. Human Kinetics; 2008. ISBN-10-073606964X

Schulz KF, Altman DG, Moher D. CONSORT 2010 statement: Updated guidelines for reporting parallel group randomized trials. BMJ. 2010;340:c332. https://doi.org/10.7326/0003-4819-152-11-201006010-00232

Sigrist R, Rauter G, Riener R, Wolf P. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. Psychon Bull Rev. 2013;20(1):21–53.https://doi.org/10.3758/s13423-012-0333-8

Starzak M, Biegajło M, Nogal M, Niźnikowski T, Ambroży T, Rydzik Ł, Jaszczur-Nowicki J. The role of verbal feedback in the motor learning of gymnastic skills: A systematic review. Appl Sci. 2022;12(12):5940. Doi:10.3390/app12125940

Stewart AD, Marfell-Jones M, Olds T, de Ridder JH. International standards for anthropometric assessment (IAK). Lower Hutt, New Zealand: ISAK; 2011. ISBN: 0-620-36207-3

Tabachnick BG, Fidell LS. Using multivariate statistics. 7th ed. Boston: Pearson; 2019.ISBN-13: 978-0-13-479054-1

Toprak T. Futbolcularda aktivasyon sonrası potansiyelinin yön değiştirme sürati üzerine akut etkisi. Master's thesis. Lisansüstü Eğitim Enstitüsü; 2019.

Tzetzis G, Votsis E, Kourtessis T. The effect of different corrective feedback methods on the outcome and self-confidence of young athletes. J Sports Sci Med. 2008;7(3):371–8. PMCID: PMC3761887

Weir JP. Quantifying test–retest reliability using the intraclass correlation coefficient and the SEM. J Strength Cond Res. 2005;19(1):231–240. Doi: 10.1519/15184.1

Windolf M, Götzen N, Morlock M. Systematic accuracy and precision analysis of video-based motion capturing systems. Exemplified on the Vicon-460 system. J Biomech. 2008;41(12):2776–2780. Doi: 10.1016/j.jbiomech.2008.06.024

World Health Organization. Obesity: Preventing and managing the global epidemic. Report of a WHO consultation (WHO Technical Report Series No. 894). Geneva: World Health Organization; 2000. PMID: 11234459

Wuest D, Bucher CA. Foundations of physical education, exercise science, and sport. 14th ed. Boston: McGraw-Hill; 2003. ISBN-10-0073523747

Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. Psychon Bull Rev. 2016;23(5):1382–1414. DOI: 10.3758/s13423-015-0999-9

Wulf G, Shea CH, Lewthwaite R. Motor skill learning and performance: A review of influential factors. Med Educ. 2010;44(1):75-84. Doi: 10.1111/j.1365-2923.2009.03421.x

Zhou Y, Shao WD, Wang L. Effects of feedback on students' motor skill learning in physical education: A systematic review. Int J Environ Res Public Health. 2021;18(12):6281. Doi: 10.3390/ijerph18126281