ORIGINAL ARTICLE

The impact of video feedback on motor skill and motivation in acrobatic gymnastics through the use of digital tools in physical education

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ABSTRACT

This study investigates the effects of video feedback (VFB) on motor learning and motivation in acrobatic gymnastics (AG), a discipline demanding high levels of coordination and spatial awareness. Forty-two non-gymnasts (aged 11.59 ± 0.70y) were assigned to either an experimental group (VFB) or a control group (verbal feedback only) and participated in an 11-session AG program over 10 weeks. The learning task involved three acrobatic figures, Airplane, Square, and Reverse handstand, performed within a choreographed sequence. Motor performance was assessed using observation grids and joint angle analysis, while motivation was measured using the situational interest scale. Results showed significantly greater improvements in the VFB group for all three figures, both in performance scores (e.g., Reverse handstand: +247% vs. +38%) and joint angles (e.g., Aeroplane: +29% vs. +8%). Moreover, students receiving VFB reported higher motivation levels. These findings underscore the pedagogical value of VFB, suggesting it enhances both technical execution and student engagement more effectively than verbal feedback alone. VFB emerges as a promising digital tool to support motor learning and motivation in physical education, particularly in complex disciplines like AG.

Keywords: Performance analysis, Acrobatic gymnastics, Video feedback, Motor learning, Motivation, Physical education.

Cite this article as:
Bouzid, M. S., Melki, H., Ben Romdhane, M., Hammoudi, S., Khalfallah, W., Rezgani, Y., Racil, G., &, Padulo, J. (2025). The impact of video feedback on motor skill and motivation in acrobatic gymnastics through the use of digital tools in physical education. *Journal of Human Sport and Exercise, 20*(4), 1277-1292. https://doi.org/10.55860/pbyv8s24

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Submitted for publication June 24, 2025.
Accepted for publication August 11, 2025.
Published August 23, 2025.
Journal of Human Sport and Exercise. ISSN 1988-5202.

doi: https://doi.org/10.55860/pbyv8s24

INTRODUCTION

Researchers in motor learning and control study in depth the conditions of teaching and learning to identify optimal strategies for significant improvements in the acquisition of motor and cognitive skills (Souissi et al., 2024). One particularly effective strategy is the integration of new technologies into the teaching and learning process (Mödinger et al., 2022; Souissi et al., 2024). Indeed, the information and communication technology (ICT) has become a crucial tool in the development of the teaching approach, as it fosters innovation in the field of education. The introduction of ICT supported the learning tools such as smartphones, tablets and software, has led to a transformation in the classrooms (Dreimane & Upenieks, 2022). The integration of new technologies in the PE has helped to identify and improve the learners' performance and implement more effective interventions, which introduces a whole new way of engaging with physical activities and exercise learning (Saklani, 2023; Siekańska et al., 2021). In fact, in the PE context, providing effective feedback is essential for improving the student's motor skills and ensuring the learning quality (Han et al., 2022). According to Bhattacharyya et al. (2020), feedback plays a crucial role in the assessment process, with numerous studies highlighting its significant impact on learning outcomes. It is often regarded as "*the most powerful single moderator that enhances achievement*." Feedback provides personalized insights derived from direct observation, thoughtfully designed and communicated to help individuals maximize their potential. Building on existing literature, recent research has expanded our understanding of observational learning as a mechanism for enhancing motor skill acquisition (Nijmeijer et al., 2024). Among the available feedback methods, the ICT has found their role through the video feedback (VFB) method, which has emerged as a promising tool to support the learning in the PE (Potdevin et al., 2018; Schmidt & Wrisberg, 2008). In this context, several research studies report that sports pedagogists and physical educators have recently been compelled by technological advancements to reconsider methods of providing movement-related feedback and to experiment with new teaching tools, most of which are centred on the use of video feedback (Potdevin et al., 2018).

Most researcher agree that VFB is considered an essential strategy for guiding learners in making real (time adjustments during practice, thereby facilitating the development and refinement of new motor skills. When used as a formative assessment, it serves as an effective tool for both tracking performance development and providing instructional guidance. Formative feedback involves also assessing learning through data collection and specific analyses tailored to the student's level, followed by giving feedback to learners through verbal, written or visual means (Morris et al., 2021). Moreover, by engaging with VFB, learners can actively analyse their own performance, allowing them to identify strengths and areas for improvement. Indeed, through video feedback, learners focused on their performance abilities, which ambled a deeper understanding and improvement, particularly in complex motor tasks requiring coordination and power to successfully execute a skill (Nowels & Hewit, 2018; Zhou et al., 2021).

In addition, several studies have showed the effectiveness of VFB in acquiring a variety of sports skills within relatively short learning periods (Mödinger et al., 2022). This included gymnastics (Merian & Baumberger, 2007; Nowels & Hewit, 2018; Potdevin et al., 2018), front crawl in swimming (Kretschmann, 2017), soccer (Harvey & Gittins, 2014), hurdling (Palao et al., 2015), volleyball (Parsons & Alexander, 2012), and weightlifting (Rucci & Tomporowski, 2010; Souissi et al., 2023). While these studies have highlighted the effectiveness of VFB in motor learning, it should be noted that in several cases, depending on the learning context, studies have also demonstrated that combining VFB with attentional cues and verbal feedback is an especially effective pedagogical strategy for optimizing learning activities (Han et al., 2022; Potdevin et al., 2018). In terms of feedback forms, in most cases, both visual feedback and the combination of visual and verbal feedback have proven to be highly effective in significantly enhancing students' motor skill development (Han et al., 2022).

Moreover, to the best of our knowledge, there has been limited research investigating the effect of VFB on motor learning in acrobatic gymnastics (AG), a highly activity. This discipline encompasses various motor skills, including complex coordination and precise execution (Šalaj et al., 2019). Mastery of these skills requires careful attention to posture and aesthetic quality, especially when performing gymnastic exercises on the springboard and the floor. Additionally, previous research has affirmed that gymnastics significantly enhances physical attributes such as strength, endurance, and bone mineral density (Jorgic et al., 2011). Nevertheless, in a discipline closely related to AG, (Potdevin et al., 2018) explored the impact of VFB on skill acquisition in gymnastics during PE sessions. The study found that the use of VFB with reliable performance data encouraged novice learners to reflect on their practice, leading to improvements in their motor skill, self-assessment, and their motivation.

Added to the technical skills improvement, AG also impacts students' spatial awareness, self-esteem, and self-confidence (González-Valero et al., 2020), while simultaneously increasing their motivation and promoting their active participation (Ramirez-Granizo et al., 2020). A strong relationship has been demonstrated between the gymnastic performance, motivation and experience enjoyment in this context (Armada Martínez et al., 2021). To examine students' motivation and engagement in PE, researchers have primarily focused on personal motivational factors, often overlooking environmental influences. Addressing this gap, interest theory provides a framework for understanding how environmental and activity-specific content impact motivation. Situational Interest (SI) is defined as the temporary appeal of an activity to individuals in a specific context and at a particular moment (Kermarrec et al., 2014). According to (Romdhane & Khacharem, 2021), situational interest can be influenced by the design and use of instructional materials. In a PE context, SI is regarded as a multidimensional concept comprising five key dimensions: novelty, challenge, attention demand, exploration intention and immediate pleasure. Additionally, a sixth dimension, total interest, has been introduced, representing the overall appreciation of SI for a given situation (Roure et al., 2016). With this in mind, numerous studies in PE have explored the impact of technology integration on student learning, particularly in relation to motor and cognitive skills development.

From this perspective, VFB has been attributed significant attention from researchers. (Roure et al., 2019) showed that integrating technology-based learning tasks in PE, (such as the "*PE Badminton*" application on a tablet) positively influences the five dimensions of SI (novelty, challenge, attention demand, exploration intention, and immediate enjoyment) when compared to traditional learning tasks during a badminton lesson (Roure & Pasco, 2018). Similarly, Roure (2019), using the SI theory, highlighted that incorporating digital technologies, such as VFB paired with teacher traditional feedback, effectively enhances students' SI in PE, particularly in a gymnastics unit (Romdhane & Khacharem, 2021).

According to recent meta-analytic research, feedback generally promotes motor skill acquisition in PE settings regardless of task complexity (Han et al., 2022). However, the existing literature presents conflicting results about the relative effectiveness of various feedback modalities (e.g., verbal, visual, augmented) (Zhou et al., 2021). Although some research reports a greater impact of visual feedback over verbal feedback, others have failed to show statistically significant differences between modalities (Mödinger et al., 2022). Such discrepancies may be due to a variety of moderating factors, including the nature of the motor tasks, their inherent difficulty, the learners' proficiency levels, and other contextual variables. Consequently, to resolve these ambiguities further research focusing specifically on the application of VFB in complex, spatially demanding exercises like AG seems necessary, both to clarify these ambiguities and to optimize teaching practices in PE.

From this perspective to the best of our knowledge, there are no effective interventions utilizing VFB in physical education that expressly target AG, despite its acknowledged promise. AG provides an interesting context for researching the impacts of VFB due to its inherent interpersonal coordination requirements, aesthetic criteria and spatial complexity. Unlike many previous studies on VFB, which focus on individual, linear movements, AG requires synchronized dyadic performance, precise postural control and frequent spatial reorientation, all aspects for which VFB is particularly important. Furthermore, using VFB with young novice AG learners could enhance their technical accuracy and self-assessment through accessible visual representations of their performance. These distinctive features highlight the pedagogical significance of VFB, as do the motivational challenges associated with the novelty and difficulty of AG in the context of PE. Therefore, the main objective of this study is to evaluate the impact of a VF intervention on the acquisition of motor skills and motivation when learning AG choreography in PE in young.

METHODS

Experimental design

The study employed a randomized, single-blind, controlled trial with repeated measures, involving two groups of non-gymnast novices with similar skill level, both instructed by the same teacher. An experimental group (EG) took part in a learning program using the video feedback system to self-correct. The VFB enables subjects to observe their actions in real-time and compare them either to a reference model or to their own prior performances. Learners have control over the displayed visual content. They were able to pause, fast-forward or rewind the video feedback. A control group (CG) received only verbal feedback and viewed static figures presented. Both groups followed a learning cycle of 11 AG sessions, including 9 learning sessions and 2 evaluation sessions, spread over 10 weeks. At the end of the cycle, participants were asked to perform three acrobatic figures in pairs in a choreographed sequence: Aero plane, Square and Reverse handstand. Acrobatic gymnastics training sessions were divided into initial and advanced sessions. the pretest was in the first session and the post-testing choregraphic sequences were at the 11th session.

Participants

A preliminary power analysis was calculated with G*Power software [version 3.1, University of Düsseldorf, Germany (Faul et al., 2009)] with a type I error of .05 and statistical power of 80%. The analysis showed that a minimum of 42 participants (e.g. divided into two groups) is sufficient to observe a significant and large effect size (d = 0.925) with a critical t = 2.024. Thus, the study sample of forty-five potential participants was initially considered for the study, three were excluded for not meeting the required conditions. Finally, 42 students (19 boys and 23 girls) were divided into two groups (Figure 1), an EG with (10 girls - 11 boys, 11.59 ± 0.70 years) and a CG with (13 girls - 8 boys, 12.20 ± 0.78 years). All participants were in good health and did not suffer from any disability, musculoarticular, cardiac, neurological or respiratory disease or dysfunction. Exclusion criteria were as follows: (a) refusal by the child to participate, (b) lack of parental consent, (c) any physical problem that temporarily or permanently prevented the student from performing the motor tests, and (d) beginners in AG with no specific previous knowledge. In addition, all participants and their parents were informed in advance about the experiment and signed an informed consent form. The study was also conducted in accordance with the Declaration of Helsinki. This protocol was approved by the local research ethics committee (0107/2023; UR18JS01).

Procedures

Both the EG and CG groups were invited to take part in a nine-session learning module in AG, with the aim of performing a choreography composed of three pairs of acrobatic figures. The figures 2, 3 and 4 show a detailed technical breakdown of the choreography. A professional teacher in AG defined all the criteria as well as technical errors correction during the choreography motor skill sessions. All of the currently available international gymnastics federation scoring code materials were used. The study's flow diagram is shown in Figure 1.

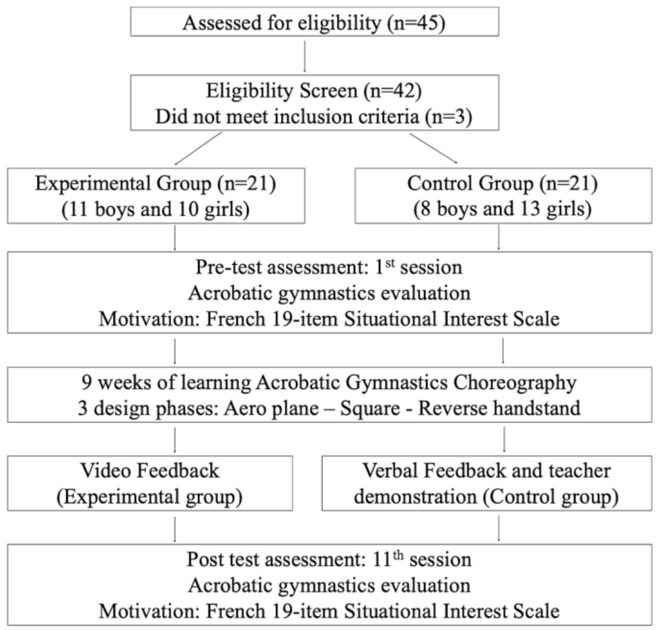

Figure 1. Flow diagram of the study.

Aero plane

The Aero plane is a static acrobatic duet figure consisting of three separate phases (Figure 2). In the setup phase (Figure 2A), the first student, acting as the carrier, lies on their back and positions their feet on the pelvis of the second student, the aerialist, who stands in front. The aerialist feels the carrier's hands while the carrier gently bends their legs. Once the aerialist's weight is fully supported by the carrier's feet, the carrier extends their legs, allowing the aerialist to achieve a stable, airplane-like position for 2 to 3 seconds during the maintenance phase (Figure 2B). In the stability phase, the carrier may hold the aerialist's shoulders for additional balance. Finally, in the dismount phase (Figure 2C), the aerialist tilts backward to descend safely. A common variation involves the aerialist extending their arms outward to maintain balance while remaining supported by the carrier's feet.

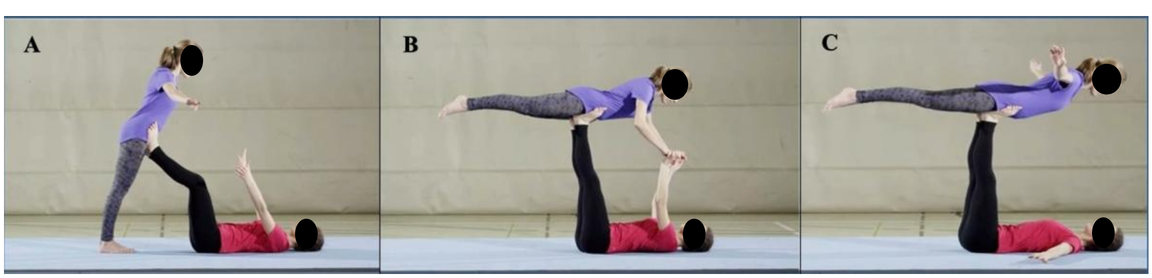

Figure 2. Aero plane design phases.

Square
Figure 3 describes the different phases of square. Firstly, the vaulted lies on the floor with their arms stretched towards the ceiling. The acrobat positions their ankles on the carrier's hands while simultaneously placing their hands on the carrier's ankles (Figure 3A). Next, the wearer straightens their upper body as the acrobat lifts their hips upwards in a synchronized movement. In the holding phase, both students create a square-like formation with their bodies and maintain the position for 2 seconds (Figure 3B). Finally, the last dismount phase consists of returning to the initial position and then pivoting to the side.

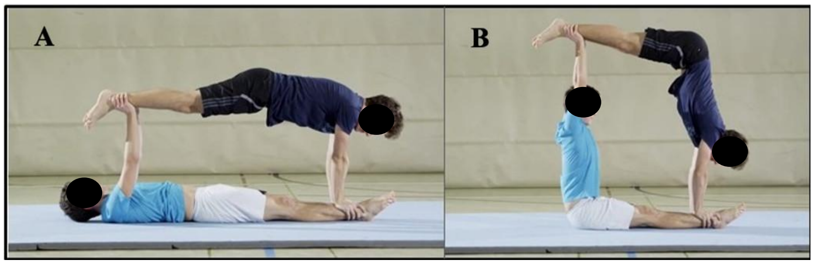

Figure 3. Square design phases.

Reverse handstand
The Reverse handstand (Figure 4) represents the third figure in the choreography and consist of two separate phases. The set-up phase (Figure 4A, B and C): the acrobat transitions into an inverted handstand, positioning themselves against the back of the carrier. The carrier firmly grasps the lower part of the acrobat's legs and gradually lowers their body until their glutes align perfectly with the aerialist's shoulder blades. While the acrobat maintains the arched position, the carrier tilts forward, keeping the back solid. The dismount phase (Figure 4D): the carrier raises their hips so as to place the acrobat on the ground in front of him. It is crucial that the carrier bends forward and round their back to effectively support the acrobat's shoulder blades at hip level while in the inverted position. The flyer executes a bridge movement over the carrier, facilitating hip elevation. For optimal execution, the carrier must maximally close the trunk lower limb angle to ensure a controlled and stable descent.

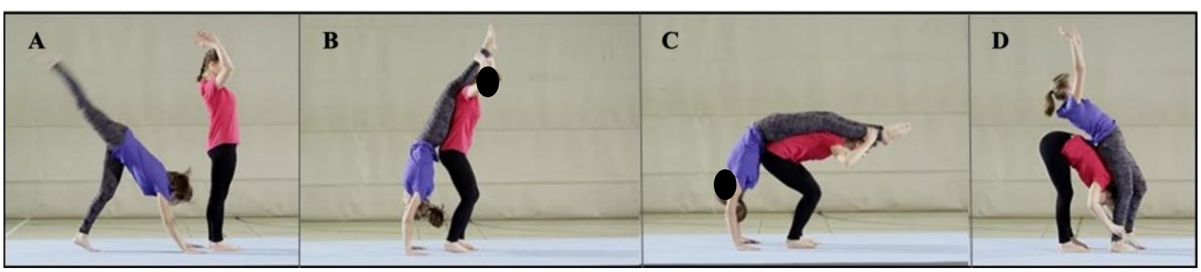

Figure 4. Reverse handstand design phases.

Assessments
Anthropometric variables
The mean measures of participants were as follows: age: 11.59 ± 0.70 years, stature 146.05 ± 2.52 cm, Body mass 37.10 ± 2.20 kg / BMI: 17.35 ± 1.23 kg/m^2. As required by the International Society for the Advancement of Kinanthropometry (ISAK), the ISAK guidelines were used for all assessments (Scafoglieri et al., 2012). Body weight was measured using a digital scale (Seca 769, Germany; accuracy 0.1 kg) and height was taken using a stadiometer (Seca 220, Germany; accuracy 0.1 cm). Each participant's body mass

index (BMI) was measured by a bioelectrical impedancemeter (TBF-300, Tanita, Tokyo, Japan) for each participant.

The video feedback device

The VFB system was implemented for the experimental group using a standardized video recording setup. Two SONY FDR-AX43A/4K digital cameras were used to capture video footage, adhering to a standardized protocol. One camera was fixed on a tripod at a height of 1.50 meters and placed 3 meters away from the gymnasts to ensure uniform and reproducible recordings. The recorded video sequences were analysed using Kinovea software (version 2023-1.2) to assess movements performance. This methodological approach is consistent with protocols adopted in previous research (Souissi et al., 2021).

Special individual assessment sheet

During the testing sessions, no feedback or corrections were provided to the learners. The recorded sequences of acrobatic figures were analysed by two AG experts (recognized as judges by the International Gymnastics Federation (FIG)) using assessment grids based on the success criteria outlined in the FIG Code of Points. Each acrobatic movement, Aero plane, Reversed handstand and Square, was analysed according to qualitative criteria (technical skills according to a two-level appreciation scale, (*i*) unsuccessful execution (-) and (*ii*) successful execution (+)) as well as a quantitative criterion, measurement angle. According to (Favre, 2017) the quantitative data were converted into scores, where negative evaluation corresponded to 0 points, and a positive evaluation corresponded to 1 point. As illustrated in Figure 5, the key angles (Y° = 90° (Figure 5A); X° = 90° (Figure 5B); α° = 45° (Figure 5C)) served as reference metrics for analysing skill development throughout the intervention.

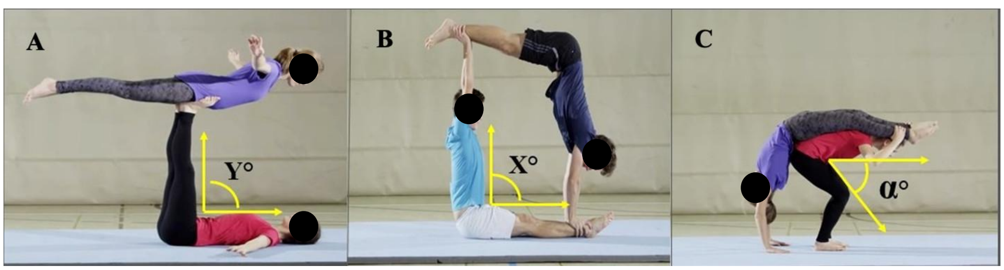

Figure 5. Angles measurement.

Motivation

The Situational Interest Scale with French validation (EMIS-EP) (Roure et al., 2016), was implemented to assess intrinsic motivation levels among students across all groups. This instrument comprises six dimensions: *(1)* instant enjoyment, *(2)* exploration intention, *(3)* novelty, (4) attention demand, (5) challenge and *(6)* total interest). Participants rated each item on a five-point scale, ranging from 1 (strongly disagree) to 5 (strongly agree).

Statistical analysis

All data are reported as mean ± standard deviation (SD). Data analysis was carried out using SPSS 25.0 statistical software (SPSS 20.0 for Windows, SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was applied to verify data normality. The independent-samples t-test was used to assess differences in youth anthropometric variables. A two-way mixed analysis of variance (ANOVA; 2 groups [CG, EG] × 2 test times [pre- and post-test]) with repeated measures was performed to analyse variations over time. The t-test for independent samples was employed to compare technical scores, angles keys indexes, and motivation between the EG and CG. A two-factor repeated measures of analysis of variance (ANOVA) was conducted to evaluate group × time effect across all variables. When a significant group × time interaction was detected, the Bonferroni post-hoc test was applied to determine intragroup differences (pre- vs. post-test). Effect sizes were calculated as partial eta-squared η_p^2 for ANOVA ($\eta_p^2 \geq 0.01$, small effect size; $\eta_p^2 \geq 0.06$, medium effect size; $\eta_p^2 \geq 0.14$, large effect size), and as Cohen's d for t-test (d ≥ 0.2, small effect size; d ≥ 0.5, medium effect size; d ≥ 0.8, large effect size). The significance level was fixed at $p < .05$.

RESULTS

Anthropometric measurements

As shown in Table 1, the anthropometric measurements were designed to define the initial level of fitness of the participants and therefore the formation of homogeneous groups with an approximately similar level of fitness to guarantee the experiment's validity. According to the results of the mixed ANOVA test, there were no significant interactions between the two groups ($p > .05$).

Table 1. Anthropometric characteristics of the sample (n = 42).

Indicator	Group	(Mean ± SD)	*p*-value
Age (years)	EG (n = 21)	11.59 ± 0.70	.896
	CG (n = 21)	12.02 ± 0.78	
Height (cm)	EG (n = 21)	158.5 ± 2.01	.123
	CG (n = 21)	153.6 ± 3.10	
Body weight (kg)	EG (n = 21)	50.89 ± 2.98	.470
	CG (n = 21)	55.32 ± 1.42	
BMI (kg/m^2)	EG (n = 21)	20.17 ± 1.24	.390
	CG (n = 21)	19.24 ± 1.22	

Note: SD: Standard deviation. BMI: body mass index. EG: experimental group. CG: control group. p-value: significant value.

Technical performance score

Regarding the score performance of the three choreography sequences, the repeated-measures ANOVA revealed a significant Group × Time interaction effect, as shown in Table 2. No significant baseline differences were observed between both groups (EG and CG) in the pre-test, confirming the homogeneity of both groups before the intervention. A significant overall improvement in performance was observed in the EG compared to the CG. The Reserve handstand had the higher impact (F = 19.42; $p < .001$; ES = 0.493) indicating a large effect size. This was followed by Square (F = 6.36; $p = .02$; ES = 0.242) and Aero plane (F = 6.14; $p = .022$; ES = 0.235), both showing moderate effect size.

Post hoc analysis using paired *t*-test further confirmed a significant improvement of the chorography performance following VFB intervention in the EG. The percentage improvement was higher for the Reverse handstand (247%; t = -6.375; $p < .000$), followed by Aero plane (176%; t = -5.36; $p < .000$) and Square (77%; t = -4.79; $p < .001$). However, the CG exhibited more moderate improvement, with only Aero plane showing a significant improvement (74%; t = -2.47; $p < .033$), while the improvement for Square (12%; t = -0.476; $p = .645$) and Reverse handstand (38%; t = -1.93; $p = .082$) were not statistically significant.

Following the VFB intervention, the post-test between-group comparison confirmed that the EG outperformed the CG across all three choreography sequences, with significant differences observed for Aero plane (t = 3.33; $p = .003$); Square (t = 3.402; $p = .004$) and the Reverse handstand (t = 5.33; $p < .000$). These findings suggest that the VFB intervention had a significant impact on motor learning outcomes, particularly for more complex acrobatic movements. It seems clear that the larger improvement observed in the EG highlight the potential of VFB in enhancing self-perception and technical performance AG.

Table 2. Effect of acrobatic gymnastic method on chorography performance in a pre- and post-test (n = 42).

Acrobatic figures	**EG (n = 21)**			**CG (n = 21)**		
	Pre	Post	Δ%	Pre	Post	Δ%
Aeroplane	1.45 ± 1.03	4.00 ± 0.77	176	1.36 ± 0.92	2.36 ± 1.43	74
Square	2.09 ± 1.37	4.18 ± 0.75	77	2.18 ± 1.25	2.45 ± 1.50	12
Reverse handstand	1.18 ± 0.98	4.09 ± 0.83	247	1.45 ± 1.03	2.0 ± 1.00	38
Acrobatic figures	**ANOVA Group**			**ANOVA (Group × Time)**		
	F	*p-value*	ES	F	*p-value*	ES
Aeroplane	6.710	.017	0.251	6.149	.022	0.235
Square	4.280	.052	0.176	6.360	.020	0.242
Reverse handstand	8.475	.009	0.298	19.420	.000	0.493

Note: Δ: percentage difference; (F) Test value; (p) significant value; ES = effect size.

Performance key angles

The analysis of effect of VFB is based on a repeated-measures ANOVA, including the effects of time and the interaction group × time. No significant baseline differences were observed between both groups.

The results of the statistical analyses using ANOVA presented in Table 3 showed a group time interaction for the three angles measured, indicating a significant overall progression in the EG compared to the CG. The strongest effect is observed for Aero plane (F = 53.39; $p < .001$; ES = 0.72), followed by Reserve handstand (F = 21.77; $p < .001$; ES = 0.52) and Square (F = 6.72; $p < .05$; ES = 0.25).

Table 3. Effect of acrobatic gymnastic method on key angles performance in a pre- and post-test.

Angle	**EG (n = 11)**			**CG (n = 11)**		
	Pre	Post	Δ%	Pre	Post	Δ%
(Y°) Aero plane	64 ± 3.28	82.73 ± 4.22	29	66.09 ± 4.06	71.55 ± 2.38	8
(X°) Square	118 ± 7.71	94.00 ± 3.19	-20	111 ± 10.50	97.82 ± 6.24	-12
(α°) Reverse handstand	34.55 ± 4.41	45.45 ± 2.20	31	32.00 ± 3.22	36.73 ± 3.84	15
Angle	**ANOVA Group**			**ANOVA (Group × Time)**		
	F	*p-value*	ES	F	*p-value*	ES
(Y°) Aero plane	13.92	.001	0.411	53.39	.000	0.728
(X°) Square	0.288	.597	0.014	6.72	.017	0.252
(α°) Reverse handstand	17.51	.000	0.467	21.77	.000	0.521

Note: Δ: percentage difference; (F) Test value; (p) significant value; ES = effect size.

A post hoc analysis showed a significant improvement of the angle measurements after VFB intervention for the EG, respectively: Aero plane 29% (t = -14.09; $p < .001$); Square -20% (t = 14.42; $p < .001$) and Reverse handstand 31% (t = -8.91; $p < .001$). However, more moderate improvement was observed in the CG, respectively: Aero plane 8% (t = -4.4; $p < .001$); Square -12% (t = 3.84; $p < .003$) and Reverse handstand 15% (t = -9.33; $p < .000$).

For the post-test, conducted after VFB intervention, the independent t-test results showed a significant improvement in the EG for both the airplane angles (t = 7.65; $p < .001$) and the Reverse handstand (t = 6.52; $p < .001$). However, no significant difference was found between groups for the Square angle (t = -1.8.84; $p = .086$) suggesting that both groups benefited similarly for this specific skill. Effect sizes support these results, with large effects observed for Aero plane (ES = 0.728) and Reverse handstand (ES = 0.52) and a small to moderate effect for the Square angle (ES = 0.25).

Motivation effects

A Kruskal-Wallis was conducted to examine differences in situational interest between the EG and the CG before and after the intervention. As illustrated in Table 4, prior to the acrobatics choreography intervention, no significant differences were found between the two groups across any of the six dimensions of the EMIS-EP scale (p > .05). These findings indicate that both groups were homogeneous in terms of intrinsic motivation before the intervention. Following the intervention, significant differences emerged in four dimensions. (i) the evolution of instant enjoyment: the EG exhibited a higher mean rank (25.71) compared to the CG (17.29), resulting in a significant difference (χ^2 = 5.518, p = .019). (ii) exploratory intent: the EG demonstrated a higher mean rank (25.93) than the CG (17.07), with a statistically significant difference (χ^2 = 5.57, p = .018). (iii) novelty: the post-test scores were significantly higher for the EG (mean rank = 29.95) compared to the CG (mean rank = 13.05), with a highly significant effect (χ^2 = 20.586, p = .001). (iv) total interest: the EG demonstrated greater overall interest (mean rank = 26.31) compared to the CG (mean rank = 16.21), with a statistically significant difference (χ^2 = 7.983, p = .005). In contrast, no significant post intervention differences were observed for attention demand (p = .072) or challenge (p = .39).

Table 4. Pre-post-test comparative intrinsic motivation analysis between acrobatic gymnastics groups (n = 42).

Intrinsic motivation variable	**Group**	**Pre-Post Intrinsic motivation index**					
		Mean rank		χ^2		Sig (p-value <.05)	
		Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Instant enjoyment	EG (n = 21)	22.62	25.71	0.365	5.518	.546	.019
	CG (n = 21)	20.38	17.29				
Exploratory intention	EG (n = 21)	22.43	25.93	0.258	5.579	.612	.018
	CG (n = 21)	20.57	17.07				
Novelty	EG (n = 21)	22.76	29.95	0.471	20.586	.493	.000
	CG (n = 21)	20.24	13.05				
Attention demand	EG (n = 21)	21.24	24.86	0.020	3.236	.889	.072
	CG (n = 21)	21.76	18.14				
Challenge	EG (n = 21)	20.14	23.07	0.537	0.739	.464	.390
	CG (n = 21)	22.86	19.93				
Total interest	EG (n = 21)	24.31	26.79	2.243	7.983	.134	.005
	CG (n = 21)	18.69	16.21				

These findings indicate that VFB learning strategies in AG positively influenced students' instant pleasure for learning, exploratory behaviour, perception of novelty and overall situational interest.

DISCUSSION

This study investigated the effects of using VFB approach as pedagogic tool on motor skill acquisition, and motivation in acrobatic gymnastics choreography during PE sessions. Acrobatic gymnastics offers a unique context for VFB due to its interpersonal coordination, aesthetic precision, and spatial complexity, making it particularly effective for enhancing motor learning and motivation in novice learners (Ávalos et al., 2020). In terms of technical performance, initial results confirmed that the anthropometric characteristics of both groups were similar. Aligning with previous studies (Thomas & Thomas, 1988) as well as those of (Palao et al., 2015), these factors do not significantly influence the outcomes of skill acquisition of the same age and skill level of the children.

Overall, the results showed a significant improvement in motor skills within the experimental group compared to the control group between the pre-test (prior to the intervention) and the post-test (after the intervention). This development was noticeable both in the technical performance scores for the execution of the three acrobatic movements and in the evolution of the joint angles measured for each movement. Importantly, the analysis of the pre-test data revealed no significant differences between the groups, confirming an initial homogeneity in skill levels, characterized as beginner. Statistical analysis further revealed a significant group × time interaction effect, indicating that the improvements observed in the experimental group. These findings highlight the effectiveness of VFB as a relevant didactic tool for enhancing motor learning. Consistent with the literature, feedback is recognized as a critical factor in facilitating the development of motor skills (Mödinger et al., 2022; Wulf et al., 2010), and serves as a key mechanism for exploring performance abilities (Han et al., 2022). In this regard, PE students require accurate and practical information to learn motor skills effectively and to identify and address their specific learning needs, as emphasized by (Schmidt & Lee, 2011).

Regarding technical performance outcomes, the improvements observed in the experimental group across the three figures, *Aeroplane* (176%), *Square* (77%) and *Reverse Handstand* (247%), were considerably greater than those recorded in the control group (74%, 12%, and 38%, respectively). These results indicate that VFB not only enhanced the quality of movement execution but also strengthened technical skill acquisition more efficiently than verbal feedback alone.

These findings support the idea that fixing motor skill mistakes is closely dependent on the learning strategy used, as highlighted by (Milanese et al., 2017). Thus, the use of VFB likely facilitated motor errors detection and adjustment, promoting a process of self-regulation and a deeper understanding of the success criteria for acrobatic figures. Consequently, VFB appears to be an effective pedagogical tool for optimizing motor skill learning. These findings are consistent with the research carried out by Merian and Baumberger (2007), as well as (Mödinger et al., 2022), who stated that by offering students an opportunity of seeing and reviewing the movement performed, mistakes can be analysed and remedied by applying appropriate adjustments. Thus, the impacts of learning new complex gymnastics element depend on the type of feedback provided.

Furthermore, the statistical analysis of joint angle evolution for each acrobatic figure revealed that the experimental group exhibited a greater ability to interpret and integrate the augmented information provided by VFB. This enhanced their postural awareness during the learning sessions and ultimately led to significant and measurable improvements in postural control. Although both groups (experimental and control) showed improvements across the three acrobatic figures, highlighting the positive effect of feedback on motor learning regardless of its nature (Han et al., 2022), the experimental group demonstrated significantly greater progress, particularly for the Aeroplane (29 vs. 8%) and Reverse handstand (31 vs. 15%) figures compared to the control group. However, for the Square figure, no significant difference was observed between the two groups, although the improvement recorded in the experimental group (-20%) remained superior to that of the control group (-12%). This finding may be explained by the lower complexity of the Square figure, which appears to demand less coordination, synchronization, and spatial complexity than the other two figures. These results underline the crucial role of verbal feedback (Kernodle et al., 2001; Starzak et al., 2022) and confirm the effectiveness of VFB in optimizing motor learning (Nowels & Hewit, 2018; Palao et al., 2015; Potdevin et al., 2018).

These results are consistent with previous studies that have demonstrated the positive impact of VFB on the learning of complex technical movements (Merian & Baumberger, 2007; Souissi et al., 2021). Additionally, they demonstrate the potential of VFB learning procedures to facilitate the acquisition and improvement of students' AG skills within a limited instructional timeframe. Similar effects have been observed in previous studies in other sport specialties, including gymnastics (Potdevin et al., 2018), front crawl swimming (Kretschmann, 2017), hurdling (Palao et al., 2015), and weightlifting (Souissi et al., 2023). These studies suggest that integrating VFB into PE teaching can serve as a powerful tool for accelerating the acquisition of technical skills and optimizing learning efficiency across a wide range of motor tasks in relatively short teaching periods, as demonstrated in the present study.

Magill and Anderson (2013) emphasized the importance of VFB in strengthening procedural memory. Their work demonstrated that VFB assists learners in developing robust and flexible motor schemas, thereby enhancing motor skill retention. They further suggested that the use of technological aids such as VFB can be effectively integrated across various educational contexts. Similarly, as highlighted by (Rè, 2017), different types of feedback contribute to motor development, suggesting that the integration of video represents an innovative approach within PE. While numerous studies have confirmed the effectiveness of VFB in motor skill acquisition, it is important to note, as Starzak et al. (2022) argue, that the role of feedback in the teaching-learning process for motor skills of varying complexity and difficulty levels has not yet been categorically established. Therefore, further research is necessary to better understand the efficacy of feedback, particularly in disciplines closely related to gymnastics.

In terms of motivational profile, the findings indicate that the development of motivation, exploratory intent, innovation, and overall interest within the experimental group significantly enhances students' intrinsic enjoyment. This intrinsic enjoyment, in turn, exerts a substantial positive effect on their performance. Furthermore, the integration of the innovative learning module and digital interventions notably contribute to an increase in students' motivation, reinforcing their engagement and fostering improved outcomes in the learning process. From a statistically point of view, this study confirms that VFB interactions fostered a motivational climate among students during AG classes in PE. Notably, both groups exhibited a significant change in motivation between the first and last AG sessions. Effectively, feedback experiences involving video technology perceived both interesting and motivating, leading to increase the improvements in instant enjoyment, exploration intention, innovation and overall interest. However, instant pleasure provides learner an immediate sense of positive satisfaction (Chen et al., 2014). It is noteworthy that the experimental group exhibited significantly higher scores in terms of instant enjoyment and exploratory intent compared to the control group. According to Roure and Pasco (2018) these two dimensions are particularly interesting because they are among the most potent variables in fostering students' interest development. Similarly, Potdevin et al. (2018) reported that VFB, had a more substantial impact on students' emotional responses in PE classes. Although both groups showed increased levels of enjoyment, the experimental group displayed a more pronounced enhancement, suggesting that the VFB may contribute to a heightened sense of engagement and satisfaction during the learning process. Learning a new skill combined with VFB increased students' engagement in their learning process, continuous readjustment of their skill development, self-assessment of task performance and collaboration with the PE teachers in the acquisition process. Though VFB is time-consuming, this digital device helps in achieving an optimal performance and enriching the learning experience of athletes.

At the statistical level, contrary to previous works, the current studies used mixed-method approach. Quantitative approaches were used to examine the potential value of VFB on students' motor skill improvement and motivation in a PE context. Moreover, to assess students' progress in motor skills learning, the acrobatic figures in pairs were digitally video-recorded and measured the attempts were calculated for each student in each session. All acrobatic movements were analysed using qualitative criteria for technical skills and a quantitative criterion for the angle measurement.

The most important limitation of this study was the time required for students to become familiar with the digital equipment used for VFB. A future study could focus on the use of VFB coupled with time-effect. Additionally, future pedagogical challenges should focus on developing PE quality of knowledge and professional skills related to the use and exploitation of digital tools by experimenting with new strategies would also help in the learning process.

Practical applications

The study highlights the significant impact of VFB in improving teaching and learning outcomes in practical physical education settings, particularly within acrobatic gymnastic. Through an analysis of students' performance and motivation, the findings suggest that VFB serves as a more effective and engaging method compared to traditional teaching techniques. Importantly, the results highlight VFB' potential as both a pedagogical and training tool that can foster increased student engagement, intrinsic motivation and motor skill acquisition. Furthermore, these outcomes suggest that VFB can be a valuable resource for physical educators, coaches and sports trainers, providing a scalable strategy for optimizing technical learning and performance in AG.

AUTHOR CONTRIBUTIONS

Mohamed Sami Bouzid: research concept and study design, literature review, data analysis and interpretation, statistical analyses. Hassan Melki: literature review, data analysis and interpretation, statistical analyses. Montassar Ben Romdhane: literature review, writing of the manuscript. Wissal Khalfallah: research concept and study design, literature review, data collection. Youssef Rezgani: research concept and study design, data collection, analysis and interpretation. Sabra Hammoudi, Ghazi Racil and Johnny Padulo: writing – review and editing, supervision.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

PATIENT CONSENT STATEMENT

Written informed consent was obtained from all study participants parents.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the acrobatic gymnastics teachers and coaches for their valuable collaboration. Special thanks are also extended to the students of Ariana pilot school for their participation in this study

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