Bridging Coaching Knowledge and AI Feedback to Enhance Motor Learning in Basketball Shooting Mechanics Through a Knowledge-Based SOP Framework

Jian-Jia Weng*
National Tsing Hua University
Hsinchu, Taiwan
jeter.weng@iss.nthu.edu.tw

Calvin Ku*
National Tsing Hua University
Hsinchu, Taiwan
calvinku1209@gmail.com

Jo Chien Wang
National Tsing Hua University
Hsinchu, Taiwan
ryks8927@gapp.nthu.edu.tw

Chih-Jen Cheng
National Yang Ming Chiao Tung University
Hsinchu, Taiwan
jenny@nycu.edu.tw

Tica Lin
Taiwan Institute of Sports Science
Taipei, Taiwan
mlin@g.harvard.edu

Yu-An Su
Acadmia Sinica
Taipei, Taiwan
yuansu@iis.sinica.edu.tw

Tsung-Hsun Tsai
National Tsing Hua University
Hsinchu, Taiwan
penguin0730@gapp.nthu.edu.tw

You-Yi Lin
Taipei First Girls High School
Taipei, Taiwan
annalin0630@gmail.com

Lun-Wei Ku
Academia Sinica
Taipei, Taiwan
lwku@iis.sinica.edu.tw

Hung-Kuo Chu
National Tsing Hua University
Hsinchu, Taiwan
hkchu@cs.nthu.edu.tw

Min-Chun Hu
National Tsing Hua University
Hsinchu, Taiwan
anitahu@cs.nthu.edu.tw

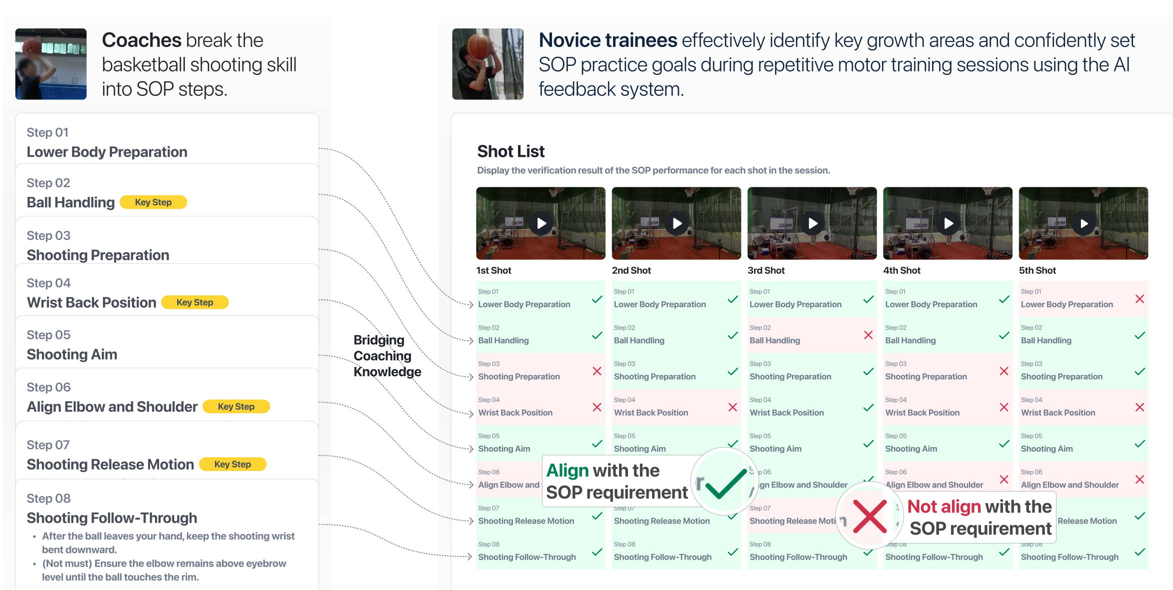

Figure 1: Our proposed SOP methodology enhances basketball shooting through expert comparisons and structured AI feedback.

通过基于知识的SOP框架桥接教练知识与人工智能反馈以提升篮球投篮机制中的运动学习

基于知识的SOP框架

翁健嘉,国立清华大学 台湾新竹
jeter.weng@iss.nthu.edu.tw

顾凯文,国立清华大学 台湾新竹
calvinku1209@gmail.com

王若谦 国立清华大学
台湾新竹
ryks8927@gapp.nthu.edu.tw

郑志仁 国立阳明交通大学 台湾新竹
jenny@nycu.edu.tw

林缇卡 台湾运动科学研究所 台湾台北
mlin@g.harvard.edu

苏育安 中央研究院 台湾台北
yuansu@iis.sinica.edu.tw

蔡宗勋 国立清华大学 台湾新竹
penguin0730@gapp.nthu.edu.tw

林宥仪 台北第一女子高级中学 台湾台北
annalin0630@gmail.com

古伦维 中央研究院 台湾台北
lwku@iis.sinica.edu.tw

朱宏国 国立清华大学 台湾新竹
hkchu@cs.nthu.edu.tw

胡敏君 国立清华大学 台湾新竹
anitahu@cs.nthu.edu.tw

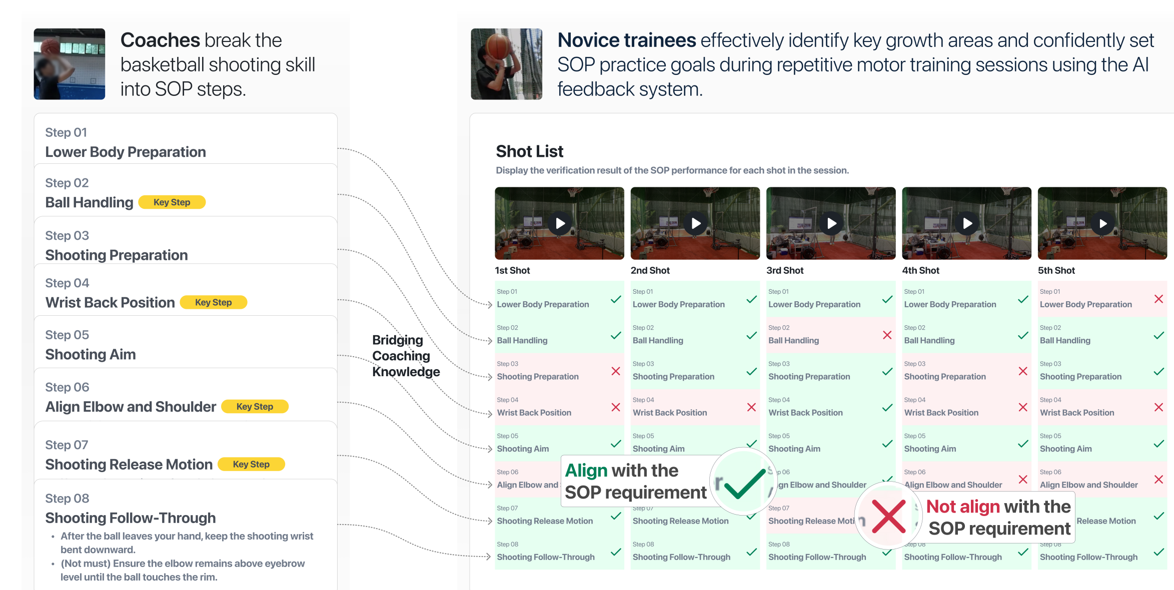

图1：我们提出的SOP方法学通过专家比较和结构化AI反馈来提升篮球投篮水平。

Abstract

We present a methodology for designing an AI feedback system aimed at assisting basketball beginners in refining their shooting techniques during independent practice sessions. Mastering shooting mechanics requires consistent, precise repetition, which traditionally depends on coaching feedback and the breakdown of movements into steps during the early stages. However, due to limited coaching resources, this guidance is often unavailable, leading to ineffective and even detrimental motor learning. To bridge this gap, we propose a Standard Operating Procedure (SOP) framework grounded in expert human knowledge, or knowledge-based SOP, which allows our AI-driven system to verify and guide players' movements in real-time. Through a formative study involving interviews with 13 coaches and players, we identified key challenges faced by beginners, such as uncertainty in movement correctness and lack of guidance during unsupervised practice. Our AI system addresses these issues by providing immediate, actionable feedback using SOP tailored to individual players. In a study with 28 participants, we confirmed that our system improves shooting form, increases confidence in adjustments, and enhances self-awareness during practice. This work highlights the potential of integrating coaching expertise with AI to empower athletes with more effective tools for self-directed practice.

Keywords

Sports/Exercise, Visualization, Empirical study that tells us about how people use a system

ACM Reference Format:
Jian-Jia Weng, Calvin Ku, Jo Chien Wang, Chih-Jen Cheng, Tica Lin, Yu-An Su, Tsung-Hsun Tsai, You-Yi Lin, Lun-Wei Ku, Hung-Kuo Chu, and Min-Chun Hu. 2025. Bridging Coaching Knowledge and AI Feedback to Enhance Motor Learning in Basketball Shooting Mechanics Through a Knowledge-Based SOP Framework. In *CHI Conference on Human Factors in Computing Systems (CHI '25), April 26–May 01, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 20 pages. https://doi.org/10.1145/3706598.3713324

1 Introduction

Repetitive motor training is essential for learning new sports skills, particularly for beginners in basketball shooting. Consistent repetition helps players internalize proper motor patterns, which are critical for developing a stable and accurate shooting form [24, 26]. However, as our formative study (cf. Section 3) reveals, current training methods often fail to support independent practice outside formal coaching sessions sufficiently. Due to limited coaching resources, coaches often cannot monitor and guide players effectively during these sessions. Some coaches utilize video recordings as a supplementary tool, sharing instructional clips or encouraging players to film their practice. However, this approach has limitations, such as delayed feedback and challenges in diagnosing posture errors [6, 7, 12]. Despite evidence showing that progressive methods (i.e., mastering small parts before advancing to more complex movements) enhance learning outcomes [15], trainees have a hard time ensuring their motions align with the coach's standards during unsupervised practice sessions, leading to ineffective motor training for beginners.

Researchers seek automated methods to provide feedback and enhance unsupervised motor training. However, delivering effective posture feedback in an automatic system without a coach's presence poses significant challenges. First, the 3D nature of movements complicates accurate assessment. Feedback must support analyzing detailed spatial movements involved in shooting mechanics. Second, real-time adjustments are necessary to help players correct their form as they practice, but automated feedback systems often struggle to accurately identify errors and offer clear, actionable advice. Third, motor learning relies heavily on proprioception, which can be difficult to cultivate without direct guidance. Furthermore, individual variations in muscle movements mean that feedback must go beyond simple metrics like shot percentage, requiring an understanding of the subtleties of posture that are challenging to quantify.

Popular approaches like digital video modeling (VM), such as Kinovea [18] and Dartfish [23], attempt to address these challenges by mapping movements onto videos, allowing players to observe and analyze their posture after practice. However, VM has limited capability to provide real-time feedback and does not effectively foster proprioception or account for individual muscle variations without coaches' input, limiting its overall impact in improving motor skills such as basketball shooting form [15, 31]. On the other hand, tools like NOAH [13] offer real-time feedback on shot trajectories but fail to address the complexity of 3D movements. This simplified feedback limits trainees' ability to develop proprioception and hinders their ability to make nuanced posture corrections. AR feedback systems enhance self-awareness through real-time 3D feedback, which improves proprioception and spatial awareness. However, they still fall short in delivering personalized, detailed feedback on more complex shooting mechanics, as shown in [22].

Despite advancements in existing tools, our review reveals a significant gap in delivering effective posture feedback during self-practice, which is crucial for developing motor skills. Specifically, there is a gap in providing posture feedback that enhances self-awareness and addresses individual posture variations. This gap highlights the need for a more comprehensive approach to posture analysis that goes beyond basic metrics and provides actionable guidance tailored to the unique requirements of each learner, particularly beginners.

To address this gap, we proposed a knowledge-based SOP framework to deliver posture feedback, which integrates coaching insights and system feedback into step-by-step posture motion breakdowns. Our study seeks to understand the requirements for designing an effective automatic posture feedback system. While previous studies focus on *what* feedback [31] and *where* [22] to present this motor feedback, our study focuses on *how* to present such

*Both authors contributed equally to this research.

ACM ISBN 979-8-4007-1394-1/25/04
https://doi.org/10.1145/3706598.3713324

摘要

我们提出了一种设计AI反馈系统的方法论，旨在帮助篮球初学者在独立练习环节中精进投篮技巧。掌握投篮机制需要持续、精确的重复，这在传统上依赖于教练反馈和早期阶段将动作分解为步骤的指导。然而，由于教练资源有限，这种指导往往难以获得，导致运动学习效果不佳甚至有害。为弥合这一缺口，我们提出了一个基于专家人类知识（或称基于知识的SOP）的标准操作程序（SOP）框架，

使我们的AI驱动系统能够实时验证并指导球员的
动作。通过一项涉及13名教练和球员访谈的形成性研究，我们识别出初学者面临的关键挑战，如动作正确性的不确定性以及无监督练习中缺乏指导。我们的AI系统通过提供针对个体球员量身定制的SOP即时、可操作的反馈来解决这些问题。在一项28名参与者的研究中，我们证实该系统能有效改善投篮形式，

提升调整时的信心，并增强练习中的自我意识。这项工作凸显了将教练专业知识与人工智能相结合的巨大潜力，能为运动员提供更有效的自主练习工具。

关键词

运动/锻炼, 可视化, 实证研究 that tells us about
人们如何使用系统

ACM参考格式：
翁健嘉、顾凯文、王若谦、郑志仁、林缇卡、苏育安、蔡宗勋、林宥仪、古伦维、朱宏国和胡敏春。2025。通过基于知识的标准操作程序框架融合教练知识与人工智能反馈以提升篮球投篮机制中的运动学习。发表于CHI人机交互会议（CHI’25），2025年4月26日至5月1日，日本横滨。美国计算机协会，美国纽约州纽约市，20页。
https://doi.org/10.1145/3706598.3713324

1 介绍

重复的运动训练对于学习新的运动技能至关重要，
尤其是篮球投篮初学者。持续重复有助于球员内化正确的运动模式，这对形成稳定且准确的投篮姿势[24, 26]至关重要。

然而，正如我们的形成性研究（参见第3节）所示，当前的训练方法往往无法充分支持正式教练课程之外的独立练习。由于教练资源有限，教练在这些训练课程中经常无法有效监督和指导球员。部分教练会使用视频记录作为

辅助工具，分享教学片段或鼓励球员拍摄自己的练习过程。但这种方法存在局限性，

例如延迟反馈和诊断姿势错误的挑战[6, 7, 12]。尽管有证据表明渐进式方法（即在掌握小部分动作后再进阶到更复杂动作）能提升学习成果[15], ，学员在无监督练习课程中仍难以确保其动作符合教练标准，导致初学者运动训练效果不佳。

研究人员寻求自动化方法来提供反馈并增强无监督运动训练。然而，在没有教练在场的情况下，通过自动系统提供有效的姿势反馈面临重大挑战。首先，动作的三维特性使得准确评估变得复杂。反馈必须支持分析涉及投篮机制的详细空间动作。其次，实时调整对于帮助球员在练习中纠正姿势是必要的，但自动反馈系统往往难以准确识别错误并提供清晰、可操作的建议。第三，运动学习高度依赖本体感觉，而缺乏直接指导时难以培养这种感觉。此外，

个体肌肉差异意味着反馈必须超越投篮命中率等简单指标，需要理解难以量化的姿势微妙之处。

诸如Kinovea [18] 和Dartfish [23], 等数字视频建模（VM）的流行方法试图通过将动作映射到视频上来应对这些挑战，让球员在练习后观察和分析自己的姿势。然而，VM提供实时反馈的能力有限，且在没有教练输入的情况下无法有效培养本体感觉或考虑个体肌肉差异，这限制了其在改进篮球投篮姿势等运动技能方面的整体效果。另一方面，NOAH [13] 等工具虽然能提供投篮轨迹的实时反馈，却无法解决三维运动的复杂性。这种简化的反馈限制了学员发展本体感觉的能力，并阻碍了他们进行细微姿势调整的能力。

增强现实反馈系统通过实时3D反馈提升自我意识，从而改善本体感觉和空间意识。

然而，如[22]所示，它们在提供针对更复杂投篮机制的个性化详细反馈方面仍存在不足。

尽管现有工具取得了进展，但我们的综述揭示了一个重要缺陷：在自主练习期间无法提供有效的姿势反馈，而这对于培养运动技能至关重要。具体而言，

当前缺乏能增强自我意识并解决个体姿势差异的姿势反馈系统。这一缺陷凸显了需要更全面的姿态分析方法，该方法应超越基础指标，为每位学习者（尤其是初学者）提供符合其独特需求的可操作指导。

为弥补这一空白，我们提出了一个基于知识的SOP框架来提供姿势反馈，该框架将教练洞察与系统反馈整合到逐步的姿势动作分解中。我们的研究旨在理解设计有效自动姿势反馈系统的需求。先前研究主要关注反馈内容[31] 及呈现位置[22]，而我们的研究则聚焦于如何呈现此类

*两位作者对本研究贡献均等。

美国计算机协会 ISBN 979-8-4007-1394-1/25/04
https://doi.org/10.1145/3706598.3713324

AI-generated feedback to bridge the gap between human expert insights and AI measurements. Specifically, through our user-centered study, we aim to answer three research questions:

- *RQ1. "What are the key user needs and considerations for designing a fully automatic AI system that improves posture alignment between basketball coaches and beginner players during self-practice sessions?"*
- *RQ2. "How can we design an effective feedback system to support progressive learning and enhance self-awareness and confidence for basketball beginners during self-practice sessions?"*
- *RQ3. "How does the progressive learning system affect the basketball beginner's self-learning experience and the accuracy of their posture alignment with their coach?"*

Based on in-depth interviews with professional basketball coaches, we identified three design goals for an AI SOP posture feedback system: providing real-time comparisons of individual movement segments against coaching standards, enabling motion replays to observe incremental adjustments, and offering guidance on prioritizing posture modifications (RQ1). Our SOP framework derives each step of shooting motion mechanics based on coaches' insights. Each step includes a posture explanation and is accompanied by a detailed video comparison to deliver precise, real-time posture feedback. Our framework further breaks down AI feedback into steps and provide summaries across sessions to allow actionable insights for trainees to develop self-awareness during training (RQ2).

To evaluate whether a structured AI feedback system based on our SOP framework can truly help beginners enhance their self-awareness and training outcomes (RQ3), we developed a prototype to provide posture feedback using the Wizard of Oz method. We conducted a controlled user study with 28 basketball beginners, comparing the traditional video modeling approach with our knowledge-based SOP approach. Our results show that the knowledge-based SOP method can deliver precise posture feedback, significantly enhancing trainees' self-awareness and alignment with training goals. Participants using the SOP system demonstrated increased awareness of their posture performance, with higher scores and more accurate posture error recognition than the baseline group. The structured feedback based on the SOP framework further enabled an effective personalized goal-setting and error-correction loop, allowing participants to identify specific errors and make targeted adjustments. By providing structured, real-time feedback, the SOP method not only improved the accuracy of trainees' movements but also boosted their confidence by fostering a deeper understanding of their own posture performance. These results validate our system design's potential to support effective motor learning, leading to consistent progress and greater satisfaction among trainees.

In summary, our study explores a knowledge-based SOP method to bridge the gap between human knowledge and automatic feedback for enhancing motor learning in basketball shooting. Our contributions are fourfold: 1) a formative study that identifies the key challenges beginners face in aligning their basketball shooting form with coaching standards, 2) an SOP approach to designing a posture feedback system that incorporates coaching knowledge with real-time video and textual feedback, 3) a user study assessing the impact of our AI SOP Posture feedback system design on beginner players across key metrics in confidence, self-awareness, and effectiveness, and 4) insights for designing future AI-driven feedback systems targeting effective human-AI partnerships in sports motor training.

2 Related Work

2.1 Video Annotation Tools

Several existing market solutions, such as Kinovea [18], Dartfish [23], Coach's Eye [33], and Kaia Health [10], offer robust video annotation capabilities that provide detailed visual feedback through frame-by-frame deconstruction of movements. These tools partially address the challenge of capturing the 3D nature of movements by allowing users to analyze posture and technique in detail. However, their reliance on post-training analysis limits their ability to provide real-time adjustments, which are critical for immediate form correction during practice sessions. Additionally, these tools often require users to have a certain level of expertise and familiarity with the software, which can overwhelm less experienced athletes and coaches, impeding their ability to develop proprioception and interpret feedback that addresses individual variations in muscle movements and posture nuances. Our system addresses these gaps by delivering intuitive, actionable feedback in real-time, directly during training, enhancing the accessibility and effectiveness of posture correction.

2.2 Trajectory-Based Basketball Training Solutions

The Noah Shooting System [13] is a widely recognized trajectory-based solution endorsed by NBA professionals and implemented in various elite training facilities. It uses pre-installed cameras to track shot angles and trajectories, providing numerical data on the ball's path and offering real-time feedback on shot outcomes. However, Noah falls short in addressing the 3D complexity of body movements, fostering proprioceptive development, and providing personalized, detailed posture feedback. These limitations often leave players and coaches to infer the necessary adjustments from the arc data, which may lead to oversimplified and less effective training interventions.

In contrast, augmented reality (AR) systems, such as the one developed by Lin et al. [22], build upon prior work [16] by integrating 3D visualizations of ideal shot trajectories, aiming to improve real-time feedback and players' self-awareness of their performance. While these systems improve on trajectory visualization, they still lack comprehensive posture guidance and often depend on wearable devices that can cause discomfort and limit usability due to their weight and restricted field of view. Focusing solely on trajectory overlooks the critical need for posture alignment, which may inadvertently reinforce improper movements and result in inconsistent performance or even injury. Our system differentiates itself by integrating both posture and movement standards, providing comprehensive feedback that supports balanced skill development in posture alignment and shooting accuracy, all without requiring cumbersome wearables.

AI生成反馈，以弥合人类专家洞察与人工智能测量之间的差距。具体而言，通过我们以用户为中心的研究，我们试图回答三个研究问题：

- 研究问题*1.* “在设计一个全自动*AI*系统以改善篮球教练与初学者球员在自我练习环节中的姿势对齐时，关键的用户需求与设计考量是什么？”
- 研究问题*2.* “如何设计一个有效的反馈系统，以支持渐进式学习并提升篮球初学者在自我练习环节中的自我意识与信心？”
- 研究问题*3.* “渐进式学习系统如何影响篮球初学者的自学体验及其与教练姿势对齐的准确性？”

基于对职业篮球教练的深度访谈，我们为AI标准操作程序姿势反馈系统确立了三个设计目标：提供个体运动片段与教练标准的实时对比、启用动作回放以观察渐进调整，以及指导学员优先进行姿势调整（研究问题1）。我们的标准操作程序框架基于教练见解推导出投篮动作机制的每个步骤。每个步骤包含姿势解释，并辅以详细的视频比较，以提供精确的实时姿势反馈。该框架还将AI反馈分解为步骤，并提供跨训练课程的总结，使学员能够获得可操作的见解，在训练中培养自我意识（研究问题2）。

为评估基于我们标准操作程序框架的结构化AI反馈系统是否能真正帮助初学者提升自我意识及训练成果（研究问题3），我们开发了一个采用绿野仙踪方法的原型系统来提供姿势反馈。我们通过对28名篮球初学者进行受控用户研究，比较传统视频建模方法与基于知识的SOP方法。结果表明，基于知识的SOP方法能提供精确的姿势反馈，显著增强学员的自我意识及与训练目标的对齐度。

使用SOP系统的参与者表现出更高的姿势表现意识，其分数和姿势错误识别准确性均优于基线组。基于SOP框架的结构化反馈进一步实现了有效的个性化目标设定和错误纠正循环，

使参与者能够识别具体错误并进行有针对性的调整。通过提供结构化的实时反馈，SOP方法不仅提高了学员动作的准确性，还通过深化其对自身姿势表现的理解增强了信心。这些结果验证了我们系统设计在支持有效运动学习方面的潜力，能带来持续进步并提升学员满意度。

总之，我们的研究探索了一种基于知识的SOP方法，以弥合人类知识与自动反馈之间的差距，从而提升篮球投篮的运动学习效果。我们的贡献体现在四个方面：1）一项形成性研究，明确了初学者在使篮球投篮姿势符合教练标准时面临的关键挑战；2）一种SOP方法，用于设计姿势反馈系统，该系统将教练知识与实时视频及文本反馈相结合；3）一项用户研究，评估了我们的AI标准操作程序姿势反馈系统设计对初学者球员在信心、自我意识和有效性等关键指标上的影响；4）为设计未来AI驱动的反馈系统提供了见解，旨在实现运动技能训练中有效的人机协作。

2 相关工作

2.1 视频标注工具

现有市场解决方案如Kinovea [18]、、Dartfish [23]、、教练之眼[33], 和Kaia Health [10], 均提供强大的视频标注功能，通过逐帧解构动作来呈现细致的视觉反馈。这些工具允许用户详细分析姿势与技术，部分解决了捕捉动作三维特性的挑战。然而，

它们对训练后分析的依赖限制了其实时调整的能力，而这对练习会话中即时姿势矫正至关重要。此外，这些工具通常要求用户具备一定的软件专业知识和熟悉度，这可能会让经验不足的运动员和教练感到无所适从，阻碍他们发展本体感觉及理解针对肌肉运动和姿势细微差异个体化反馈的能力。我们的系统通过实时提供直观、可操作的反馈，直接在训练过程中提升姿势矫正的可及性和有效性，从而弥补了这些不足。

2.2 基于轨迹的篮球训练解决方案

诺亚投篮系统 [13] 是广受认可的基于轨迹的解决方案，获NBA专业人士背书并被应用于各类精英训练设施中。该系统通过预装摄像机来追踪投篮角度与轨迹，提供关于球体路径的数值数据，并实时反馈投篮结果.

然而，NOAH在应对身体动作的三维复杂性方面存在不足，未能促进本体感觉发展，也未能提供个性化的详细姿势反馈。这些局限常常使得球员和教练只能从弧线数据中推断必要调整，这可能导致训练干预过于简化且效果不佳，降低训练的有效性。

相比之下，增强现实（AR）系统，如Lin等人[22], 开发的系统[16]，通过整合理想投篮轨迹的三维可视化，旨在改进实时反馈并提升球员对其表现的自我意识。

尽管这些系统改进了轨迹可视化，但仍缺乏全面的姿势指导，且往往依赖可穿戴设备，这些设备可能因重量和受限视野导致不适并限制可用性。仅关注轨迹会忽视姿势对齐的关键需求，可能无意中强化不当动作，导致表现不稳定甚至受伤。我们的系统通过整合姿势和动作标准实现差异化，提供全面反馈，支持姿势对齐和射击准确性的平衡技能发展，且无需使用笨重的可穿戴设备。

2.3 Posture-Based Suggestion Solutions

Recent advancements in posture-based feedback systems, such as those employing lightweight real-time models like MoveNet [1], provide 2D joint angle calculations and real-time rule-based audio feedback for activities like workouts and yoga [2]. However, these activities are typically governed by well-established SOP and do not involve the complex coordination and kinetic chains seen in sports like basketball shooting. Moreover, such systems often overlook individual biomechanical variations, which limits their efficacy in enhancing complex motor skills, such as a basketball set shot. In this work, we investigate how to decompose intricate motor skills like the basketball set shot and develop methods for presenting feedback that bridges the gap between human expert insights and AI measurements. Our approach aims to provide personalized, context-sensitive feedback that captures the intricate biomechanical nuances of shooting mechanics, addressing the limitations of current feedback systems by aligning feedback guidance more closely with expert coaching standards.

Existing basketball posture studies, such as those by Nakai et al. [27] and Chen et al. [4], have explored the relationship between posture and shooting success using 2D pose estimation algorithms like OpenPose [3]. While these works contribute valuable insights into how posture affects performance, they primarily rely on 2D data and do not provide comprehensive real-time feedback, thus failing to capture the 3D complexities of shooting movements and the necessity for immediate posture adjustments. Furthermore, although these systems highlight skill-level discrepancies, they often lack the personalized feedback needed to accommodate individual muscle movement variations, leaving players to interpret and adjust based only on 2D joint angle data.

In other sports, studies on 3D visualization tools, such as table tennis [20, 34] and badminton [21], demonstrating the potential of monocular 3D human pose estimation models in enhancing posture analysis. However, these approaches often provide visual tutorials of sports movement without offering clear, real-time feedback that users can immediately act upon, limiting their ability to effectively foster proprioception and guide personalized improvements. By contrast, our system adopts a human-AI interaction design that not only enhances self-awareness but also delivers specific, actionable insights aligned with expert coaching, ensuring that players receive feedback that builds confidence and supports consistent progress in their training.

3 Formative Study

To gain a comprehensive understanding of the challenges faced by novice basketball players during independent practice sessions, we conducted a formative study involving basketball beginners and experienced coaches. Based on interview results, we summarized three key challenges that need to be addressed in the system design in Section 4.

3.1 Study Setup

3.1.1 Participants.
We recruited five beginner basketball players (P1-P5; M=1, F=4; Age: 18-24), with less than two years of training experience and limited knowledge of the sport, and eight professional basketball coaches (C1-C8, M=5, F=3; Age: 30-55; Teaching experience: 8-20), with experience in mentoring students across various levels, from primary school to university. To gain realistic insights into basketball shot training, we paired each player with a coach. In total, we observed 5 training groups. Three more coaches (C6-C8) were interviewed separately. Table 1 shows how participants are divided in our formative study.

Group	ID	Role	Sex	Experience
1	C1 P1	Coach Player	M F	18 years of teaching <1 year in training
2	C2 P2	Coach Player	F F	5 years of teaching <1 year in training
3	C3 P3	Coach Player	M F	20 years of teaching 1.5 years in training
4	C4 P4	Coach Player	F F	17 years of teaching <1 year in training
5	C5 P5	Coach Player	M M	9 years of teaching <1 year in training
N/A	C6	Coach	M	8 years of teaching
N/A	C7	Coach	M	20 years of teaching
N/A	C8	Coach	F	25 years of teaching

Table 1: Background of formative study participants.

3.1.2 Procedure.
To observe how beginners learn complex movements like shooting a basketball in their self-practice, we adopted the common practice of using video recordings as supplementary supports in our study. Each training group consisted of a coaching phase, a self-practice phase, and a post-training feedback phase, and concluded with a semi-structured interview with both the coach and player.
Coaching phase: The coach provided foundational teaching on executing a basketball set shot, 2.5m from the hoop. Both the coach's and player's postures were recorded from the side using a mobile phone positioned 3 meters away to capture full-body views.
Self-practice phase: The player began practice shooting without the coach's feedback. After each shot, they can review their posture videos and compare them with the coach's demonstration. This process was repeated ten times.
Post-training feedback phase: After observing the player training on their own, the coach offered targeted feedback through verbal explanations, physical demonstrations, and video replays to help improve the player's shooting techniques.
Post-study interview: At the end of the study, we interviewed the player on their challenges during self-practice and their needs for additional guidance. Players were also shown examples of 2D [18, 33] and 3D pose analysis tools [20], commonly used in sports training for movement evaluation. Later, we solicited the coach's feedback and ideas on mechanisms to improve their coaching procedures.

3.2 Identifying User Challenges in Self-Training

We identified three key challenges that beginners face in practicing shooting techniques independently, followed by our design goals for a basketball shot training AI SOP posture feedback system to address these issues.

2.3 基于姿势的建议解决方案

基于姿势的反馈系统的最新进展，例如采用MoveNet [1],等轻量级实时模型的系统

提供二维关节角度计算和基于规则的实时音频反馈，适用于锻炼和瑜伽等活动[2]。然而，

这些活动通常遵循完善的标准操作程序，且不涉及篮球投篮等运动中出现的复杂协调和动力链。此外，此类系统往往忽略个体生物力学差异，从而限制了其在提升复杂运动技能（如篮球定点投篮）方面的效果。本研究探讨如何分解篮球定点投篮等复杂运动技能，并开发呈现反馈的方法，以弥合人类专家见解与人工智能测量之间的差距。我们的方法旨在提供个性化、情境敏感的反馈，捕捉投篮机制中精细的生物力学细微差别，通过使反馈指导更贴近专家教练标准，解决当前反馈系统的局限性。

现有篮球姿势研究，如Nakai等人的研究，
等人 [27] 和Chen等人 [4], 探究了
姿势与投篮成功率之间的关系，采用了二维姿态估计算法
如OpenPose [3]。尽管这些研究提供了有价值的见解
关于姿势如何影响表现，但它们主要依赖二维
数据且无法提供全面的实时反馈，因此
未能捕捉到投篮动作的三维复杂性
需要立即进行姿势调整的必要性。此外，尽管这些系统凸显了技能水平差异，但它们往往
缺乏必要的个性化反馈来满足个体需求
肌肉运动变化，留给球员去解读和调整
仅基于二维关节角度数据。
在其他运动领域，关于三维可视化工具的研究，例如表格
网球 [20, 34] 和羽毛球 [21], 展示了潜力
单目三维人体姿态估计模型在改善姿势中的应用
分析。然而，这些方法通常提供视觉教程
在运动过程中缺乏清晰、实时反馈的情况下
用户能够立即采取行动，限制了其有效执行的能力。
培养本体感觉并指导个性化改进。
相比之下，我们的系统采用了人机交互设计，而非
不仅增强自我意识，还提供具体的、可操作的
见解，与专家指导保持一致，确保球员获得
能够建立信心并支持持续进步的反馈
在他们的训练中。

3 形成性研究

为了全面理解所面临的挑战
针对篮球新手在独立练习环节中的情况，我们
开展了一项涉及篮球初学者与
经验丰富的教练的形成性研究。基于访谈结果，我们总结出
三项需要在系统设计中解决的关键挑战，
详见第4节。

3.1 研究设置

3.1.1 参与者。
我们招募了五位篮球初学者（P1-P5；男=1，女=4；年龄：18-24岁），他们的训练经验不足两年且对该运动了解有限，以及八位职业篮球

组别	ID	Role	Sex	经验
1	C1 P1	教练 球员	M F	18年教学经验 <1 年训练经验
2	C2 P2	教练 球员	F F	5年教学经验 <1 年训练经验
3	C3 P3	教练 球员	M F	20年教学经验 1.5年训练经验
4	C4 P4	教练 球员	F F	17年教学经验 <1 年训练
5	C5 P5	教练 球员	M M	教学9年 <1 年训练
N/A	C6	教练	M	8年教学经验
N/A	C7	教练	M	20年教学经验
N/A	C8	教练	F	25年教学经验

表1: 形成性研究参与者背景。

教练（C1-C8，男=5，女=3；年龄：30-55岁；教学经验：8-20年），他们具有指导不同水平学生的经验，

从小学到大学。为了获得关于篮球投篮训练的真实见解，我们为每位球员配备了一名教练。总共观察了5个训练小组。另外还单独采访了三名教练（C6-C8）。表1展示了我们形成性研究中参与者的分组情况。

3.1.2 程序
为了观察初学者如何在自我练习中学习投篮等复杂动作
我们采用了研究中常见的做法
将视频记录作为辅助支持手段
每个训练小组包含一个教练阶段和一个自我练习
阶段，以及训练后反馈阶段，最后以
与教练和球员的半结构化访谈结束。
教练阶段：教练提供了关于
执行篮球定点投篮的基础教学，2.5m 距离篮筐。教练和
球员的姿势均通过侧面视角用手机
在3米外拍摄以捕捉全身视图。
自主练习阶段：球员在没有
教练反馈的情况下开始练习投篮。每次投篮后，他们可以回顾自己的姿势
视频，并与教练的示范进行对比。这一
过程重复了十次。
训练后反馈阶段：在观察球员自主训练后，教练通过

口头解释、身体示范和视频回放提供针对性反馈。
帮助提升球员的投篮技巧。
研究后访谈：在研究结束时，我们采访了
球员在自我练习期间遇到的挑战及其对额外
指导的需求。我们还向球员展示了运动中常用
[18, 33] 和三维姿势分析工具[20], 的示例,
用于动作评估训练。随后，我们征求了教练的
关于改进其教练流程机制的反馈与建议。

3.2 识别自我训练中的用户挑战

我们识别出初学者在独立练习投篮技巧时面临的三个关键挑战，
随后提出了我们针对篮球投篮训练AI标准操作程序姿势反馈系统的设计目标，
以期解决这些问题。
解决这些问题。

Pain Points	**Design Requirements**
01: Uncertainty in meeting coaching standards	**01**: Providing real-time comparisons of individual movement segments against coaching standards
02: Unnoticed misalignment between perceived and actual posture	**02**: Enabling motion replays to observe incremental adjustments
03: Not confident in prioritizing posture adjustment	**03**: Offering guidance on prioritizing posture modifications

Table 2: Pain points and corresponding design requirements.

3.2.1 *Pain Point 01: Uncertainty in Meeting Coaching Standards*.

When a technique is broken down into multiple steps, trainees often miss key training points during self-practice, frequently expressing the need to see the posture video replay. Without the coach's video guidance, these omissions could significantly reduce the effectiveness of self-training. As Coach C4 noted, *"We emphasize five key points in the movement, but if a student only executes two, their posture won't receive the proper feedback, leading to frustration over time and eventually causing them to doubt their own learning ability."* Furthermore, through interviews with both coaches and players, we found that even when players replayed their own videos, they still overlooked critical aspects. This is largely due to the complexity of shooting techniques and the beginners' lack of a solid knowledge framework to identify errors. As C5 mentioned, *"During the coaching phase, the students may only partially understand the movements but hesitate to seek clarification. As coaches, we often assume they've grasped the concept, but when they struggle to perform the actions correctly, we realize they've missed important details in the video."*

3.2.2 *Pain Point 02: Unnoticed Misalignment Between Perceived and Actual Posture*.

All participants realized during practice that the movements they thought they were performing were different from what they saw in their recorded videos. For example, as P1 remarked, *"I thought I played like a professional athlete, but the video showed something different."* This discrepancy may be attributed to beginners' limited experience and understanding of basketball techniques. Additionally, as Coach C6 pointed out, it could also be due to beginners' muscles and fascia still adapting to the new physical demands, making immediate adjustment difficult. Learner P3, after reviewing videos of both themselves and the coach, realized that the body might need some time to catch up with the mind: *"When I played the coach's video in slow motion, I noticed there should have been a slight pause here. The flow of the movement was different from what I did. I might not be able to replicate it right away, but now I understand how to correct it."*

3.2.3 *Pain Point 03: Not Confident in Prioritizing Posture Adjustment*.

We found that beginners, after reviewing their shooting practice videos, often notice discrepancies in their movements but struggle to make all the necessary adjustments at once due to the high cognitive load. They tend to rely on the coach's guidance to prioritize which corrections to focus on. P1 illustrated this by comparing their uncertainty in adjusting basketball techniques to their confidence in other sports: *"In basketball, I don't have enough knowledge, so I want the coach to review my performance and prioritize the corrections for me. With weight training, I have enough experience to know what adjustments to make, so I don't need someone to sort it out for me."*

3.3 Design Requirements

During post-study interviews, we discovered that novice players encountered significant challenges with existing 2D and 3D training tools. The primary obstacles stemmed from the players' limited understanding of basketball techniques and their inability to effectively interpret the visual data presented by these advanced systems, leaving them uncertain about their next steps. In response to these identified pain points and the shortcomings of current solutions, we proposed three key design requirements for designing an effective posture training system to address the primary challenges beginners face during independent practice.

3.3.1 *Design Requirement 01: Evaluate Real-Time Compliance with Step-by-Step Coaching Standards*.

All interviewed coaches agreed that while there is no absolute standard for every breakdown of the shooting motion, general principles apply. Coaches adapt these principles based on their teaching style and areas of focus. As coaches C3, C6, C7, and C8 mentioned, many key aspects of shooting technique can be visually assessed during instruction to identify students' posture errors. They also expressed a desire for a system that allows coaches to input personalized teaching points, enabling the system to quickly determine whether students' movements align with these points. As C7 explained, *"Beginners often don't know what the ideal shooting posture looks like. This scoring mechanism could provide them with immediate feedback. It can provide benefits to both parties: students can identify areas for improvement during self-practice, and coaches can use the system to highlight key posture requirements."* Additionally, coaches suggest that instructional steps should be sequenced according to the movement chain, with clear and simple explanations to aid memory. Several coaches recommend incorporating percentage and trend changes for each breakdown of the movements. This approach not only helps students track their progress but also fosters trust between the student and the coach. As C6 emphasized, *"Students can see their own improvement and trust the validation of the coach's expertise."*

3.3.2 *Design Requirement 02: Clearly Replay and Compare Correct and Incorrect Movements*.

To enhance beginners' awareness of their postures, we recommend, based on interview findings, that player postures be replayed in alignment with each step of the process. Coaches noted that beginners often struggle to identify movement issues from videos due to their unfamiliarity with proper form. Coaches C4, C6, and C7 have recorded videos of their own shooting motions and shared them online with trainees to demonstrate necessary adjustments during

痛点	**设计要求**
01: 达到教练标准的不确定性	01: 提供个体运动片段与教练标准的实时比较
02: 感知与实际姿势间未被注意的偏差	02: 启用动作回放以观察渐进调整
03: 对优先调整姿势缺乏信心	03: 提供关于优先调整姿势的指导

表2: 痛点及对应设计要求。

3.2.1 痛点*01:* 满足教练标准的不确定性。

当一项技巧被分解为多个步骤时，学员在自我练习中常会遗漏关键训练要点，频繁表示需要观看姿势视频回放。若缺乏教练的视频指导，这些疏漏会大幅降低自我训练的效果。正如教练C4所言：“我们强调动作中的五个关键点，但如果学员只做到其中两点，他们的姿势就无法获得应有的反馈，久而久之会产生挫败感，最终导致他们怀疑自身的学习能力。”此外，通过对教练和球员的访谈，我们发现即使球员回放自己的视频，仍会忽略关键细节。这主要源于投篮技巧的复杂性以及初学者缺乏识别错误的扎实知识框架。如C5所述：“在教学阶段，学员可能仅部分理解动作要领却羞于寻求 clarification。作为教练，我们常误以为他们已掌握概念，但当他们无法正确执行动作时，我们才意识到他们遗漏了视频中的重要细节。”

3.2.2 痛点*02*：感知姿势与实际姿势间未被察觉的错位

所有参与者在练习过程中都意识到，他们自认为完成的动作与录像视频中呈现的存在差异。例如P1感叹道：“我以为自己打得像个职业运动员，但视频显示的完全不同。”这种差异可能源于初学者对篮球技术的经验与理解有限。此外，正如教练C6指出的，这也可能是因为初学者的

肌肉和筋膜仍在适应新的身体需求，导致即时调整存在困难。学习者P3在观看自己和教练的对比视频后意识到，身体可能需要时间才能跟上意识的节奏：“当我用慢动作播放教练的视频时，发现这里本应有个细微停顿。动作的连贯性与我的实际操作不同。虽然无法立即复现，但现在我知道该如何纠正了。”

3.2.3 痛点*03*：在优先调整姿势方面缺乏信心调整。

我们发现，初学者在回看自己的投篮练习视频后，常能察觉动作中的差异，但由于认知负荷较高，往往难以一次性完成所有必要调整。他们倾向于依赖教练的指导来确定纠正重点的优先级。参与者1通过对比自己在篮球技术调整上的不确定性与在其他运动中的信心来说明这一点：“在篮球方面，我知识储备不足，所以希望教练能评估我的表现并为我排序纠正要点。而重量训练方面，我有足够的经验来知道该做哪些调整，因此不需要别人来帮我梳理。”

3.3 设计要求

在研究后访谈中，我们发现新手球员在使用现有的2D和3D训练工具时遇到了重大挑战。主要障碍源于球员对篮球技术的理解有限，以及他们无法有效解读这些先进系统提供的视觉数据，

导致他们对下一步行动感到不确定。针对这些已识别的痛点以及当前解决方案的不足，

我们提出了三项关键设计要求，旨在设计一个有效的姿势训练系统，以解决初学者在独立练习过程中面临的主要挑战。

3.3.1 设计需求*01*：评估实时遵循分步骤教练标准的合规性。

All 采访 教练 同意 that 而 存在 is no 绝对

对于投篮动作的每一个分解环节，通用原则都是标准。教练会根据其教学风格和重点领域调整这些原则。正如教练C3、C6、C7和C8所提到的，许多投篮技巧的关键方面可以在教学过程中通过视觉评估来识别学生的姿势错误。他们还表达了对一个系统的渴望，该系统允许教练输入个性化教学要点，使系统能够快速判断学生的动作是否与这些要点一致。正如C7解释的那样，“初学者通常不知道理想投篮姿势是什么样子。”

这种评分机制可以为他们提供即时反馈。
它可以为双方带来好处：学生可以在自我练习中发现改进领域，教练可以利用系统突出关键姿势要求。”此外，教练建议教学步骤应按照动作链的顺序排列，并提供清晰简单的解释以帮助记忆。

几位教练建议为每个动作分解环节加入百分比和趋势变化。这种方法不仅帮助学生跟踪他们的进度，还培养了学生与教练之间的信任。正如C6强调的那样，“学生可以看到自己的改进，并信任教练专业知识的验证。”

3.3.2 设计需求*02*：清晰回放与比较正确与错误动作。

To 增强 初学者的 意识 of 他们的 姿势, we 建议，

基于访谈结果，建议将玩家姿势按流程每一步进行对齐回放。教练指出，初学者常因

对正确姿势不熟悉而难以通过视频识别动作问题。教练C4、C6和C7已录制自身投篮动作视频并分享
在线与学员演示训练期间的必要调整

routine training. As C8 mentioned, *"I previously recorded my students' video clips and directly pointed out the lack of muscle extension in their movements."* The system should also emphasize both correct and incorrect movements, along with the coach's instructional videos at each step, to allow students to quickly compare their actions for fine-tuning. As C4 stated, *"You need to show students which movement details to maintain, which areas are weak and need improvement... or use video comparisons between the instructional video and the student's performance."*

*3.3.3 **Design Requirement 03: Provide Clear Guidance on Prioritizing Posture Modifications**.* After students complete their shooting practice, the system should clearly indicate which specific movement breakdown should be prioritized for correction. Our observations of coach-student interactions during teaching and correction revealed that all coaches recommend focusing first on hand movements, as their accuracy has a direct impact on shooting performance. As Coach C7 explained, *"When practicing hand movements, don't worry about the feet. Once the hand movements are correct, we can then address the feet. Later, it's crucial to ensure stability in feet, and then focus on generating power from the heels and hips."* From a beginner's perspective, knowing the order of corrections is equally important. Ideally, the system should provide a mechanism that allows coaches to rank corrections, helping students focus on key areas for improvement. As P1 mentioned, *"I'm not sure if the coach can see the system's recommendations, but ultimately, the coach needs to evaluate and tell me what to fix first since they are familiar with my performance."*

3.4 Summary

In summary, beginners often face challenges maintaining training quality without a coach, and existing methods, like side-view recording, fail to fully capture movement issues. We identified three design requirements that address critical challenges as a basis for feature development in the next section.

4 System Design

To address the challenges identified in the formative study, we designed and built a prototype of AI SOP posture feedback system to test its effectiveness for beginners. The prototype was refined through a pilot study, incorporating feedback from four professional coaches (C4, C6, C7, C8) and iterative brainstorming among our research team.

4.1 Breakdown of the SOP for Basketball Set Shot and SOP Tutorial Video

To address Design Requirement 01, we collaborated with coach C4 to design an SOP for basketball set shot summarized in Table 3 based on her domain knowledge backed up by relevant shooting biomechanics literature. Key steps are marked by the ★ symbol. Checkmarks (✓) indicate verification points, enabling both trainees and coaches to assess whether each step has been correctly executed. This ensures that trainees receive continuous feedback and maintain alignment with coaching standards.

Based on this SOP, we recorded videos of the coach demonstrating each step, along with an additional clip that combines all the steps into a complete sequence. These videos feature the coach's explanations, enhanced with subtitles and visual aids such as arrows to highlight key movements and instructions. This tutorial aims to provide clear, step-by-step guidance, making it easier for trainees to understand and replicate the shooting technique.

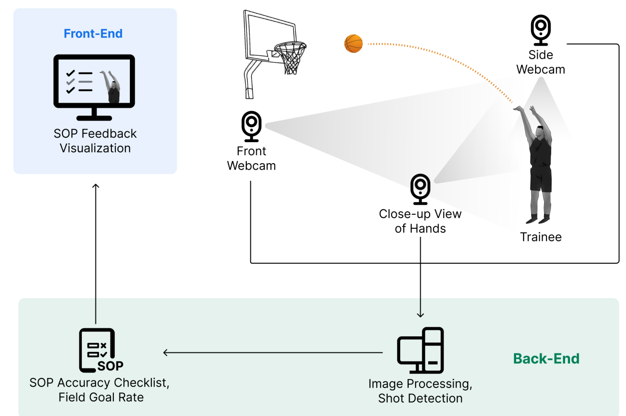

Figure 2: AI posture SOP feedback system design framework.

4.2 System Design Framework and Prototype

The framework of our proposed prototype for the AI SOP posture feedback system is illustrated in Figure 2. We implemented a front-end interface using ReactJS and a back-end server with NodeJS to manage video streaming, storage, AI processing, and feedback visualization. The system processes video streams from cameras using the AI-based method developed by Kao et al. [17] to automatically detect basketball shots and segment continuous footage into concise clips capturing each shot from start to finish. These clips were stored in the server's database and accessed by a remote coach, who evaluated the shot performance using an SOP checklist on Google Sheets, employing a Wizard of Oz approach to simulate AI-generated feedback. The completed evaluations were then downloaded and integrated with the videos, enabling the system to present participants with specific, actionable feedback on their shooting performance. Each set of annotated shot videos, paired with the SOP results, was accessible via unique URLs, providing trainees with a structured and user-friendly interface to review their feedback.

4.3 SOP Posture Performance Data Visualization

To help beginners effectively evaluate their practice alignment with coaching standards (Design Requirement 01), enhance their self-awareness (Design Requirement 02), and boost their confidence in setting training goals (Design Requirement 03), we developed a system with User Interface (UI) illustrated in Figure 3, which includes key features such as Session SOP Performance (F1), Shot List (F2), SOP Posture Video Clip Comparison (F3), Shot Replay (F4), Coach SOP Posture Tutorial (F5), and SOP Posture Session Overview Trend (F6).

常规训练中。正如*C8*所述：“我之前录制了学员的视频片段，直接指出他们动作中缺乏肌肉伸展的问题。”系统还应同时强调正确与错误的动作，并在每个步骤附上教练教学视频，以便学员快速对比自身动作进行微调。*C4*表示：“你需要向学员展示哪些动作细节需要保持，哪些环节薄弱需要改进……或者使用教学视频与学生表现的视频对比。”

3.3.3** 设计需求**03：提供明确的
优先调整姿势指导。
在 学生 完成 他们的 投篮 练习， the 系统
应明确指示哪些具体动作分解需要优先纠正。我们观察教练在教学和纠正过程中的师生互动发现，所有教练都建议首先关注手部动作，因为其准确性直接影响投篮表现。正如教练C7解释的那样：“练习手部动作时，不必担心脚部。一旦手部动作正确，我们就可以着手调整脚部。之后，确保脚部稳定性至关重要，然后专注于从脚跟和臀部发力。”从初学者的角度来看，了解纠正顺序同样重要。理想情况下，

该系统应提供一种机制，允许教练对纠正措施进行排序，帮助学生专注于关键的改进领域。

正如参与者*1*所言：“我不确定教练是否能查看系统的推荐，但最终教练需要评估并告诉我优先修正什么，因为他们熟悉我的表现。”

3.4 总结

总之，初学者在没有教练的情况下常面临保持训练质量的挑战，而现有方法（如侧视录像）无法全面捕捉动作问题。我们确定了三项设计要求，以解决关键挑战，作为下一节功能开发的基础。

4 系统设计

为解决形成性研究中发现的挑战，我们
设计并构建了AI标准操作程序姿势反馈系统的原型
以测试其对初学者的有效性。该原型经过
试点研究的完善，整合了四位专业教练
（C4、C6、C7、C8）的反馈意见，并通过研究团队
研究团队。

4.1 篮球固定动作标准操作程序分解 投篮与标准操作程序教程视频

为满足设计需求01，我们与教练C4合作，基于其专业领域知识并参考相关投篮生物力学文献，设计了篮球定点投篮的标准操作程序（总结于表3）。关键步骤以★符号标记。

勾选标记（✓）表示验证点，使学员和教练能够评估每个步骤是否正确执行。

这确保学员能持续获得反馈，并与教练标准保持对齐。

根据这份标准操作程序，我们录制了教练演示每个步骤的视频，并额外剪辑了一段将所有步骤整合为完整序列的视频。这些视频包含教练的讲解，并辅以字幕和箭头等视觉辅助工具来突出关键动作和指导。本教程旨在提供清晰的逐步指导，帮助学员更轻松地理解和模仿投篮技巧。

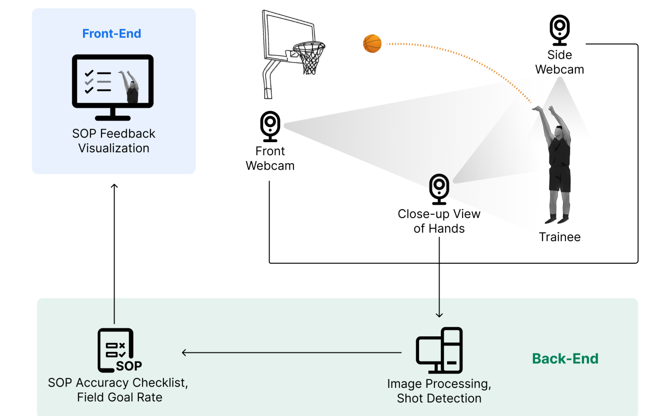

图2：AI姿势SOP反馈系统设计框架

4.2 系统设计框架与原型

我们提出的AI标准操作程序姿势反馈系统原型框架如图2所示。我们使用ReactJS实现了前端界面，并通过NodeJS搭建后端服务器来管理视频流、存储、AI处理和反馈可视化。该系统利用Kao等人开发的基于AI的方法[17] 处理来自摄像机的视频流，自动检测篮球投篮动作，并将连续画面分割成从开始到结束捕捉每次投篮的简洁片段。这些片段存储在服务器数据库中，由远程教练通过Google表格上的标准操作程序检查表评估投篮表现，采用绿野仙踪法模拟AI生成反馈。完成的评估结果随后被下载并与视频整合，使系统能够向参与者提供关于其投篮表现的具体、可操作的反馈。每组标注的投篮视频与标准操作程序结果配对，通过唯一URL访问，为学员提供结构化且用户友好的界面以查看反馈。

4.3 标准操作程序姿势表现数据可视化

为帮助初学者有效评估其训练与
教练标准（设计需求01）的对齐程度，提升自我认知（设计需求02），并增强他们在设定
训练目标（设计需求03）时的信心，我们开发了一个系统，其用户界面 (UI) 如图3所示，该系统包含关键功能，如会话标准操作程序性能 (F1)、投篮列表 (F2)、标准操作程序姿势视频片段比较 (F3)、投篮回放 (F4)、教练SOP姿势教程（F5）以及标准操作程序姿势会话概述趋势 (F6)。

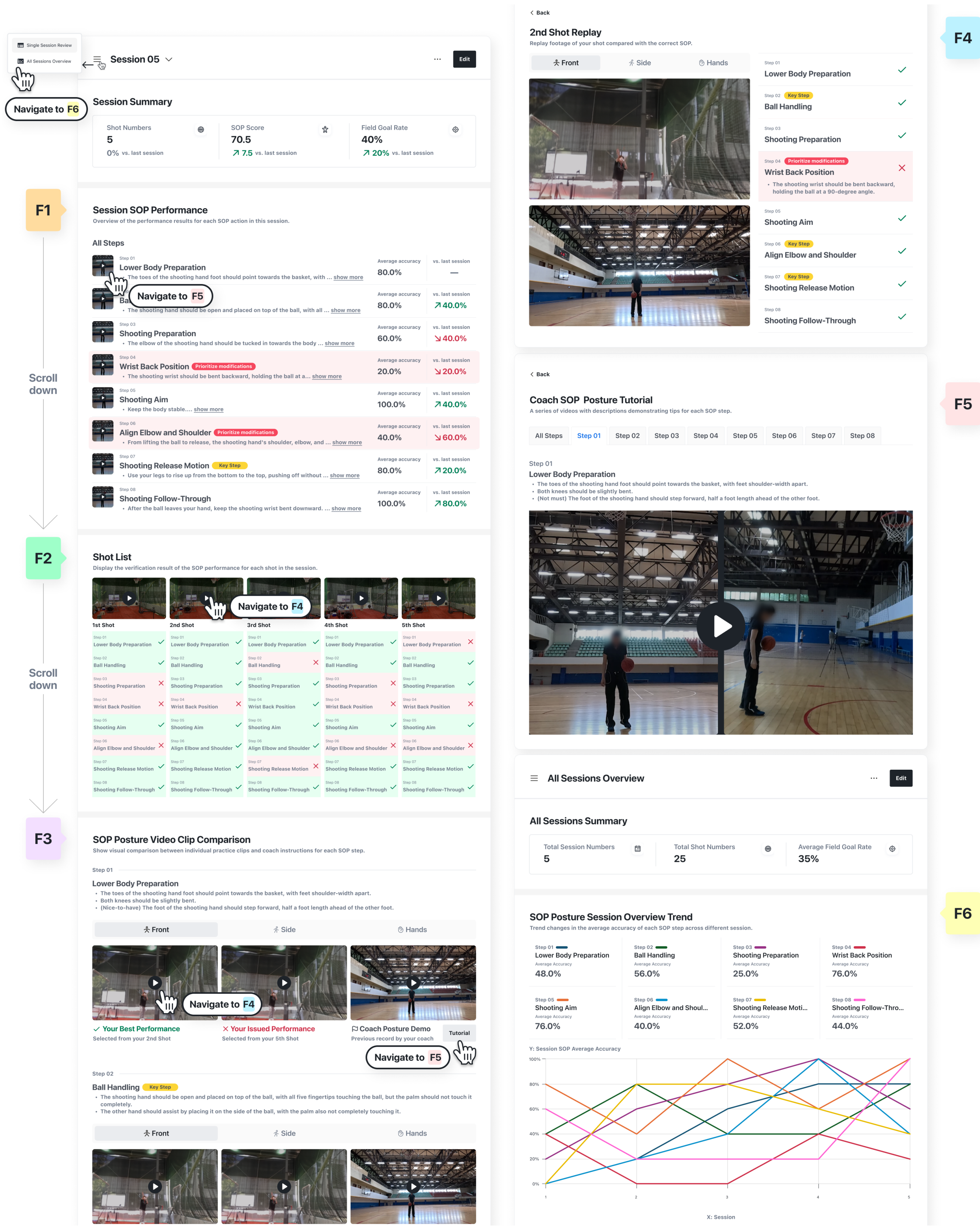

Figure 3: The AI feedback SOP system. Key features include Session SOP Performance (F1), Shot List (F2), SOP Posture Video Clip Comparison (F3), Shot Replay (F4), Coach SOP Posture Tutorial (F5), and SOP Posture Session Overview Trend (F6).

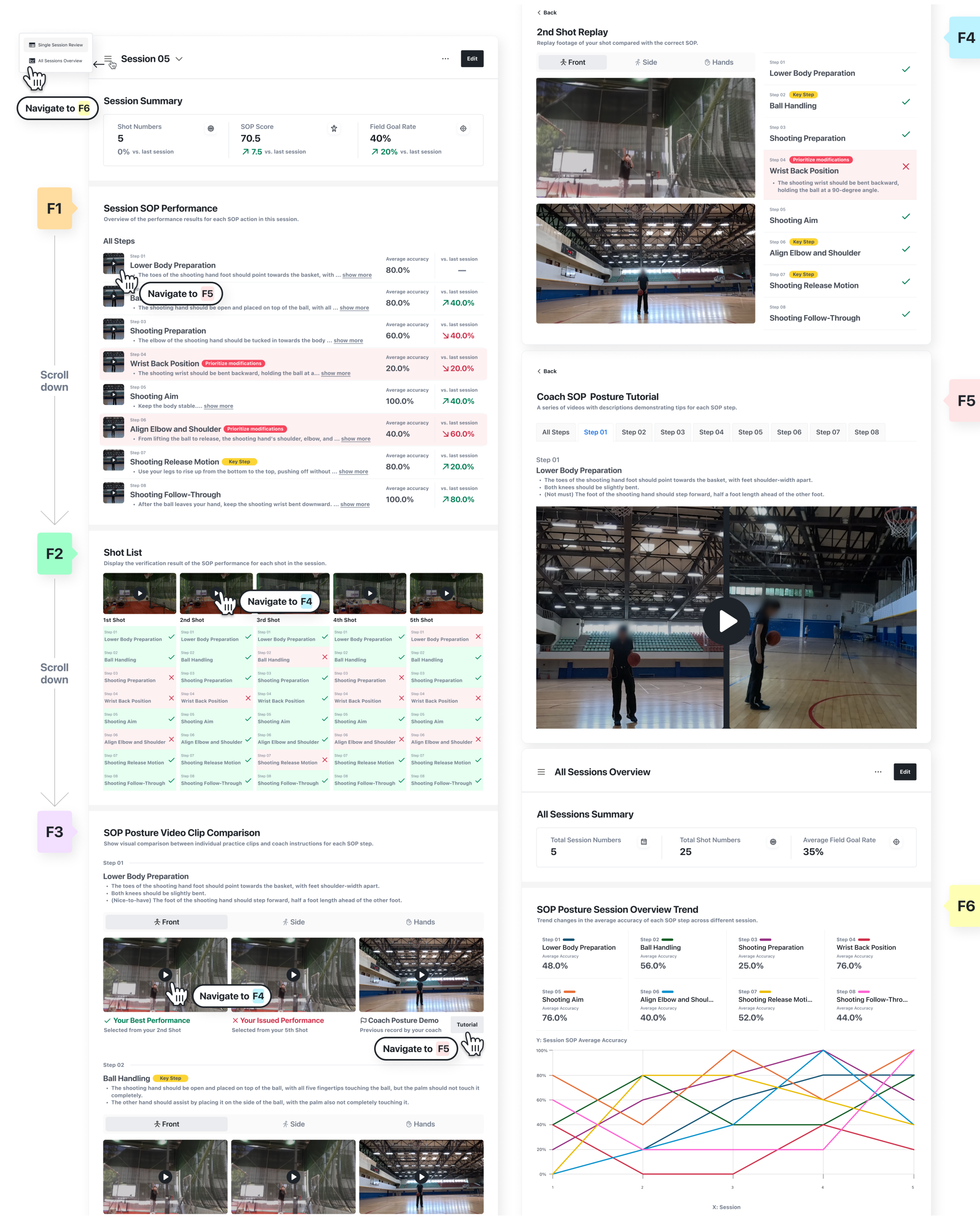

图3：AI反馈SOP系统。关键功能包括会话SOP表现（F1）、投篮列表（F2）、标准操作程序姿势视频片段比较（F3）、投篮回放（F4）、教练SOP姿势教程（F5）和标准操作程序姿势会话概述趋势（F6）。

Step	Description
1. Lower Body Preparation	✓ The toes of the shooting hand foot should point towards the basket, with feet shoulder-width apart. [8, 19, 25, 29, 30] ✓ Both knees should be slightly bent. [14, 19, 30] ★ The foot of the shooting hand should step forward, half a foot length ahead of the other foot. [8, 11, 19]
★2. Ball Handling	✓ The shooting hand should be open and placed on top of the ball, with all five fingertips touching the ball, but the palm should not be completely touching it. [29] ✓ The other hand should assist by placing it on the side of the ball without contacting it with your palm. [14, 28, 32]
3. Shooting Preparation	✓ The elbow of the shooting hand should be tucked in towards the body. [19, 25] ✓ As the ball is brought back, the hips should slightly squat backward. [30]
★4. Wrist Back Position	✓ The shooting wrist should be bent backward, holding the ball at a 90-degree angle. [19, 28]
5. Shooting Aim	✓ Keep the body stable. ✓ Raise the ball to the front of the shooting hand's forehead. [28, 30] ✓ Lean slightly forward, eyes focused on the front edge of the rim. [25, 28, 30, 32]
★6. Align Elbow and Shoulder	✓ From lifting the ball to release, the shooting hand's shoulder, elbow, and wrist should extend forward in a straight line, aligned with the basket. [11, 28]
★7. Shooting Release Motion	✓ Use your legs to rise up from the bottom to the top, pushing off without jumping. [28–30] ✓ Extend the shooting hand, snap the wrist downward, and follow through with the fingers in a straight line toward the basket. [9, 14, 19, 25, 28, 29] ★ The left hand should not apply force. [9, 14, 19, 25, 28, 29]
8. Shooting Follow-Through	✓ After the ball leaves your hand, keep the shooting wrist bent downward. [25, 28–30] ★ Ensure the elbow remains above eyebrow level until the ball touches the rim. [25, 28–30]

Table 3: Standard Operating Procedure (SOP) Steps for Basketball Shooting: This table outlines the SOP steps derived from interviews with professional basketball coaches, supplemented by findings from shooting-related research papers. The steps are organized to guide beginners through the shooting process, emphasizing key techniques and best practices. The symbol ★ denotes particularly important steps, while the checkmark (✓) shows instructions to be verified for each action.

4.3.1 ***Session SOP Performance.*** Based on Design Requirement 01, Session SOP Performance (F1) in the Figure 4 was crafted to provide trainees with a clear view of performance metrics for each SOP step during a session. Steps are listed sequentially according to the coach's SOP, displaying current session accuracy and changes from the previous session, allowing trainees to track their performance in a structured and intuitive manner.

Each SOP step is paired with a tutorial video to enhance trainees' understanding through visual guidance. A visualization of 'Average Accuracy' and percentage changes from the previous session are provided to enable trainees to monitor their progress at a glance. To prevent cognitive overload for beginners, critical steps are marked as 'Key Step,' emphasizing essential actions to support a smoother learning process, as recommended by coaches. If performance on these key steps falls below a pre-defined threshold (e.g., 50% as determined by coaches), the system dynamically updates the label to 'Prioritize Modifications,' highlighted with a red block to draw attention. This adaptive feedback mechanism helps trainees focus on areas for improvement and guides their priorities for future sessions, fulfilling Design Requirement 03.

Insights from the pilot study suggested that reducing the emphasis on field goal rate would help trainees concentrate on posture. As a result, following discussions with coaches, the field goal rate was discreetly positioned in a less prominent area of the interface. This subtle adjustment directs trainees' attention towards posture practice, minimizing distractions from less critical metrics and enhancing training effectiveness.

4.3.2 ***Shot List and Shot Replay.*** Shot List (F2) and SOP Replay (F4) in the in the Figure 5 provide shot performance and video views aiming at enhancing beginners' ability to assess their adherence to coaching standards and improve posture awareness. Each shot

Step	描述
1. 下半身准备	✓ 投篮手侧的脚趾应指向篮筐，双脚与肩同宽。[8, 19, 25, 29, 30]✓ 双膝应略微弯曲。[14, 19, 30] ★ 投篮手侧的脚应向前迈出半步，比另一只脚超前半个脚掌长度。[8, 11, 19]
★2. 持球	✓ 投篮手应张开置于球上方，五指指尖均接触球体，但手掌不可完全贴住球面。 [29] 另一只手应辅助性地置于球体 ✓ 侧面，避免用手掌接触球。[14, 28, 32]
3. 投篮准备	✓ [19, 25] 投篮手的肘部应向身体内侧收紧。 ✓ 当球后引时，臀部应略微向后下蹲。[30]
★4. 手腕后屈姿势	✓ 投篮手腕应向后弯曲，使球保持90度角。[19, 28]
5. 投篮瞄准	✓ 保持身体稳定。✓ [28, 30] ✓ 将球举至投篮手前额前方，微微前倾，眼睛注视篮筐前沿。[25, 28, 30, 32]
★6. 对齐肘部和肩膀	✓ 从举球到释放，投篮手的肩膀、肘部和手腕应向前伸直成一条直线，与篮筐对齐。[11, 28]
★7. 投篮释放动作	✓ [28 30] 用腿部 ✓ 从下往上蹬起，不跳跃的蹬地。– 伸展投篮手，手腕向下弹，手指跟随动作沿直线朝篮筐方向。[9, 14, 19, 25, 28, 29] ★ 左手不应施加力量。[9, 14, 19, 25, 28, 29]
8. 投篮跟随动作	✓ 球离手后，保持投篮手腕向下弯曲。[25, 28–30] ★ 确保肘部保持在眉毛水平以上，直至球触及篮筐。[25, 28–30]

表3：篮球投篮标准操作程序（SOP）步骤：本表列出了根据对职业篮球教练的访谈，并结合投篮相关研究论文的发现所制定的SOP步骤。这些步骤旨在引导初学者完成投篮过程，强调关键技术和最佳实践。符号★表示特别重要的步骤，而勾选标记（✓）则表示需要验证的每个动作指令。

4.3.1 会话SOP表现。根据设计需求01，图4的设计旨在为学员 会话标准操作程序性能(F1) 提供会话期间每个标准操作程序步骤性能指标的清晰视图。步骤按照教练的标准操作程序依次列出，显示当前会话准确率及与前一会话的变化，使学员能够以结构化且直观的方式追踪自身表现。

每个标准操作程序步骤均配有教程视频，通过视觉指导强化学员的理解。系统提供‘平均准确率’的可视化展示及与前一次训练的百分比变化，使学员能一目了然地监控自身进展。为防止初学者认知负荷过重，关键步骤会进行特殊标记。作为‘关键步骤’，强调支持更顺畅学习过程的基本操作，正如教练所建议的那样。如果这些关键步骤的表现低于预设阈值（例如50%），系统会触发额外关注。由教练决定后，系统会动态更新标签为‘优先修改’，并用红色区块高亮以吸引注意这种自适应反馈机制帮助学员聚焦于需要改进的领域，并指导他们在未来训练中的优先事项，从而满足设计需求03。

试点研究的见解表明，减少对投篮命中率的强调有助于学员专注于姿势训练。

因此，在与教练讨论后，投篮命中率被谨慎地放置在界面中较不显眼的位置。

这一细微调整引导学员将注意力集中在姿势练习上，减少次要指标的干扰，从而提升训练效果。

4.3.2 投篮列表与投篮回放。射击列表 (F2) 和标准操作程序回放 (F4) 在图5中提供了投篮表现和视频视图旨在增强初学者评估自身动作规范性的能力达到教练标准并提升姿势意识。每次投篮

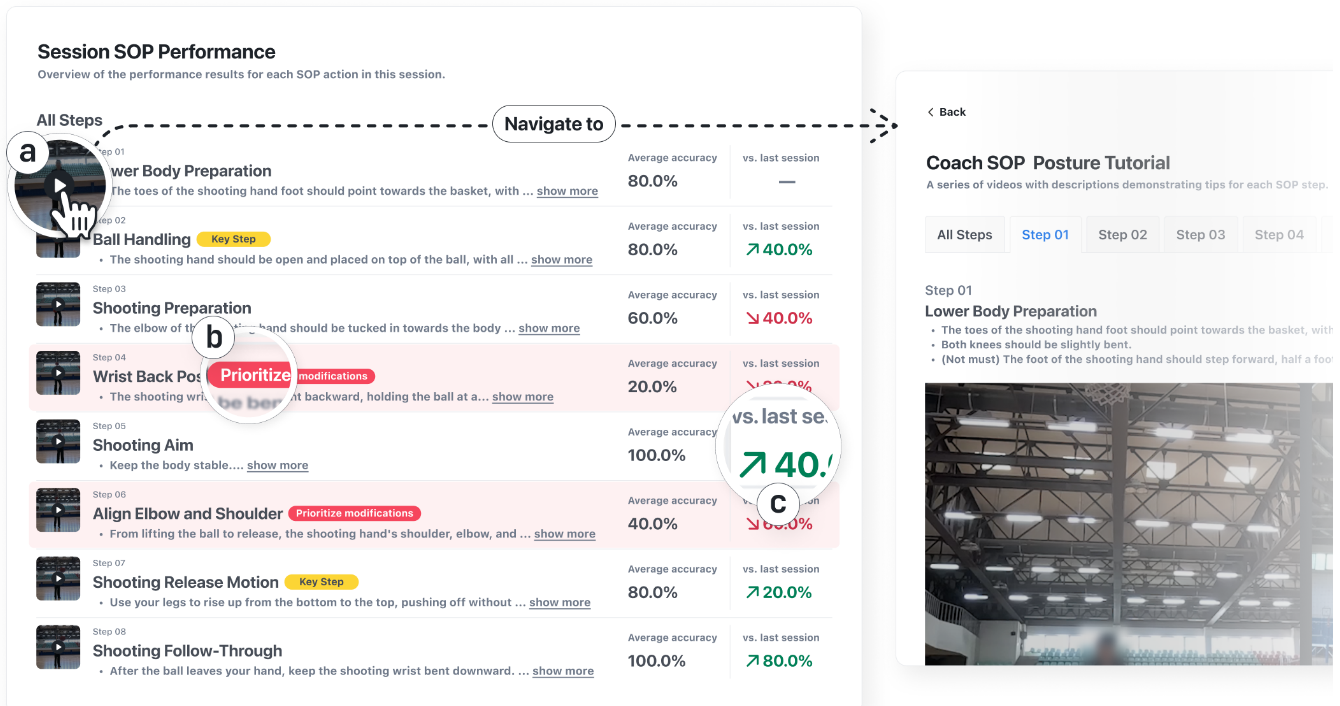

Figure 4: SOP Session Performance (F1) allows users to overview the performance results for each SOP steps in the current session. Users can click the video thumbnail (a) to review a specific SOP step tutorial in Coach SOP Posture Tutorial (F5). The "Prioritize Modifications" label (b) helps users gain clarity on which SOP step to prioritize next. Users can track their progress for all steps compared to the last session (c).

taken during a session is documented with a snapshot and replay option, along with a detailed performance breakdown against predefined SOP steps. To highlight areas for improvement, steps are visually marked: "✓" (correct) with a light green background color denotes compliance, and "✗" (incorrect) with a light red background color signals deviations. This intuitive use of color coding, paired with bold fonts, allows users to swiftly pinpoint errors and make targeted adjustments (Design Requirement 01).

4.3.3 SOP Posture Session Overview Trend. The SOP Posture Session Overview Trend (F6) in the in the Figure 6 visually tracks changes in average accuracy for each SOP step across multiple sessions, providing trainees with a clear view of their performance trends. By plotting performance trajectories for each predefined step, the graph highlights patterns of improvement and SOP steps needing further attention, guiding beginners to focus on specific techniques that require additional practice (Design Requirement 03). This intuitive design, shaped by coach feedback, emphasizes the use of clear visual indicators such as line charts to simplify the understanding of performance trends, making it easier for beginners to quickly grasp their progress and adjust their training priorities accordingly. Additionally, the "All Session Summary" in F6 offers a comprehensive overview of key metrics, including the total number of sessions, shots, and the average field goal rate, providing users with a holistic view of their overall progress (Design Requirement 01). This combination of detailed trend analysis and summary metrics ensures that trainees have a complete understanding of their development throughout their training journey.

4.3.4 SOP Posture Video Clip Comparison. SOP Posture Video Clip Comparison (F3) in the Figure 7 interfaces are designed to boost players' self-awareness by encouraging a focus on the finer details of their performance. To fulfill Design Requirement 02, it highlights the player's best execution of each SOP step among a session in the "Your Best Performance" panel, helping them identify and replicate correct postures. Trainees can select different camera viewing angles (including front, side, and close-up view of hands) to make more comprehensive observations for analyzing their postures. If players are uncertain about a specific step or do not have a correct execution recorded in the "Your Best Performance" panel, they can click the "tutorial" button to review the Coach SOP Posture Tutorial (F5), which presents a coach-led video demonstration of the step. This video-based feedback approach, combined with SOP-based comparison, helps players observe and accurately mimic movements, reinforcing proper techniques through clear visual guidance.

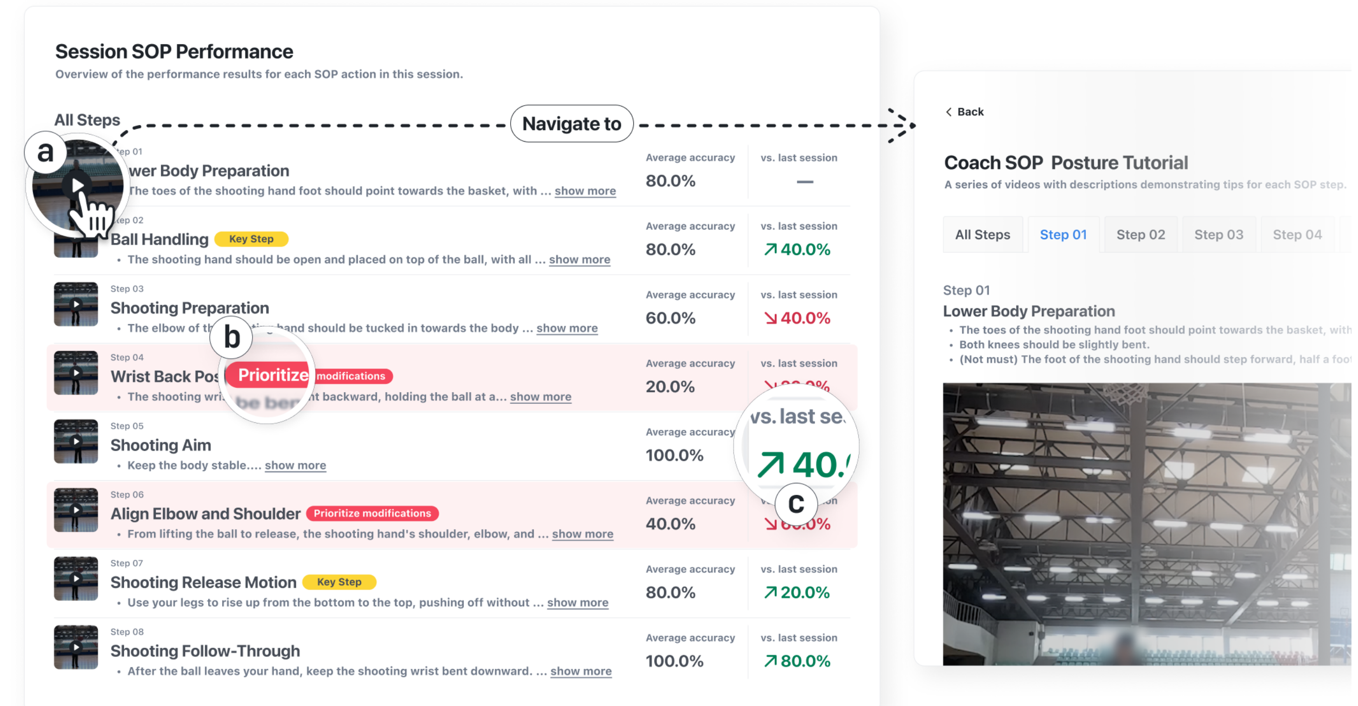

图4：SOP会话性能（F1）允许用户概览当前会话中每个SOP步骤的表现结果 用户可点击视频缩略图（a）查看教练SOP姿势教程（F5）中特定SOP步骤的教程。“优先修改”标签（b）帮助用户明确下一步应优先处理的SOP步骤。用户可跟踪所有步骤相较于上一次会话（c）的进展。

在训练过程中都会被记录为快照和回放选项，以及针对预定义SOP步骤的详细性能分析。为突出改进领域，步骤被

视觉标记：“√”（正确）配以浅绿色背景

表示合规，而“✗”（错误）配以浅红色背景色标识偏差。这种直观的颜色编码使用，结合粗体字体，使用户能快速定位错误并进行有针对性的调整（设计需求01）。

4.3.3 **标准操作程序姿势会话概述趋势。该*SOP姿势*会话概述趋势（F6）在图6**中直观地追踪了多个训练课程中各SOP步骤平均准确率的变化，为学员提供其表现趋势的清晰视图。通过绘制每个预设步骤的表现轨迹，该图表突显了改进模式与SOP步骤需要进一步关注，引导初学者专注于特定需要额外练习的技术（设计需求03）。这一由教练反馈塑造的直观设计强调使用清晰的视觉指标（如折线图）来简化对表现趋势的理解，使初学者

能快速掌握自身进展并相应调整训练优先级

此外，F6中的"所有会话摘要"提供了关键指标的全面概述，包括总数的训练课程、投篮次数及平均投篮命中率，为用户提供以全面视角了解学员的整体进展（设计需求01）。这种详细的趋势分析与总结指标相结合的方式，确保学员能完整理解其在训练历程中的发展情况。

4.3.4 标准操作程序姿势视频片段比较。标准操作程序姿势视频片段比较 (F3) 在图7界面中的设计旨在通过鼓励关注细节来提升球员的自我意识关于他们的表现。为满足设计需求02，该功能着重球员在训练中每个标准操作程序步骤的最佳表现“最佳表现”面板中，帮助他们识别并复制正确姿势。学员可以选择不同的摄像机视角

（包括正面、侧面和手部特写）来进行

更全面的观察以分析他们的姿势。如果球员对某个特定步骤不确定或在“最佳表现”面板中没有记录正确的执行动作，他们

可以点击“教程”按钮查看教练标准操作姿势教程（F5），其中呈现了教练指导的视频演示该步骤。这种基于视频的反馈方法，结合基于SOP的对比，帮助球员观察并准确模仿

动作，通过清晰的视觉反馈强化正确技巧指导。

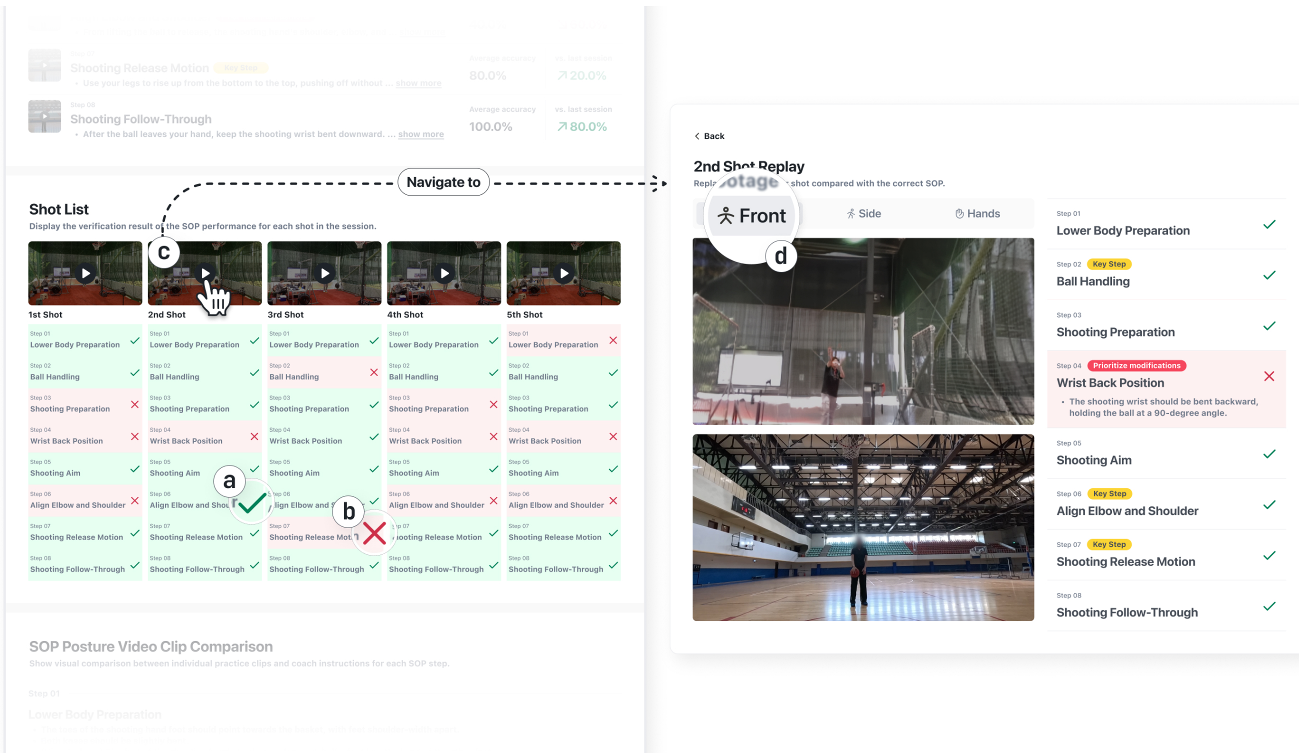

Figure 5: Shot List (F2) displays the verification result of the SOP performance for each shot in the session. The automatically generated signals (ab) indicate whether the trainees' posture aligns with the SOP requirement. To review footage of specific shots side-by-side with the correct SOP video, the trainees can click the video thumbnail (c) to access Shot Replay (F4) and switch between different camera angles using the toggle (d).

5 Experiment

Our study aims to verify whether SOP-based feedback can achieve better outcomes in shooting posture training compared to traditional video feedback methods. We conducted a controlled user study, collecting both qualitative user feedback and quantitative data on SOP posture correctness. We compare participant's performance and feedback with and without the use of our designed system prototype, assessing its impact on improving shooting form.

5.1 Participants and Setup

We targeted individuals with limited basketball experience who are eager to improve their shooting form. A total of 28 participants (A1-A14 & B1-B14; M = 15, F = 13; Age: 18-44) were recruited. To achieve a more gender-balanced and diverse age range among beginners, we utilized online forums to find qualified participants from the Hsinchu city area. All participants reported having *"no prior professional shooting learning"* with *"low shooting accuracy and poor shooting mechanics"*. Participants were evenly distributed into two groups based on the conditions mentioned in Section 5.2: Group A (Video Feedback / without SOP feedback) and Group B (SOP Feedback). Each participant received a compensation of 10 USD for taking part in the study. Additional details about each participant information can be found in the supplementary material.

To simulate AI feedback, we employed the Wizard of Oz method, where a coach (an experienced former national basketball player and current university team coach), was positioned in a separate room to assess the participants' shooting posture correctness using a predefined SOP checklist. This approach allowed the coach to provide real-time evaluations that mimicked the functionality of an AI-driven SOP feedback system.

The study took place in an indoor laboratory, with a designated shooting area separated from the working and resting areas by safety nets. The basketball hoop was installed at the regulation height of 3.05 meters. Participants were instructed to shoot the ball from a marked spot 2.5 meters away from the hoop. Cameras were mounted at three angles: one in front of the participant, capturing the entire body, and two at the sides (one providing a full-body view and the other offering a close-up view of the player's hands) to capture comprehensive footage from different perspectives. The coach then used the recorded videos to evaluate shooting correctness based on the SOP checklist. A 65-inch LG Touch Screen Monitor was placed next to the shooting area to display the SOP feedback system. Participants were asked to review the system feedback via the touchscreen monitor after completing each shooting session .

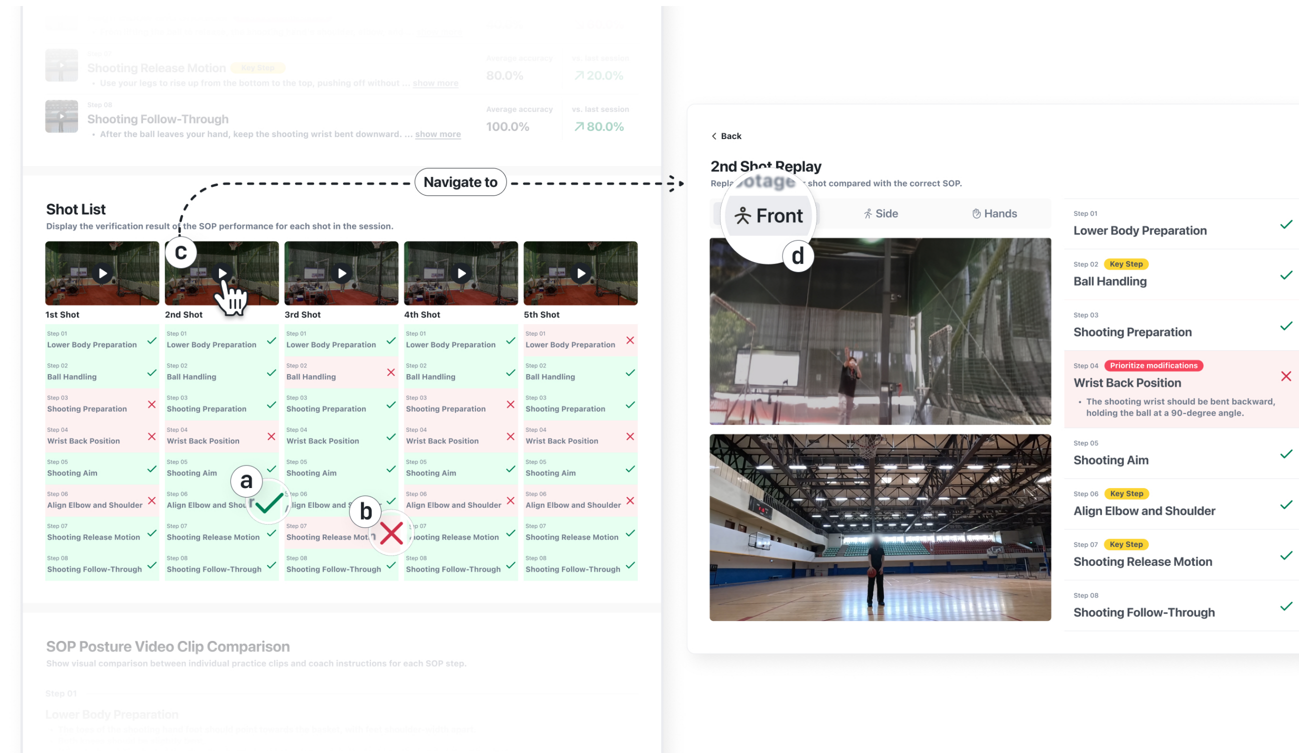

图5：射击列表 (F2) 显示训练中每次射击的标准操作程序表现验证结果。系统通过自动生成信号 (ab) 标示学员姿势是否符合标准操作程序要求。若需将特定射击画面与标准操作程序视频进行对比，学员可点击视频缩略图 (c) 进入射击回放 (F4)，并通过切换按钮 (d) 选择不同摄像机角度。

5 实验

我们的研究旨在验证，与传统视频反馈方法相比，基于标准操作程序的反馈能否在投篮姿势训练中取得更好的效果。我们开展了一项受控用户研究，既收集了定性用户反馈，也获取了关于标准操作程序姿势正确性的定量数据。通过对比参与者在使用与未使用我们设计的系统原型时的表现及反馈，评估该系统对改善投篮形式的影响。

5.1 参与者和设置

我们针对篮球经验有限但渴望提升投篮形式的个体展开研究。共招募了28名参与者（A1-A14和B1-B14；男{v1}，女{v2}；年龄18-44岁）。为达成更具性别平衡性和多样化年龄范围的样本，参与者需满足基础运动能力标准并通过初步筛选。针对初学者，我们通过在线论坛招募符合条件的参与者这些参与者均来自新竹市地区。所有人均表示此前未接受过专业射击学习，且存在射击准确性低投篮机制不完善的问题。根据5.2章节所述条件，参与者被均匀分配至根据第5.2节所述条件分为两组：组别A组（视频反馈/无SOP反馈）与B组（SOP反馈）。每位参与者获得了10美元作为参与研究的补偿。关于每位参与者的更多详细信息相关信息可在补充材料中找到。

为模拟人工智能反馈，我们采用了绿野仙踪方法，由一名教练（一位经验丰富的前国家篮球队队员现任大学队教练）在单独的房间内评估参与者的射击姿势正确性，使用预定义的标准操作程序检查表。这种方法使教练能够提供实时评估，模拟人工智能驱动的标准操作程序反馈系统的功能。

研究在室内实验室进行，设有专门的投篮区域，通过安全网与工作和休息区隔开。篮球框安装在标准高度3.05米处。参与者被要求投篮。从距离篮筐2.5米的标记点出发。摄像机被安装在三个角度：一个位于参与者正面，捕捉全身画面，另外两个位于侧面（一个提供全身视图另一个则特写球员手部）以从不同角度获取全面影像。教练随后利用录制的视频评估投篮正确性依据标准操作程序检查表。一台65英寸LG触摸屏显示器被放置在投篮区域旁边以显示标准操作程序反馈系统。参与者被要求通过系统反馈进行审查在完成每次射击训练后使用触摸屏显示器。

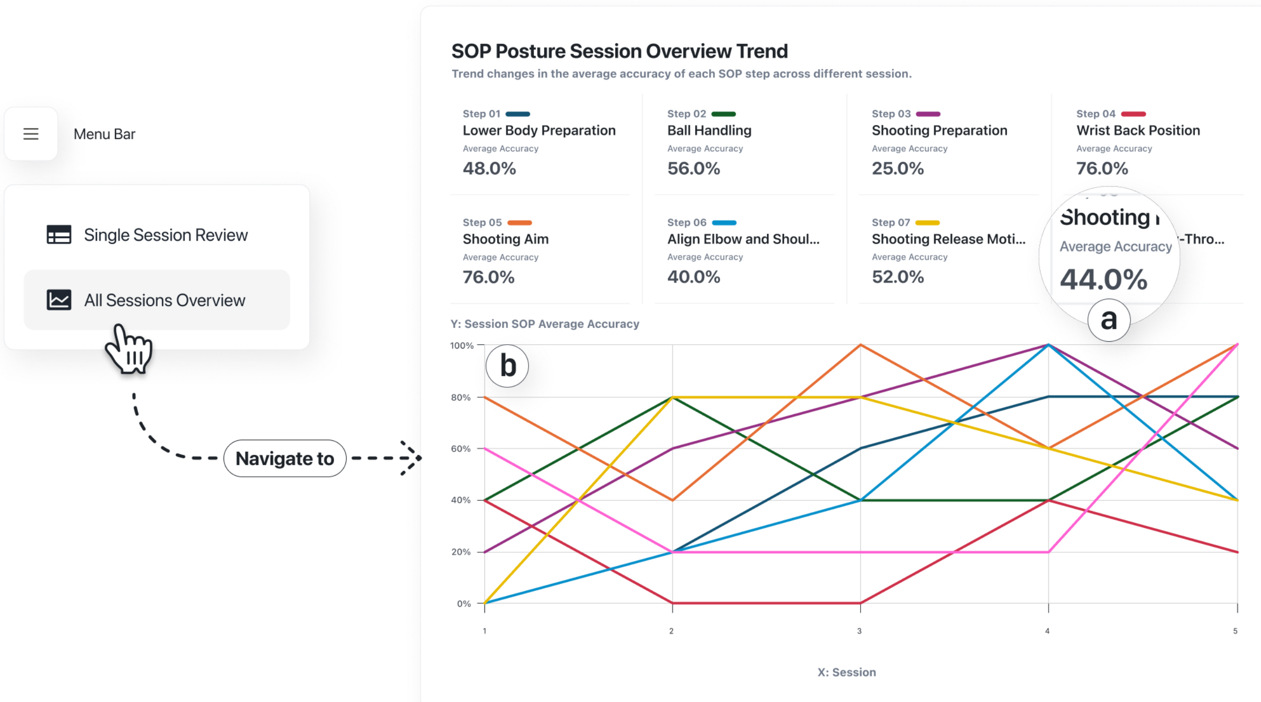

Figure 6: SOP Posture Session Overview Trend (F6). Users can monitor each step's SOP average accuracy rate over practice sessions (a) and track changes in the average scores of different SOP steps (b) over practice sessions.

5.2 Experimental Conditions

Video Feedback: Participants were provided with a webpage that first displayed the coach's step-by-step SOP tutorial video clips, followed by their own session recordings for comparison and review. The system did not offer any analysis of the participants' step-by-step posture performance.

SOP Feedback: Participants accessed our designed feedback system through a touchscreen monitor, allowing them to navigate the provided features (from F1 to F6) and identify which steps to focus on for improvement.

5.3 Design and Procedures

Figure 8 illustrates our experimental procedure, which consisted of the following phases for each group.

Introduction (5 minutes): The study began with an overview of experiment motivation, objectives, and protocol of the research. Then, all participants were required to review and sign a formal consent document before advancing to the subsequent stages.

Pretest & Learning (10 minutes): All participants were asked to take five shots to establish a baseline for measuring performance improvements. They then watched an Coach SOP Posture Tutorial (F5) based on Table 3, which demonstrated proper shooting mechanics.

Training Session (40 minutes): At each training session, participants completed a standardized assessment by retaking 5 shots to evaluate skill progression. Group A engaged with raw video replays and the Coach SOP Posture Tutorial (F5) without additional annotations, while Group B utilized our SOP feedback system, receiving simulated AI coaching guidance. Post-session interviews systematically assessed participants' movement performance self-awareness and their confidence in establishing subsequent practice objectives.

Final Survey (5 minutes): All participants completed a post-study questionnaire to provide subjective feedback on the overall system. Group B, which received SOP feedback, conducted additional targeted feature rankings of the AI feedback posture SOP system.

5.4 Objective Evaluation

We collected video data and user inputs from our system. As introduced in Section 3.2, key objectives for enhancing training effectiveness include clear comparisons of correct and incorrect movements, prioritization of posture modifications, and real-time evaluation of compliance with coaching standards. To assess participants' performance, we measured movement accuracy, posture adjustment consistency, adherence to coaching guidelines, and shot percentage. Below, we define the performance metrics used in the quantitative analysis.

Initial Baseline: To evaluate how user performance is impacted by the given system, we established a baseline by measuring posture correctness as their shot accuracy during the pretest.

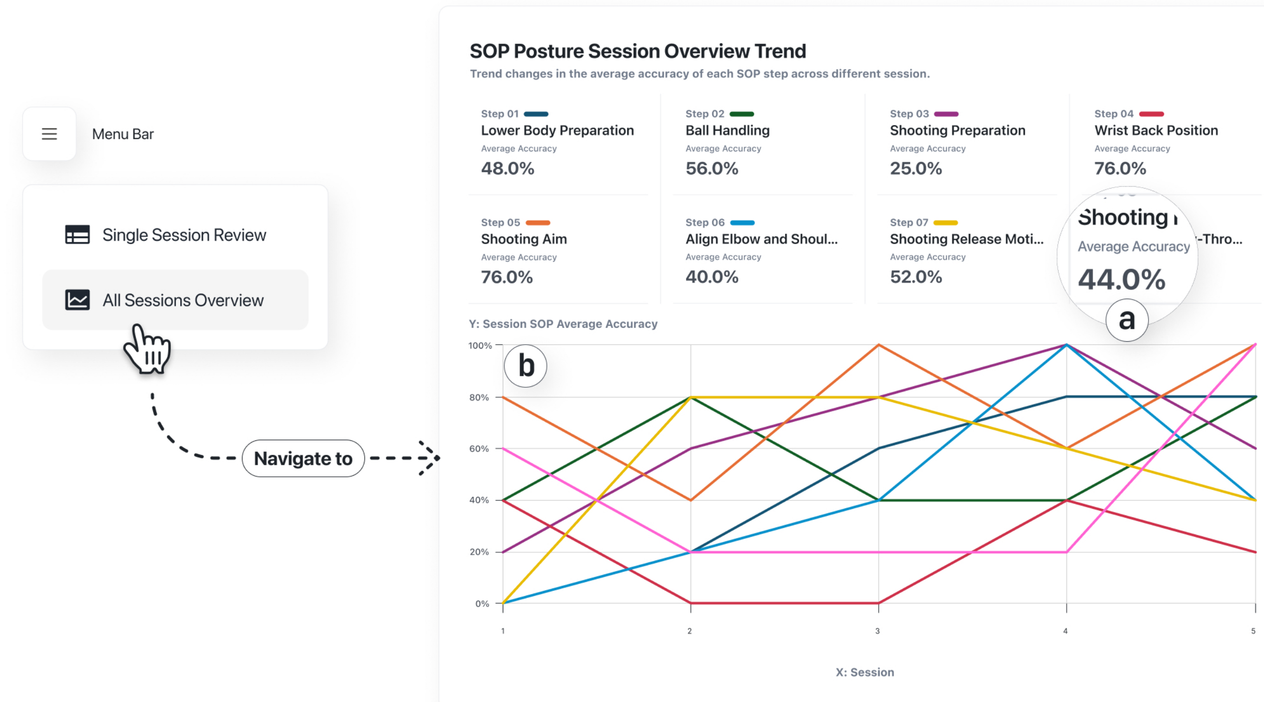

图6：标准操作程序姿势会话概述趋势 (F6)。用户可通过练习会话监测每个步骤的SOP平均准确率(a)，并追踪不同SOP步骤的平均分数在练习会话中的变化趋势(b)。

5.2 实验条件

视频反馈：参与者被提供一个网页，首先显示教练的逐步SOP教程视频片段，

随后观看自己的会话记录以进行比较和回顾。
该系统未对参与者的逐步姿势表现提供任何分析。

SOP反馈：参与者通过触摸屏显示器访问我们设计的反馈系统，使他们能够导航所提供的功能（从F1至F6），并确定需要改进的步骤。

5.3 设计与程序

图8展示了我们的实验流程，该流程为每个组别包含以下阶段。

介绍（5分钟）：研究开始时概述了实验动机、目标和研究协议。

然后，所有参与者需在进入后续阶段前审阅并签署一份正式同意文件。

前测与学习（10分钟）：所有参与者被要求进行5次投篮以建立衡量表现提升的基线。随后，他们观看了基于表3的教练标准操作姿势教程（F5），该教程展示了正确的投篮机制。

训练阶段（40分钟）：每次训练中，参与者通过重新完成5次投篮进行标准化评估以检验技能进展。A组使用原始视频回放和未添加额外标注的教练SOP姿势教程（F5），而B组则运用我们的标准操作反馈系统，接收模拟人工智能教练指导。课后访谈系统评估了参与者的动作表现自我意识及制定后续练习目标的信心。

最终调查（5分钟）：所有参与者完成了一份研究后问卷，以提供对整体系统的主观反馈。接受SOP反馈的B组还额外对AI反馈姿势标准操作程序系统进行了针对性功能排名。

5.4 客观评估

我们从系统中收集了视频数据和用户输入。如第3.2节所述，提升训练效果的关键目标包括清晰对比正确与错误动作、

优先进行姿势调整，以及实时评估对教练标准的合规性。为评估参与者表现，我们测量了动作准确性、姿势调整一致性、遵循教练指导情况及投篮命中率。

下文将定义定量分析中使用的性能指标。

初始基线：为了评估用户表现如何受到给定系统的影响，我们通过测量姿势正确性作为他们在前测中的投篮准确性来建立基线。

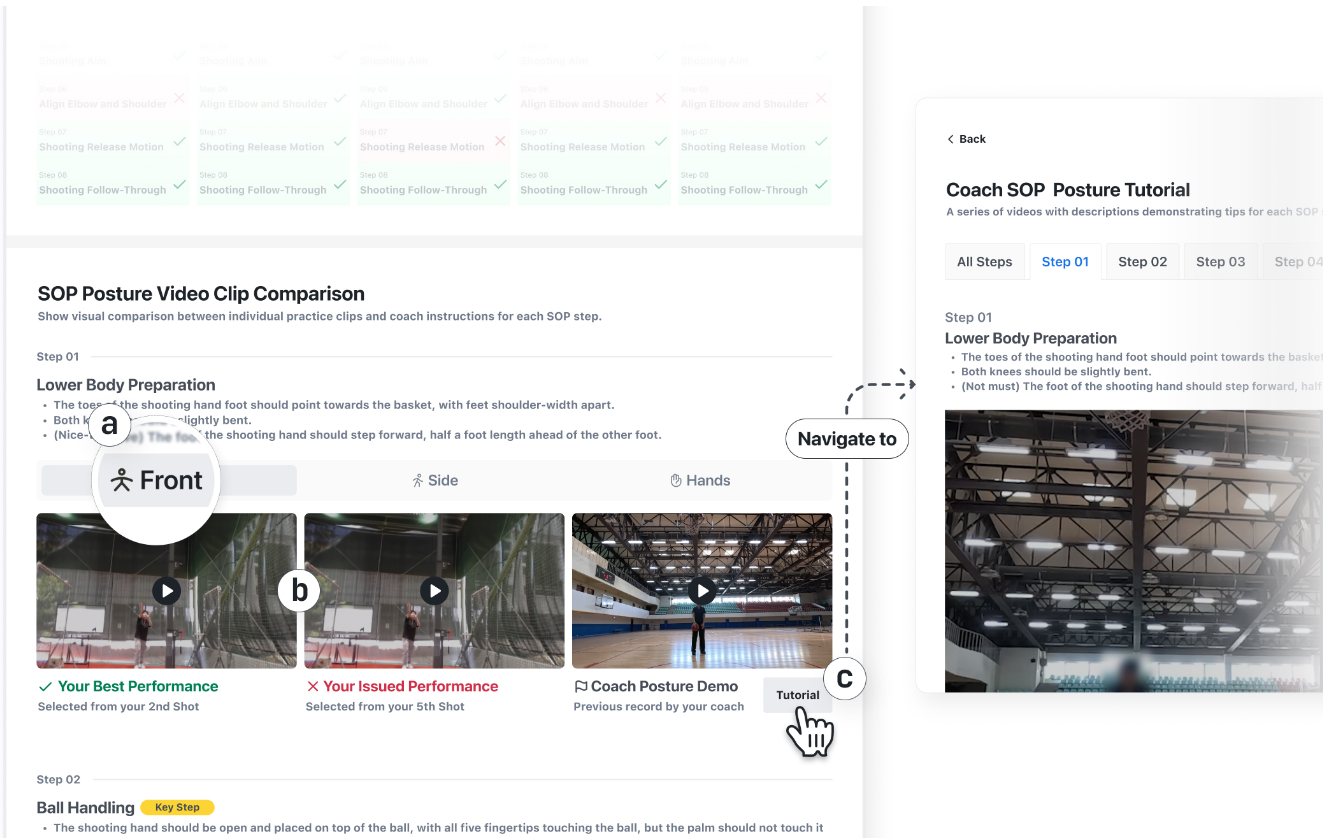

Figure 7: SOP Posture Video Clip Comparison (F3) enables beginners to (a) switch camera angles of videos (b) for a specific SOP step to identify posture issues or replicate their previously correct posture. If they need to revisit the SOP requirement details, they can click (c) to navigate to Coach SOP Posture Tutorial (F5).

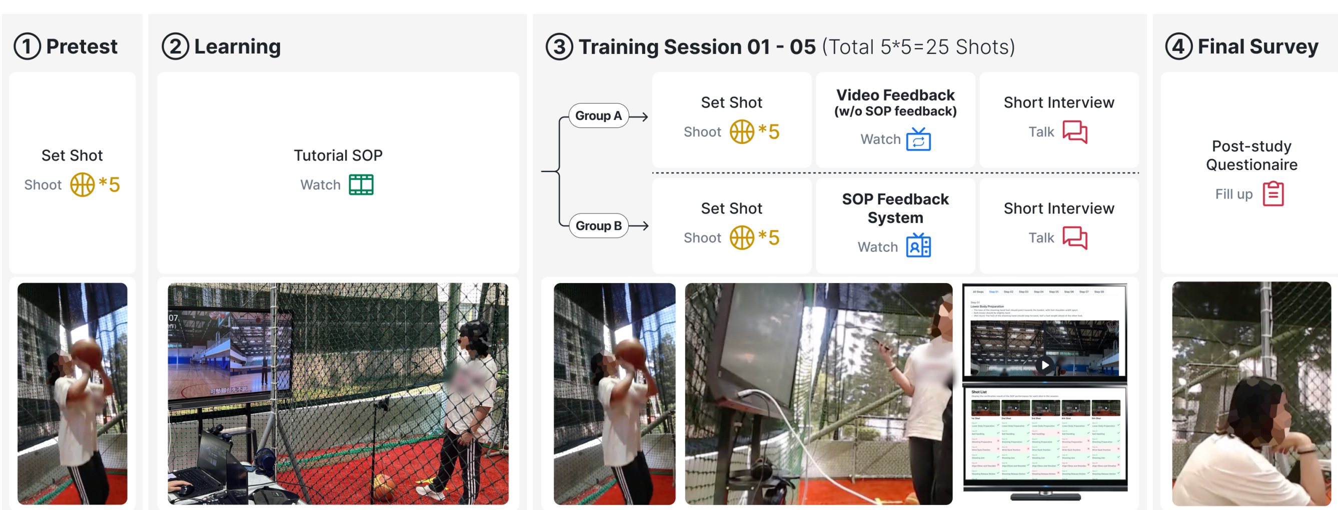

Figure 8: Experimental procedure. Participants were split into two groups: Group A and Group B.

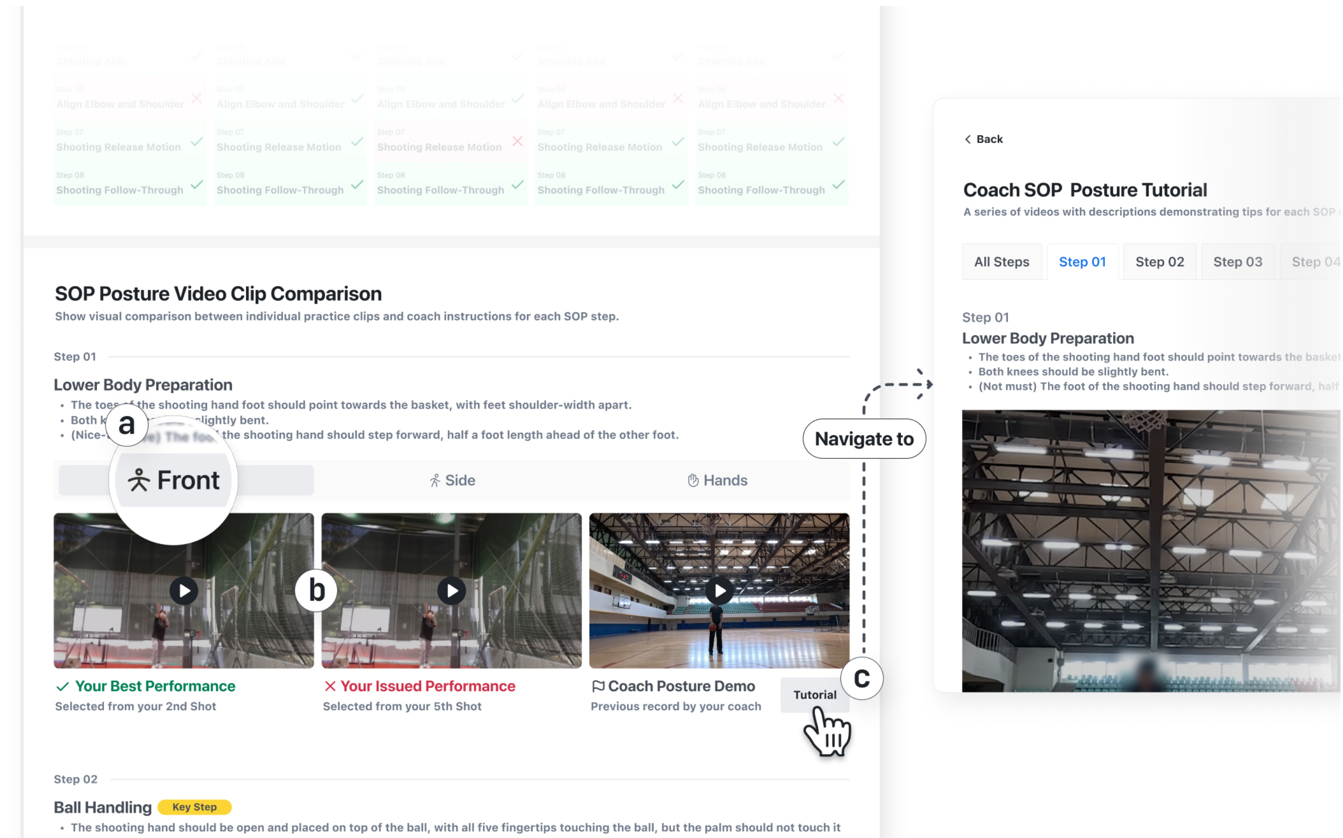

图7：标准操作程序姿势视频片段比较 (F3) 使初学者能够 (a) 切换视频的摄像机角度 (b) 针对特定标准操作程序步骤以识别姿势问题或复制他们之前正确的姿势。如果他们需要重新查看标准操作程序要求的详细信息，可以点击 (c) 导航至教练SOP姿势教程（F5）。

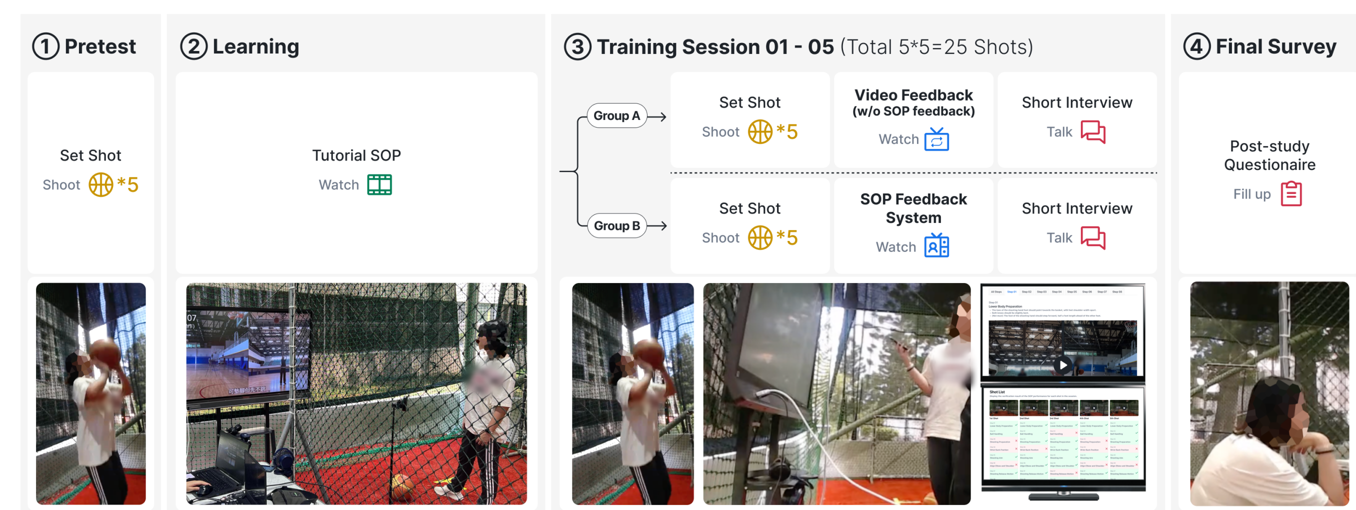

图8：实验流程。参与者被分为两组：A组和B组。

Posture Correctness: To measure improvements in shooting posture throughout a training session, the coach marked if each SOP step is correct or not for each shot in the session.
Field Goal Performance: To provide an objective assessment of shooting performance, we compared the field goal percentage after each session for both experiment groups.

5.5 Subjective Evaluation

To assess user experience and system effectiveness, we gathered subjective feedback through post-study surveys and semi-structured interviews. For the interviewed response, three independent coders analyzed the data using qualitative coding, focusing on confidence, self-awareness, and system usability. In the post-study surveys, each aspect was rated by participants based on a 7-point Likert scale.
Confidence: This metric aimed to evaluate the extent to which the system boosted participants' confidence by offering detailed, actionable feedback that guided their performance improvements during training.
Self-awareness: The system's ability to enhance participants' self-reflection was measured by examining how effectively it helped them recognize their own errors, make informed adjustments, and gain a deeper understanding of their training process. Self-evaluations were validated through a post-study survey and by comparing interview responses with a professional coach's feedback on posture performance.
System Usability: Usability was assessed based on indicators such as usefulness, ease of use, intention to use, and overall satisfaction. These metrics offered a comprehensive evaluation of how well the system supported participants in achieving their training goals and their overall satisfaction with the its features and functionality.

6 Results and Discussion

In this section, we present the study results based on quantitative shot measurements and subjective performance evaluations. Key insights are outlined in each subsection, along with detailed supporting evidence and corresponding discussions.

6.1 The AI Feedback SOP System Improves Trainees' Posture Awareness, Ensuring Better Alignment with Training Goals

6.1.1 *Participants Demonstrated Greater Self-awareness of Their Posture Performance When Using AI Posture SOP Feedback System.*

In the middle of the Figure 9 illustrates the subjective ratings in awareness. Group B participants (with SOP feedback) reported significantly higher ratings than Group A (without SOP feedback), as indicated by ANOVA analysis (α = 0.05, where α refers to the significance level).

Based on qualitative user feedback, the structured SOP feedback allowed participants in Group B to precisely identify specific errors. The Figure 10 also indicates the Session SOP Performance (F1) and Shot List (F2), participants were able to pinpoint specific parts of incorrect body movements and explain personal observations. For example, B03 in his session 03 described: *"Aftering reading the score, this time I remembered to maintain wrist extension while holding the ball. Previously, in Step 06, my elbow and shoulder weren't aligned, but this time I improved by 60%. I didn't do this instinctively before, but I made a conscious effort to adjust during the first two rounds. However, my elbow still wasn't above my eyebrows during the follow-through (pointing to Step 08) [...] Also, in the preparation phase, my elbow didn't tuck in toward my body, and I didn't bend my knees before shooting."* This clarity led several participants to uncover previously unnoticed mistakes in their practice. Shot Replay (F4) further improved trainees' understanding of their posture misalignment. Participants were able to make direct comparisons between their actions and SOP closely, and identify discrepancies in incorrect postures. For instance, participant B5 recognized that their foot placement was off, deriving deeper insights beyond the provided guidance. In total, 10 out of 14 participants using both SOP Posture Video Clip Comparison (F3) and Coach SOP Posture Tutorial (F5) were able to accurately identify and infer the reasons behind their errors. The bar chart in Figure 10 illustrates that participants heavily relied on these two features (F3 and F5) to learn new posture movements during their training sessions.

Conversely, Group A (without SOP feedback) participants, who trained only with video feedback, displayed tendencies toward overconfidence in their posture performance, leading to misjudging their posture alignment and making counterproductive adjustments. 7 out of 14 participants wrongly believed they had fully corrected their movements to align with the coach's form, despite their scores indicating otherwise. For example, participant A11 assumed their SOP posture accuracy was between 80-90% after reviewing their video, while the actual accuracy was below 40%. Another type of misjudgment was observed when participants mistakenly modified correct movements into incorrect ones, demonstrated by four participants in Group A. This pattern of misjudgment observed in Group A underscores the challenges faced by trainees when structured, targeted feedback was not provided.

Taken together, Group B demonstrated higher self-awareness and greater clarity in describing their posture errors while Group A participants could only describe general problems in body posture or overall fluidity with difficulties discerning specific problems.

6.1.2 *Using AI Posture SOP Feedback System Enables Participants to Better Align Postures with the Coach's Training Requirements.*

Figure 11 shows the participants' posture SOP accuracy compared to the coach's training requirements throughout the user study. Group A (without SOP feedback) showed a modest average improvement of 29% with higher variability in performance (σ=22%), while Group B (with SOP feedback) demonstrated a more substantial average improvement of 48% with a lower variability (σ= 18%), reflecting more consistent and substantial progress. This comparison demonstrates that incorporating SOP feedback into training accelerates improvement and enhances the consistency of performance outcomes, emphasizing the value of SOP-driven feedback in refining posture accuracy and stability among trainees.

Despite the SOP feedback's positive impact on self-awareness and posture alignments, it is worth noting that **focusing on posture performance may not lead to immediate field goal improvement.** As shown in Figure 12, neither Group A (without SOP feedback) nor Group B (with SOP feedback) showed notable

姿势正确性：为衡量训练阶段中投篮姿势的改进情况，教练会标记每个标准操作程序步骤在该阶段每次投篮中是否正确执行。

投篮表现：为提供投篮表现的客观评估，我们比较了两个实验组在每阶段训练后的投篮命中率百分比。

5.5 主观评价

为评估用户体验和系统有效性，我们通过研究后调查和半结构化访谈收集主观反馈。针对采访回应，三名独立编码员采用定性编码分析数据，重点关注信心、

自我意识，以及系统可用性。在研究后调查中，
每个方面均由参与者基于7点李克特量表进行评分。

信心：该指标旨在评估系统通过提供详细、

可操作的反馈来指导他们在训练期间的表现提升，从而增强参与者信心的程度。

自我意识：系统增强参与者自我反思的能力通过以下方式衡量：考察其帮助他们识别自身错误、做出明智调整以及更深入理解训练过程的有效性。自我评估通过研究后调查得到验证，并将访谈回答与专业教练对姿势表现的反馈进行对比。

系统可用性：可用性根据有用性、易用性、使用意向和总体满意度等指标进行评估。

这些指标全面评估了系统在支持参与者达成训练目标方面的效果，以及他们对系统功能和特性的总体满意度。

6 结果与讨论

本节基于定量投篮测量和主观性能评估呈现研究结果。各小节将概述关键见解，并附详细的支持证据和相应讨论。

6.1 AI反馈SOP系统提升学员姿势意识，确保与训练目标更好对齐

6.1.1 使用*AI*姿势*SOP*反馈系统时，参与者对其姿势表现展现出更强的自我意识

In the middle of the 图 9 展示了 the 主观 评分 in
意识。B组参与者（有SOP反馈）报告的评分显著高于A组（无SOP反馈），

如方差分析所示（α = 0.05，其中α指显著性水平）。

根据定性用户反馈，结构化的SOP反馈使B组参与者能够精确识别具体错误。

图10还显示了会话标准操作程序性能 (F1) 和投篮 (F2)，参与者能够明确指出错误身体动作的具体部分并解释个人观察结果。List

例如，*B03*在会话*03*中描述道："这次阅读评分后，我记得在持球时保持手腕伸展。之前，在步骤06中，我的肘部和肩膀没有对齐，但这次我改善了60%。我以前没有本能地做到这一点，但在前两轮训练中有意识地进行了调整。然而，在随球动作中（指向步骤08），我的肘部仍然没有超过眉毛高度*[...]*此外，在准备阶段，我的肘部没有向内收拢贴近身体，投篮前也没有屈膝。"这种清晰的反馈让多名参与者发现了之前练习中未注意到的错误。投篮回放（F4）进一步加深了学员对姿势偏差的理解。参与者能够将自己的动作与标准操作程序姿势进行直接对比，并识别错误姿势中的差异。例如，参与者B5意识到自己的脚步位置不正确，从而获得了超出指导内容的更深层次见解。总计14名参与者中，有10人同时使用标准操作程序姿势视频片段比较（F3）和教练标准操作程序姿势教程（F5），能够准确识别并推断出错原因。图10的柱状图显示，参与者在训练课程中高度依赖这两项功能（F3和F5）来学习新的姿势动作。

相反，A组（无SOP反馈）的参与者们，
仅通过视频反馈进行训练，表现出对自身姿势表现过度自信的倾向，导致他们

错误判断姿势对齐并做出适得其反的调整。14名参与者中有7人
错误地认为自己已完全纠正了动作。
尽管分数不理想，他们仍调整动作以匹配教练的姿势
但实际表现并非如此。例如参与者A11在查看自己的
视频后，认为其标准操作程序姿势准确度在80-90%之间

而实际准确率却低于40%。另一种误判类型
表现为参与者错误地将正确动作修改为错误动作，A组中

有4名参与者出现此类误判模式
A组学员所面临的挑战凸显了
未获得结构化、针对性反馈时的困境。
总体而言，B组学员表现出更高的自我意识

且在描述姿势错误时更为清晰明确，而A组
参与者仅能笼统描述身体姿势方面的普遍问题
或整体流畅性障碍，难以辨识具体问题所在。

6.1.2 使用*AI*姿势*SOP*反馈系统使参与者能更好地将姿势与教练的训练要求对齐。

图 11 展示了 the 参与者的 姿势 SOP 准确性 对比
在整个用户研究期间与教练的训练要求进行对比。
A组（无SOP反馈）表现出29%的适度平均提升，但表现变异性较高（σ=22%），

而B组（有SOP反馈）则展现出48%的更显著平均提升，且变异性较低（σ= 18%），

反映出更一致且实质性的进展。这一对比表明，将SOP反馈纳入训练可加速改进并提升表现结果的一致性，突显了SOP驱动反馈在提高学员姿势准确性和稳定性方面的价值。

尽管SOP反馈对自我意识和姿势对齐有积极影响，但值得注意的是，专注于姿势表现可能不会立即带来实地目标的提升。如图12所示，无论是A组（无SOP反馈）还是B组（有SOP反馈）均未表现出显著

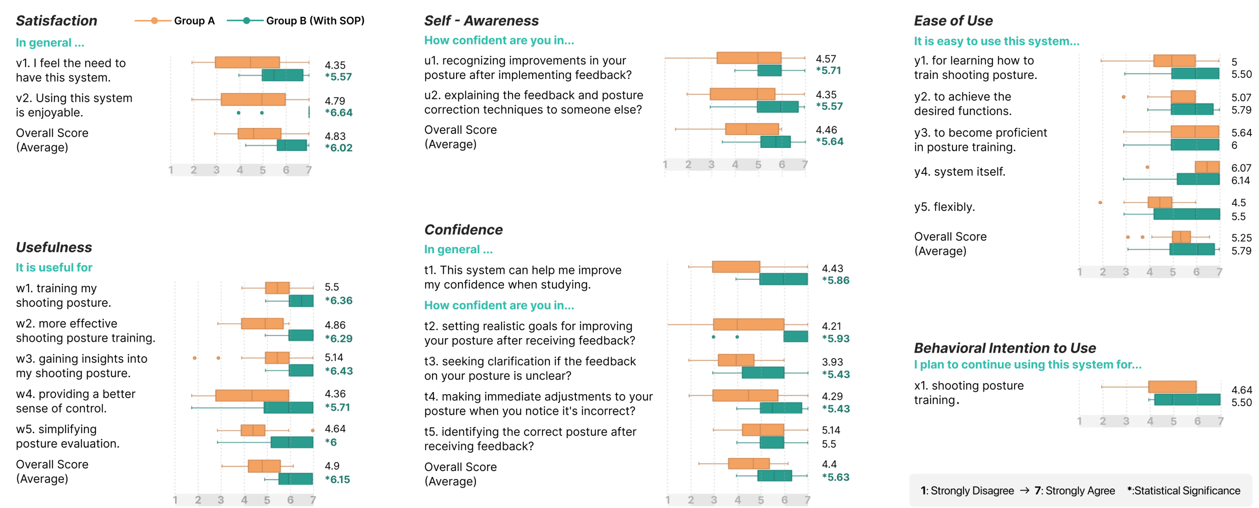

Figure 9: Comparison of confidence and awareness levels between Group A (without SOP feedback) and Group B (with SOP feedback), alongside user scores for Satisfaction, Usefulness, Behavioral Intention to Use, and Ease of Use.

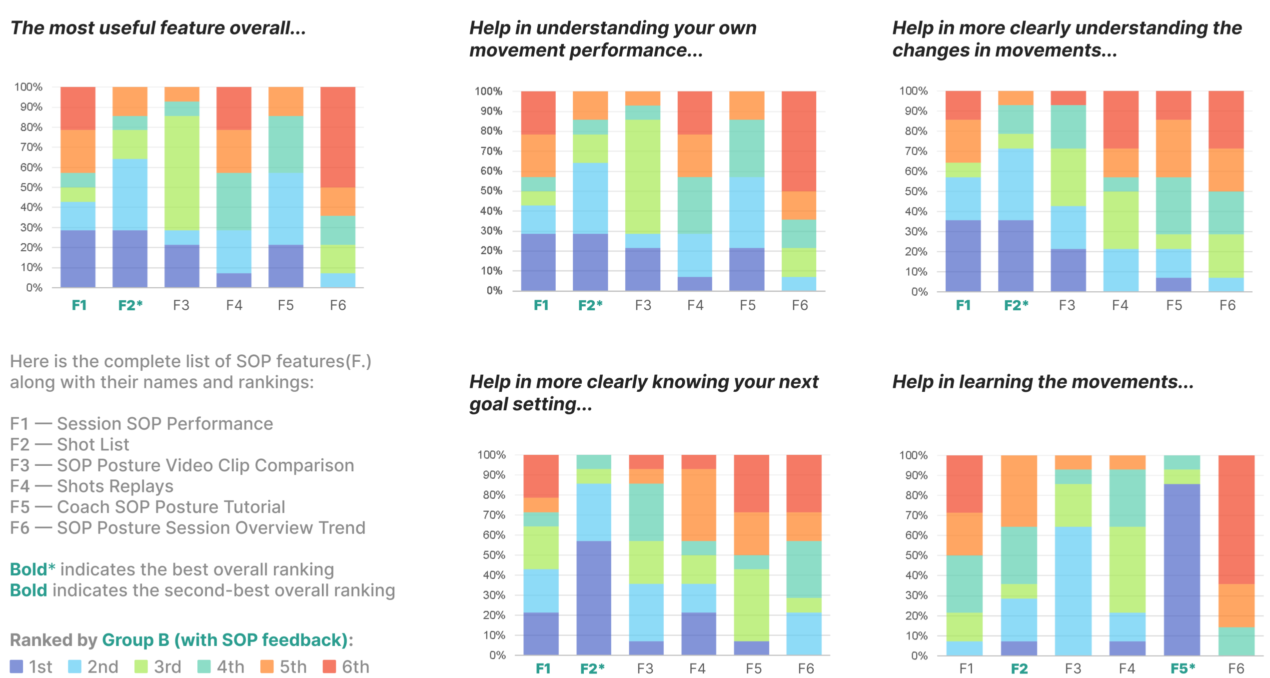

Figure 10: The charts illustrate Group B participants' rankings of the various SOP features displayed in Figure 3. These features were evaluated based on their perceived usefulness in understanding movement, setting goals, and learning correct posture. The Y-axis represents the cumulative percentage of rankings provided by the 14 participants. Each bar is segmented by color, corresponding to rankings from 1st to 6th place, providing a clear visual representation of participants' prioritization of these features.

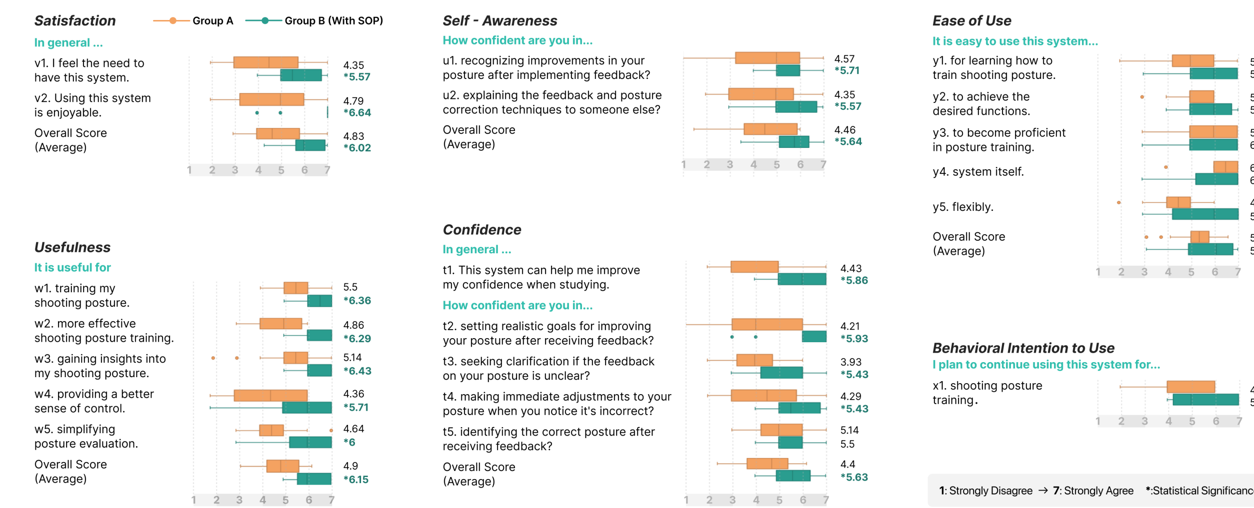

**图9：A组（无SOP反馈）与B组（有SOP反馈）在信心与认知水平上的对比
以及用户在满意度、有用性、使用行为意向和易用性方面的评分**

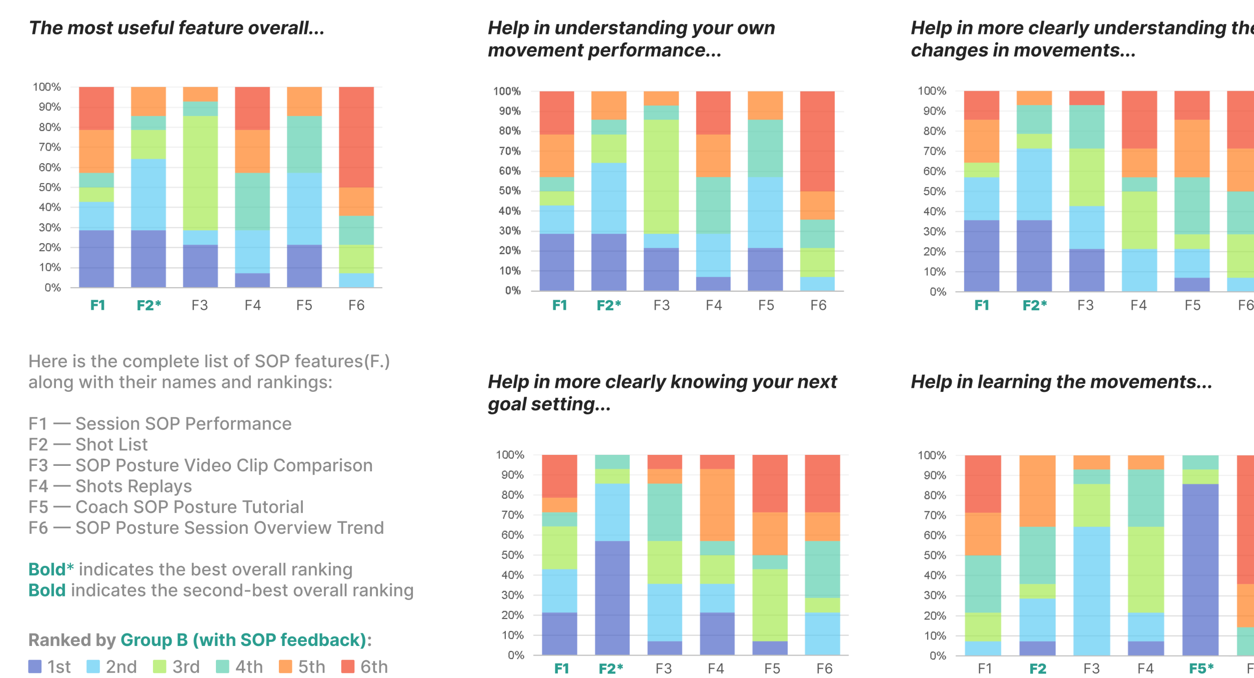

图10：图表展示了B组参与者对图3中各项SOP功能的排名评估。这些功能根据其在理解运动、设定目标和学习正确姿势方面的感知有用性进行评分

**Y轴代表14名参与者提供的排名累计百分比，每根柱状图按颜色分段
对应第1至第6名的排名，清晰直观地展示了参与者对这些功能的优先级排序。**

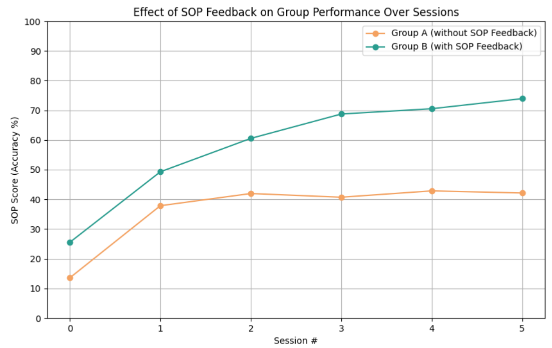

Figure 11: Session-wise SOP average scores (%) between Group A (without SOP feedback) with Group B (with SOP feedback) across sessions. Group B shows significant improvement in SOP accuracy across sessions, demonstrating the benefit of SOP feedback.

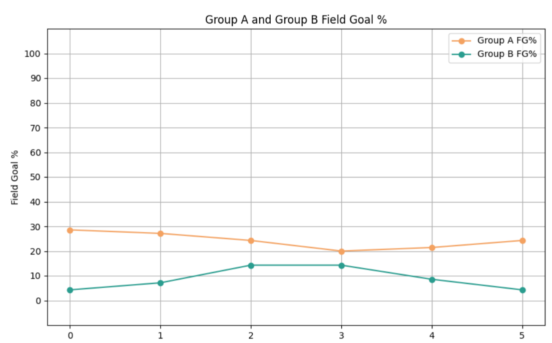

Figure 12: Field goal percentage for Group A (without SOP feedback) and Group B (with SOP feedback) across sessions. Neither group significantly improved field goal percentages, which was expected given the short training period.

improvement in field goal percentages over the short-term training period of the user study. As motor skills like basketball shooting require a longer training period with more repetitions [5, 35, 36] to achieve substantial improvements, ensuring athletes obtain timely feedback and make necessary adjustments to posture movements are essential to enhance performance over time. In fact, during our formative study, coaches actually recommended that beginners prioritize movement correctness over shooting accuracy and that accuracy information should be de-emphasized to prevent distractions. By improving posture awareness and ensuring consistent, precise repetition, SOP feedback could offer a solid basis for long-term performance gains, helping bridge the gap between novice execution and professional standards.

6.2 The AI Posture SOP Feedback System Enables Precise Goal-Setting and Enhances Error Correction for More Effective Training

*6.2.1 **AI Posture SOP Feedback System Boosts Trainees' Confidence in Setting and Executing Their Training Goals.*** Figure 9 revealed that Group B (with SOP feedback) consistently reported higher ratings than Group A (without video feedback) on questions regarding confidence levels in goal setting, seeking clarity, making adjustments, and identifying correct posture, with statistically significant differences for t1 through t4 (ANOVA, α = 0.05). The "Overall Confidence Rate" across all questions confirmed that Group B had a higher confidence distribution compared to Group A, suggesting a positive impact of the SOP system despite the smaller margin in question a5.

In the training sessions, we discovered that nearly all participants in Group B could clearly articulate which step they needed to improve in the next session. They demonstrated solid understanding of their goals and the rationale behind their choices, often using Session SOP Performance (F1) to review their performance on previously set goals. Two strategies were applied by Group B to make adjustment plans. 7 participants in Group B **followed the system's recommendations**, prioritizing modifications suggested by the SOP. Another 4 participants focused on **correcting the lower-scoring steps sequentially** as they memorized the sequence. For example, B10 concentrated on key steps marked by the SOP feedback, prioritizing critical steps for making adjustments, such as Step 04 and 06, while ignoring less relevant steps. On the other hand, B5 focused on Step 02 and 03 from Session 02, increasing both scores from 0 to 100 by the last session 05. The strategic goal-setting by Group B led to all 14 participants showing improvements in their SOP scores over 32 sessions after setting specific goals. In addition, we observed that when Group B faced uncertainty about certain SOP steps, 6 participants adjusted their movements between shots to compare with the SOP Checklist provided by Shot List (F2), showing the AI posture SOP feedback system's ability to guide effective self-correction.

In contrast, Group A participants (without SOP feedback) often set vague or irrelevant goals and exhibited a lack of direction in their training. For instance, A10, in Session 03, set an overly broad goal, *"I think I just need to be more fluid and coordinated,"* Some Group A members even ceased to set goals after a few shots, as seen with A7, *"I actually don't know what I'm doing. I am aimlessly shooting the ball."*, and A11 by Session 04, felt there were no goals left to pursue. Despite clear experimental instructions to focus on learning and adjusting movements in the beginning, 5 of 14 participants from Group A shifted their goals to aspects unrelated to shooting form in later sessions. For example, A4 in Session 05 redirected focus to whether the ball was spinning, and A5, distracted from movement adjustments, began concentrating on shooting accuracy after noticing an increase in made shots. Similar patterns were observed with A6, A8, and A7, who discussed the muscle force of their shooting rather than focusing on form corrections.

Taken together, Group B (with SOP feedback) participants were able to monitor their SOP performance effectively and strategically set their training goals based on SOP feedback, allowing more effective training compared to Group A.

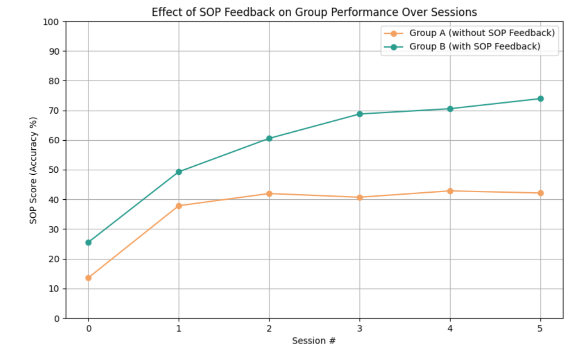

图11：按会话划分的SOP平均得分（%）对比组别 A（无SOP反馈）与组别B（有SOP反馈） 在各训练课程中的表现。组别B在 各课程期间的SOP准确性上显示出显著改进，证明了 SOP反馈。

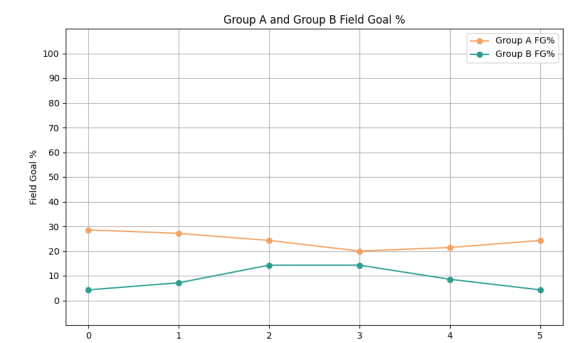

图12：A组（无SOP反馈）与B组（有SOP反馈）在各训练课程中的投篮命中率。

两组均未显著提升投篮命中率， 这在短期训练期内是预期结果。

短期训练期间投篮命中率的改进 用户研究阶段。如同篮球投篮这类运动技能 需要更长的训练期和更多重复次数[5, 35, 36] 才能 实现实质性改进，确保运动员获得及时 反馈并对姿势动作做出必要调整 对于长期提升表现至关重要。事实上，在 我们的形成性研究中，教练们特别建议初学者 应优先关注动作正确性而非投篮准确性，且 应淡化准确性信息以避免注意力分散。通过提升姿势意识并确保一致、 精确重复，标准操作程序反馈可为长期表现提升奠定坚实基础，帮助弥合新手 执行与专业标准。

6.2 AI姿势SOP反馈系统实现精确目标设定并增强错误纠正以达成更有效训练

*6.2.1 **AI姿势SOP**反馈系统增强学员设定* 与执行 *g* 的信心 *g* 他们的训练 *g* 目标。 图9显示B组（有SOP反馈）始终 报告的评分高于A组（无视频反馈） 关于目标设定中信心水平的问题，寻求 清晰度，进行调整，以及识别正确姿势， t1至t4存在统计学显著差异（方差分析，α = 0.05）。所有问题的"总体信心率"证实 B组的信心分布高于 A组，表明SOP系统产生了积极影响，尽管 在问题a5上的优势幅度较小。

在训练课程中，我们发现B组几乎所有参与者都能清晰说明下一阶段需改进的步骤。他们展现出对目标及选择理由的扎实理解，常利用会话标准操作程序性能 (F1) 复盘既定目标的完成情况。B组采用两种策略制定调整计划：7名成员遵循系统建议，优先处理SOP标注的修改项；另有4名成员按记忆顺序逐个修正低分步骤。例如，B10专注于SOP反馈标记的关键步骤（如步骤04和06），优先调整重点环节而忽略次要步骤；B5则针对会话02的步骤02和03进行强化，至会话05时两项分数均从0提升至100。通过这种策略性目标设定，B组14名参与者在设定具体目标后的32次训练课程中，SOP分数均有所提升。此外，

我们观察到，当B组对某些SOP步骤存在不确定性时，6名参与者在投篮间隙调整动作以对照射击列表(F2)提供的标准操作程序检查表，这展示了AI姿势SOP反馈系统引导有效自我纠正的能力。

相比之下，A组参与者（无SOP反馈）经常 设定模糊或不相关的目标，并在其 训练中表现出方向性缺失。例如，A10在会话03中设定了一个过于宽泛的目标， "我认为我只需要更流畅和协调"。部分A组 成员甚至在几次投篮后就不再设定目标，如 A7表示："其实我并不知道自己在做什么，只是漫无目的地投篮。"而到了会话04时，A11则感觉已无目标可 追求。尽管实验初期明确要求参与者专注于学习 和调整动作，但A组14名参与者中有5名 将目标转向了与投篮形式无关的方面 。例如在会话05中，A4转而将注意力 注意力集中在球是否旋转上，而A5则分心于 动作调整，开始专注于投篮准确性 在注意到命中投篮增加后。类似的模式也 在A6、A8和A7身上观察到，他们讨论了 投篮时的肌肉力量而非专注于姿势纠正。

综上所述，B组（有SOP反馈）的参与者 能够有效且战略性地监控其标准操作程序表现 根据SOP反馈设定训练目标，从而允许更多 与A组相比的有效训练。

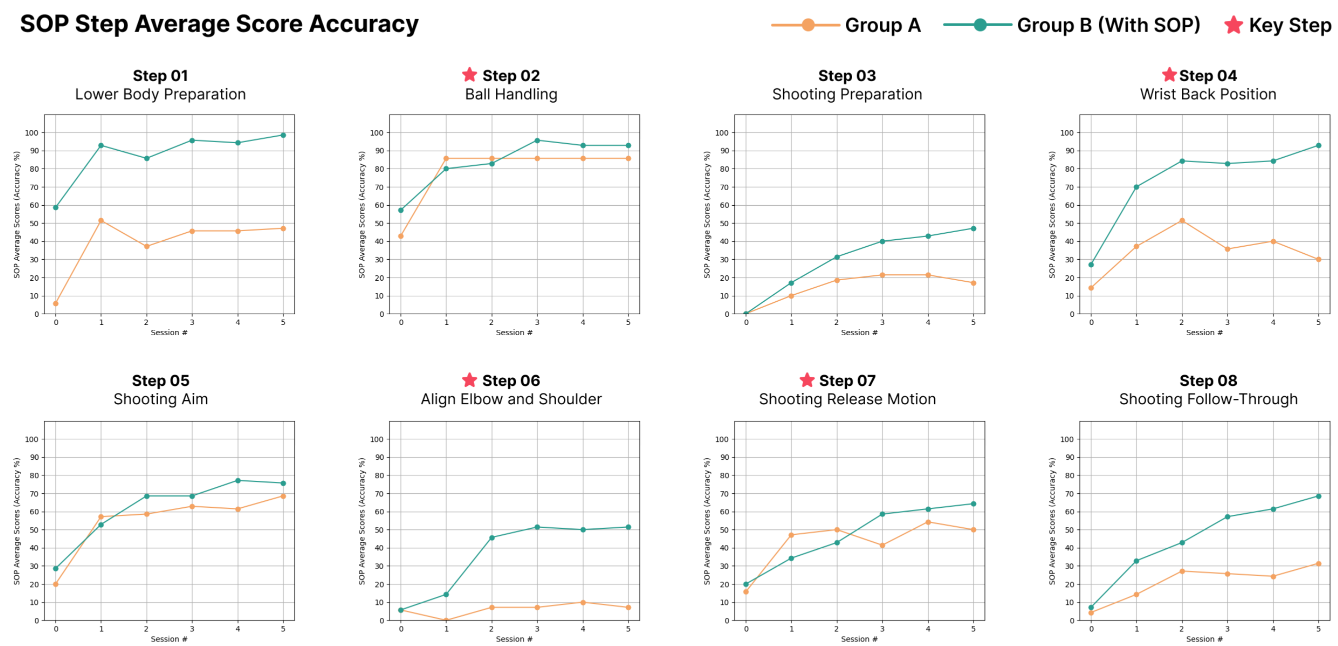

Figure 13: Average SOP Step Accuracy Scores for Group A (without SOP feedback) and Group B (with SOP feedback) across sessions. Group B consistently outperforms Group A, especially in key steps (⋆), showing the effectiveness of SOP feedback in improving shooting accuracy and posture alignment.

6.2.2 *Trainees Using the AI Posture SOP Feedback Found it Easier to Maintain Proper Posture Alignment and Correct Their Posture Errors.*

Figure 13 presents individual SOP step scores for participants in Group A (without SOP feedback) and Group B (with SOP feedback) across sessions. Group B shows a consistent upward trend in SOP scores, while Group A's performance has a higher variable and lacks a consistent improvement, particularly in Steps 03, 04, 05, and 08. These results suggest that SOP feedback facilitates continuous improvement and self-correction of posture errors in sessions, allowing trainees to align their posture more effectively with the coach's SOP requirements. Conversely, relying solely on training tutorials and replay videos may partially improve posture alignment, but trainees are likely to demonstrate inconsistent improvement and reach a plateau more quickly compared to those using the AI posture SOP feedback system.

Despite these benefits, **trainees using AI posture SOP feedback system may occasionally overlook some corrections after setting new goals; however, these oversights can be addressed easily once identified**. Seven participants in Group B experienced drops in scores when shifting their focus to new goals, inadvertently neglecting previously corrected steps. However, all these participants were able to identify the missed steps in the following session using Session SOP Performance (F1) and SOP Posture Session Overview Trend (F6) and subsequently adjusted their goals to correct the oversight. For example, B2 noted after reading the system in her Session 03, *"I thought I was focusing on the basket earlier, but now I see that I wasn't. In the previous round, I made corrections in Step 05 and was properly aiming at the basket, but in this round, Step 05 reverted back to how it was in the first session."*. Moreover, two SOP high-scoring participants in Group B who had nearly perfected their movements by Session 03 or 04 temporarily shifted their goals to getting more balls in. This change led to noticeable drops in SOP scores in subsequent sessions. However, they recognized this issue and reverted their focus back to movement accuracy instead of shot frequency. For instance, B11 commented, *"I rushed through the shots in that session, likely missing key posture details. My field goal percentage didn't improve, but my posture score dropped. I realized I should focus on stabilizing my movements before targeting accuracy."* In contrast, three participants in Group A faced similar oversight issues, but after changing their goals, they failed to correct their dropped scores, reflecting the lack of structured feedback to guide them back on track.

6.3 The AI Posture SOP Feedback System Helps Trainees Build Appropriate Confidence through Consistent Feedback While Maintaining Motivation Throughout Motor Training

In addition to the subjective confidence ratings in Figure 9, qualitative feedback revealed that **trainees felt more confident and motivated to correct their posture alignment when using AI posture SOP feedback system**. Initially, most participants experienced a decline in shot accuracy, leading to questions about the correlation between SOP scores and performance. However, Group

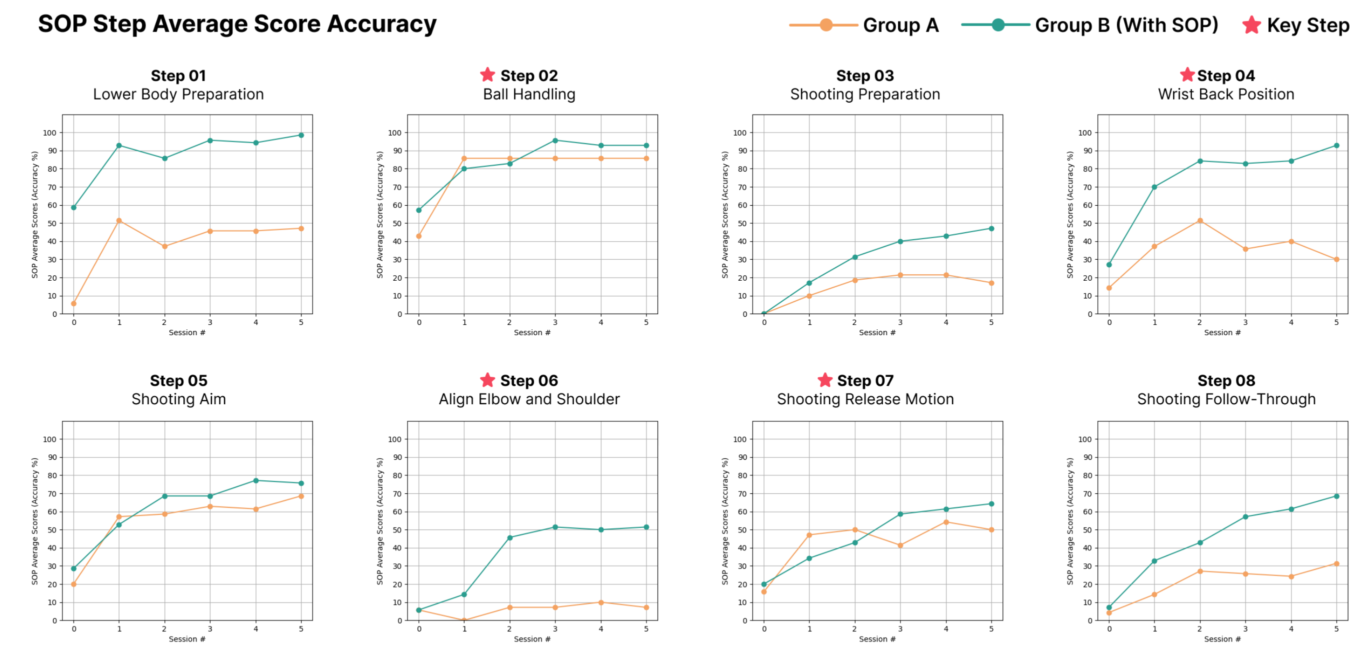

图13：A组（无SOP反馈）与B组（有SOP反馈）的平均标准操作程序步骤准确率得分对比训练课程。B组表现持续优于A组，尤其在关键步骤（★）上，展现了SOP反馈对提升射击准确性和姿势对齐的有效性。

6.2.2 使用*AI*姿势*SOP*反馈的学员认为更易维持正确姿势对齐并纠正其姿势错误

图13展示了A组（无SOP反馈）和B组（有SOP反馈）参与者在各训练课程中的个人SOP步骤得分。B组在SOP分数上呈现持续上升趋势，而A组的表现波动较大且缺乏持续改进，尤其在步骤03、04、05中。这些结果表明，SOP反馈有助于在训练课程中持续改进和自我纠正姿势错误，

使学员能更有效地将其姿势与教练的SOP要求对齐。相比之下，仅依赖训练教程和回放视频可能部分改善姿势对齐，

但学员的改进可能不一致，且会比使用AI姿势SOP反馈系统的学员更快进入平台期。

尽管有这些优势，使用AI姿势SOP反馈系统的学员在设定新目标后偶尔会忽略某些纠正；然而这些疏忽一旦被发现即可轻松解决。B组的七名参与者在转移注意力到新目标时经历了分数下降，

无意中忽略了先前纠正过的步骤。然而，所有这些参与者都能在后续会话中通过会话标准操作程序性能 (F1) 和标准操作程序姿势会话概述趋势 (F6) 识别出遗漏的步骤，并相应调整了目标以纠正疏忽。例如，B2 在阅读其会话03中的系统后指出：“我以为之前一直在专注篮筐，但现在发现并非如此。上一轮中，我在步骤*05*中进行了纠正并正确瞄准了篮筐，但本轮训练中，步骤*05*恢复至与首次训练课程相同的设置。此外，B组两名SOP高分参与者在会话03或04时已近乎完善其动作表现，却暂时将目标转向提高投球数量。这一转变导致后续训练课程中SOP分数显著下降。不过他们

及时意识到问题，重新将重点转回动作准确性而非投篮频率。例如参与者B11表示：

“我在那组投篮中仓促出手，可能忽略了关键的姿势细节。我的投篮命中率没有提升，但姿势分数却下降了。我意识到应该先稳定动作，再追求准确性。”相比之下，A组的三名参与者遇到了类似的监督问题，但在调整目标后，他们仍未能纠正下降的分数，反映出缺乏系统性通过反馈引导他们重回正轨。

6.3 AI姿势SOP反馈系统助力学员通过持续反馈建立适当信心，同时在整个运动训练过程中保持动机

除了图9中的主观信心评分外，定性反馈显示学员在使用AI姿势SOP反馈系统时对纠正姿势对齐更有信心和动力。最初，大多数参与者的投篮准确性有所下降，这引发了对SOP分数与表现之间关联性的疑问。然而，B组

B (with SOP feedback) participants showed increased motivation as they noticed improvements in posture after setting and executing clear SOP training goals. 10 participants noted that rising SOP scores encouraged continued refinement (e.g., B2: *"I did feel that I improved a little with each round [...] Initially, with my preset form, the shots were going in, but after adjusting my posture, I missed in the following sessions. This made me question whether I should revert to my original shooting form. However, seeing my SOP score improve gave me the motivation to keep working on it."*). Meanwhile, three participants attributed their initial decline in accuracy to being in the modification phase, believing long-term practice would eventually lead to improvement, drawing parallels to their experiences in other sports like badminton and table tennis. Like what B9 mentioned after her Session 04, *"I believe that in any competitive sport, there are moments when things happen by luck, and consistency may not always be guaranteed. However, if you're aiming for professional-level performance, you must continuously refine these small details to achieve consistent results."*

In contrast, **without the SOP feedback, trainees are more prone to overconfidence in their SOP.** Group A, who trained without the SOP feedback, exhibited two extreme behaviors: diminished confidence or overestimation of their performance. Some participants lost confidence entirely, questioning the purpose of certain SOP steps and the value of their practice. For example, in Session 04, A13 complaint *"I can see that there's already a difference. [...] I know my hands position didn't actually reach the required height, but I don't think I should adjust it further. (Why?) I feel that the height is more related to personal habits, and I don't really like using my wrist to control the ball."*). On the other hand, several participants overestimated their progress, with six believing their performance in the fifth session was their best. However, the actual SOP scores indicated otherwise, as some participants even recorded their lowest SOP scores during this session. This overconfidence, akin to the Dunning-Kruger effect, led them to prematurely assume mastery (For example, A14 said *"I think I'm perfect now; I can focus on field goal rate."*).

Overall, with the AI posture SOP feedback, trainees were more confident and motivated to correct their posture alignment. The system provided objective feedback that corrected misconceptions and fostered realistic self-assessment, sustaining motivation through visible improvements. As the post-survey result showed in the Figure 9, such differences made participants rate the AI posture SOP feedback system as more useful and satisfying in assisting their motor training.

6.4 Players with Previous Training in Other Sports Show a Faster Learning Pace and Greater Confidence in Adapting to the AI Posture SOP Feedback System

Five from Group A and three participants from Group B mentioned their prior experience in other sports, respectively, including fitness training (A5), volleyball (A6, A14), rock climbing (A11), and ceremonial rifle drills (A5) in Group A, and kendo (B12), cheerleading/gymnastics/taekwondo (B11), and badminton/volleyball (B3) in Group B. Based on analyzing participants' qualitative feedback, we found that players with previous sports experiences demonstrated greater confidence in using the SOP system and a faster learning pace. This advantage is likely attributed to their ability to quickly memorize detailed steps and incorporate feedback into their practice more easily. For example, B12 shared that his sports experience in Kendo and Kyudo was similar to learning our SOP basketball set shot, leading to his improvement from 0% in the pretest to over 80% by Session 03. Similarly, B11, who nearly achieved 100% SOP accuracy by Session 03 said: *"I consider myself someone who learns and corrects movements relatively quickly, thanks to my previous sports experiences. [...] Cheerleading, in particular, demands an even greater understanding of movement accuracy compared to ball sports."* Participants with sports backgrounds in Group A, as detailed in the supplementary material, demonstrated an average SOP improvement of 51.88%, whereas those in Group B, who received SOP feedback, achieved a significantly higher average improvement of 70.63%. This likely transferable learning experience suggests that the AI SOP posture feedback system could offer benefits beyond basketball shot training, with potential applications in other areas of sports skill development. However, to further validate the system's effectiveness in leveraging existing skills for performance alignment, additional data from different experimental settings will be required.

7 Design Implications

We discuss the design implications for future AI SOP feedback posture systems for sports skill training, including the timing and type of AI feedback based on our knowledge-based SOP framework.

7.1 Timing of Technological Interventions in the Teaching Workflow

7.1.1 Adopt SOP System During and After Initial Learning Phases to Enhance Comprehension and Reinforce Self-Training.

Our evaluation of the SOP system revealed that following the initial coaches' instructions with the SOP framework significantly enhanced trainees' understanding of each step in the shooting mechanics, leading to effective self-assessment and error correction, as discussed in Section 6.1 and Section 6.2. As the biggest challenge for beginner learners was ensuring their training meets coaching standards, introducing the SOP during initial training provides a structured approach to understanding the nuances of motor skills. Furthermore, structured feedback provided according to these SOP steps, initially guided by coaches and later supported by AI-driven feedback, helps learners obtain familiar training insights as they transition to independent practice.

Participants B4 and B6, for example, struggled with Step 02 in the initial training phase, specifically with how their left hand should interact with the ball, despite multiple attempts to adjust their positioning. Receiving initial in-person guidance from a coach would help them understand the correct posture more quickly, reducing trial and error before using the AI SOP posture feedback system. Providing AI feedback that aligns with coaches' training goals could also save time for coaches after they have provided hands-on instructions. As Coach 05 noted, *"In large group classes, providing individualized attention can be time-consuming. A detection system that allows students to practice independently and identifies*

（有SOP反馈）的参与者表现出更高的积极性，因为他们注意到在设定并执行明确的SOP训练目标后姿势有所改善。10名参与者指出，上升的SOP分数鼓励了持续改进（例如B2：“我确实感觉到每一轮*[…]*都有所进步。最初，按照我预设的姿势，投篮起初能命中，但调整姿势后却在后续训练课程中频频失误。这让我开始怀疑是否该回归原来的投篮形式。不过，看到SOP分数提升给了我继续改进的动力。”）。与此同时，三名参与者将初始准确性下降归因于正处于调整阶段，他们相信长期练习终将带来进步，并类比了在羽毛球和乒乓球等其他运动中的经验。如B9（女）在会话04后所言：“我认为任何竞技运动中，

都存在运气成分，稳定性未必总能保证。但若追求职业级表现，就必须持续打磨这些细节以获得稳定结果。”

相比之下，缺乏SOP反馈的学员更容易对自身SOP产生过度自信。未接受SOP反馈的A组表现出两种极端行为：信心丧失或高估表现。部分参与者完全失去信心，质疑某些SOP步骤的意义及训练价值。例如在会话04中，A13抱怨道：“我已经看出差异了。*[…]*虽然知道手部姿势未达要求高度，但认为无需再调整。（为什么？）我觉得高度更多是个人习惯问题，而且不喜欢用手腕控球。”）。另一方面，六名参与者高估进展，认为第五次训练的表现最佳。然而实际SOP分数显示，部分人甚至在此次训练中创下最低分。这种过度自信，

类似于邓宁-克鲁格效应，导致他们过早地认为自己已经精通（例如，A14表示“我认为我现在很完美；可以专注于投篮命中率了。”）。

总体而言，借助AI姿势SOP反馈，学员在纠正姿势对齐时更加自信且动机更强。该系统提供的客观反馈纠正了误解，培养了现实的自我评估，并通过可见的改进持续激发动机。如图9所示的后续调查结果，这些差异使得参与者认为AI姿势SOP反馈系统在辅助其运动训练方面更有用且更令人满意。

6.4 有其他运动训练经验的球员在适应AI姿势SOP反馈系统时表现出更快的学习速度和更大的信心

姿势SOP反馈系统

A组中有5名参与者（A5、A6、A14、A11、A5）和B组中有3名参与者（B12、B11、B3）分别提及了他们先前在其他运动中的经验，包括健身训练（A5）、排球（A6、A14）、攀岩（A11）和礼仪步枪训练（A5）在A组中，以及剑道（B12）、啦啦队/体操/跆拳道（B11）和羽毛球/排球（B3）在B组中。基于对参与者定性反馈的分析，我们发现具有先前运动经验的球员表现出在使用SOP系统时更大的信心和更快的学习速度。这一优势可能归因于他们能够快速记忆详细步骤并更容易地将反馈融入练习中。例如，B12分享说他在剑道和弓道中的运动经验与学习我们的SOP篮球定点投篮相似，这使他的表现从前测的0%提升到会话03时的80%以上。同样，B11在会话03时几乎达到100%的SOP准确率，他表示：“我认为自己是一个学习和纠正动作相对较快的人，这得益于我之前的运动经验。*[…]*特别是啦啦队，相比球类运动，它需要对动作准确性有更高的理解。”如补充材料中详述，A组中具有运动背景的参与者表现出51.88%的平均SOP改进，而B组中接受SOP反馈的参与者则实现了显著更高的70.63%平均提升。这种可能可转移的学习经验表明，AI标准操作程序姿势反馈系统可能提供超越篮球投篮训练的好处，并有可能应用于运动技能发展的其他领域。然而，为了进一步验证系统在利用现有技能进行表现对齐方面的有效性，还需要来自不同实验设置的额外数据。

7 设计启示

我们基于知识型SOP框架，探讨了未来用于运动技能训练的人工智能标准作业程序反馈姿势系统的设计启示，包括AI反馈的时机和类型。

7.1 技术干预时机 教学流程中的

7.1.1 在初始学习阶段及后续阶段采用*SOP*系统以提升理解力并强化自主训练

我们对SOP系统的评估表明，在教练初始指导后引入标准操作程序框架，显著提升了学员对投篮动作每个步骤的理解，从而实现有效的自我评估与错误纠正，

如第6.1节和第6.2节所述。由于初学者面临的最大挑战是确保训练符合教练标准，在初始训练阶段引入SOP为理解运动技能的细微差别提供了结构化方法。

此外，根据这些SOP步骤提供的结构化反馈——初期由教练引导，后期辅以人工智能驱动反馈——能帮助学习者在过渡到独立练习时获得熟悉的训练洞察。

例如，参与者B4和B6在初始训练阶段就难以掌握步骤02，特别是左手应如何与球互动的问题，尽管他们多次尝试调整自身位置。若能从一开始就接受教练的现场指导，将帮助他们更快理解正确姿势，减少在使用AI标准操作程序姿势反馈前反复试错的过程。系统。提供与教练训练目标一致的人工智能反馈也能为教练节省时间，在他们提供了实际操作指导之后。正如5号教练所述：“在大班课程中，

提供个性化关注可能非常耗时。一个检测该系统允许学生独立练习并识别

where their posture needs adjustment could significantly reduce the time required for corrections." By categorizing coaches' instructions into SOP steps followed by structured AI feedback, such an AI feedback system can enhance overall learning efficiency for both learners and coaches while maintaining training quality.

7.1.2 *Provide Staged Evaluations to Improve Memorability of Motion Sequence and Training Effectiveness*.

Although the SOP provides a structured approach as learners familiarize themselves with a new motor skill, we found that beginners often struggle to memorize all the steps at once. During the experiment with both Group A and Group B, none of the participants were able to memorize all the steps after watching the coach's SOP tutorial in their initial attempt. Several participants frequently referred to the monitor to review the SOP step sequence before shooting, highlighting the challenge of retaining all steps simultaneously. Participant B7 noted that learning would be more manageable if she could focus on mastering a few steps at a time rather than all at once.

In particular, steps that involved multi-joint coordination movements, such as Step 06 in Figure 13, posed significant difficulties. Many participants had difficulty mastering it, with progress plateauing after Session 03 despite the SOP system's support. Conversely, steps involving simpler single-joint movements, such as Steps 01, 02, 04, and 05, were more easily accomplished after following the SOP tutorial.

These findings suggest the effectiveness of using a staged evaluation approach in our SOP framework, where challenging SOP steps are tackled progressively, allowing learners to target small parts as they develop a better control of muscle movement for each body part over time[15]. By focusing on a few steps at a time, this method can facilitate more effective learning and continuous improvement, better aligning with the needs of beginners who may find the full sequence overwhelming when introduced all at once.

7.1.3 *Provide Personalized, Interactive Feedback in Real-Time to Enhance Immediate Error Correction*.

Obtaining real-time feedback was perceived helpful by all participants across Group A and B. Moreover, with the support of SOP feedback, learners demonstrated an increased level of self-awareness, often requesting personalized feedback to further enhance their learning experience. Eight participants in Group B suggested incorporating targeted visual aids, such as indicators that pinpoint problematic body parts, which would facilitate them to make focused adjustments faster. Participants also expressed a desire for immediate feedback on their own performance with video replay, including step-by-step scores after each shot and the ability to view full-body videos of their shooting motion directly on the screen. Participant B5 proposed to extend feedback beyond binary "✔" (correct) or "✘" (incorrect) indicators, requesting a percentage-based evaluation that reflects the accuracy improvement for each movement. This more nuanced feedback approach could alleviate the complexities of steps involving multiple movement requirements, such as Step 06.

Additionally, voice interaction was deemed helpful to get timely feedback for sports motor training. During our study, participants B12–14 explored the use of voice commands during training sessions, requesting specific sections from the researcher without needing to touch the screen. This feedback suggests that integrating voice commands into the SOP system may significantly enhance user interaction by providing faster access to desired information. Typical commands included reviewing progress on previous goals via Session SOP Summary (F1), diagnosing poorly performed steps, and refining objectives using SOP Posture Video Clip Comparison (F3) along with the Coach SOP Posture Tutorial (F5) for the next session. Future systems can integrate these enhancements and create a more responsive training experience, empowering trainees' with more immediate, actionable feedback.

7.2 Types of AI Feedback for Personalized Motor Training

7.2.1 *Adjust Posture Tolerance to Addresses Individual Variations in SOP Training*.

Both coaches and participants recommended that the SOP checklist detection should include customizable tolerance ranges to account for individual physical differences. This design consideration is crucial for future AI SOP posture feedback systems, as body movements can vary significantly between individuals. Without this flexibility, inaccurate feedback could not only result in ineffective training but also increase the risk of injury.

During later training sessions, participants B6 and B11 reported wrist discomfort when attempting to meet the requirements of Step 04, which involved holding the ball with a wrist bent at a 90-degree angle. Consequently, despite not achieving higher scores in this step, they chose to stop making further adjustments. Similarly, Coach C4 suggested that increasing the tolerance range could help reduce frustration, noting, *"Because everyone's physical makeup, flexibility, learning ability, and coordination vary, it may not be realistic for all participants to meet the exact same SOP requirements. Being classified as incorrect might feel discouraging or disengaging for some participants."* Therefore, future research is needed to develop methods for generating personalized feedback grounded in scientific or empirical knowledge of motor skill learning.

7.2.2 *Correlate Performance Metrics with SOP Posture to Derive Deeper Training Insights*.

From a coaching perspective, an essential goal beyond achieving mechanical repetition in motor training is to foster personalized understanding and develop individualized training plans that support athletes' unique strengths. All coaches (C1–C8) emphasized that correlating SOP movements with shooting accuracy and incorporating larger datasets over time would enable coaches to guide trainees in discovering their unique strengths. C7 highlighted how variations in natural strength and preferred movements influence player roles: *"Some players have significant overall strength and don't need to rely on their legs for power; focusing on aiming with their hand and core strength can effectively propel the ball. Others excel in free throws due to the minimal leg movement required, but struggle with mid-range shots. Identifying these strengths and weaknesses can help tailor training to individual needs."*

Additionally, several coaches (C3, C7, C8) also noted that integrating field goal percentage data with SOP training could make their guidance more persuasive and motivating. As C3 noted, tracking data can clearly show athletes how specific adjustments improve their success rates, thus fostering engagement and improvement.

他们姿势需要调整的地方可显著降低
纠正所需的时间。"通过将教练指导分类
为SOP步骤后接结构化AI反馈，此类AI
反馈系统能同步提升学习者与教练的
整体学习效率，同时保障训练质量。

7.1.2 提供阶段性评估以提升记忆性动作序列与训练效果

尽管 the SOP 提供了 a 结构化 方法 as 学习者
当初学者尝试熟悉一项新的运动技能时，我们发现他们往往难以一次性记住所有步骤。在A组和B组的实验中，所有参与者在初次观看教练的标准操作程序教程后，均未能完整记忆所有步骤。多位参与者频繁参考显示屏来回顾标准操作程序步骤序列后才进行投篮，

这凸显了同时掌握所有步骤的挑战性。
参与者B7指出，如果能专注于逐步掌握少量步骤而非一次性学习全部内容，学习过程会更可控。

特别是涉及多关节协调运动的步骤（如图13中的步骤06）带来了显著困难。

多数参与者难以掌握该步骤，即便有SOP系统的支持，进展仍在会话03后进入平台期。相反，

涉及较简单单关节运动的步骤，如步骤01、02、04和05，在遵循标准操作程序教程后更容易完成。

这些发现表明，在我们的标准操作程序框架中采用分阶段评估方法的有效性，其中具有挑战性的SOP步骤被逐步攻克，使学习者能够随着时间推移针对身体各部位肌肉运动发展出更好的控制能力[15]。通过一次专注于少量步骤，这种方法可以促进更有效的学习和持续改进，

更好地契合初学者的需求，他们可能会在一次性接触完整序列时感到不知所措。

7.1.3 提供个性化的实时互动反馈以增强即时错误纠正能力。

所有A组和B组参与者均认为获取实时反馈很有帮助。此外，在标准操作程序反馈的支持下，学习者表现出更高水平的自我意识，

经常要求获得个性化反馈以进一步提升学习体验。B组的八位参与者建议加入针对性视觉辅助工具，例如能精确定位问题身体部位的指示器，这将帮助他们更快地进行针对性调整。参与者还表达了希望即时获得自身表现反馈的愿望，包括视频回放功能，

每次投篮后的逐步评分，以及直接在屏幕上查看自己投篮动作的全身视频。

参与者B5提议将反馈机制扩展到二元化的"√"（正确）或"✘"（错误）指示之外，要求采用基于百分比的评估来反映每个动作的准确性提升。这种更细致的反馈方式可以缓解涉及多重动作要求的步骤的复杂性，

例如步骤06。

此外，语音交互被认为有助于为运动技能训练获取及时反馈。在我们的研究中，参与者B12-14在训练环节探索了语音命令的使用，无需触碰屏幕即可向研究人员请求特定部分。

该反馈表明，将语音命令集成到SOP系统中，可以通过更快获取所需信息来显著提升用户交互体验。

典型指令包括通过会话SOP摘要（F1）回顾先前目标的进展，诊断表现不佳的步骤，

并利用标准操作程序姿势视频片段比较（F3）和教练SOP姿势教程（F5）为下一阶段训练优化目标。未来的系统可以整合这些改进，创造更具响应性的训练体验，从而赋能学员。

提供更即时、可操作的反馈。

7.2 个性化运动训练中的人工智能反馈类型

7.2.1 调整姿势容忍度以应对标准操作程序训练中的个体差异。

Both 教练 and 参与者 推荐 that the SOP 检查清单
检测应包含可定制的容忍范围以适配
个体生理差异。这一设计考量对
未来人工智能标准操作程序姿势反馈系统至关重要，因为人体动作可能因人而异。若缺乏这种

灵活性，不准确的反馈不仅会导致无效
训练，还可能增加受伤风险。

在后续训练课程中，参与者B6和B11报告称，在尝试满足步骤04的要求时出现手腕不适，该步骤需要以90度角弯曲手腕持球。因此，尽管未能在此步骤获得更高分数，

他们选择停止进一步调整。同样地，教练C4建议扩大容忍范围可能有助于减少挫败感，并指出："由于每个人的身体构造、灵活性、

学习能力和协调性各不相同，要求所有参与者都完全符合相同的标准操作程序要求可能并不现实。被归类为错误可能会让部分参与者感到沮丧或失去动力。"因此，未来研究需要开发基于运动技能学习的科学或实证知识来生成个性化反馈的方法。

7.2.2 将性能指标与标准操作程序姿势相关联以获取更深层次的训练洞察。

从教练视角来看，除了达成
运动训练中的机械重复旨在培养个性化
的理解并制定支持运动员独特优势的个性化训练计划。所有教练（C1–C8）都强调

将标准操作程序动作与射击准确性相关联，并随着时间推移整合更大的数据集，将使教练能够引导

学员发现他们独特的优势。C7特别指出
自然力量和偏好动作的差异如何影响

球员角色："有些球员拥有显著的整体力量，因此不需要
需要依靠腿部来发力；专注于用手部
瞄准并运用核心力量能有效推动球。另一些球员则擅长
罚球，因为所需腿部动作较少，但在
中距离投篮方面表现欠佳。识别这些优势和劣势有助于
根据个人需求定制训练。"

此外，几位教练（C3、C7、C8）还指出，将投篮命中率数据与标准操作程序训练相结合，可以使他们的指导更具说服力和激励性。正如C3所言，追踪数据能清晰地向运动员展示具体调整如何提升其成功率，从而促进参与度和改进。

By correlating training data with performance, coaches can not only monitor progress and gain deeper insights, but also provide more effective, data-driven coaching.

7.2.3 ***Provide Proactive Training Support to Improve Goal Setting and Execution under Plateau Phase.***
Trainees developing sports motor skills may experience a plateau phase after a period of time. Several participants in Group B experienced challenges in advancing their SOP performance on specific steps, suggesting that physical limitations, rather than a lack of understanding, were the primary barriers. Participants (B4, B5, B6, B8, and B12) particularly struggled with complicated steps like Step 06, where they found it difficult to execute the required movements despite recognizing the issues.

To address this, the AI SOP posture feedback system should offer options or reminders for trainees to seek expert insights, helping to identify specific areas for improvement and refine training goals, thereby keeping progress on track. Coaches C6 and C7 emphasized that participants often experience plateaus not because of conceptual misunderstandings of the SOP, but rather due to the need for further development in physical strength or coordination. As C6 articulated, *"Initially, we guide them through simpler, short-range exercises, such as improving single-hand support strength to help achieve a 90-degree elbow angle. [...] Although students can visually mimic wrist extensions, physical constraints often hinder their ability to perform the movements correctly. When the system lacks tailored recommendations or standard troubleshooting techniques, my intervention becomes crucial in addressing such challenges."*

Additionally, C4 observed that even when participants had technically mastered SOP movements, some still struggled with successful shot execution due to insufficient strength. To enhance learner engagement, the system could dynamically suggest adaptive modifications based on expert advice, such as adjusting shooting distance, to ensure training effectiveness and maintain motivation. This approach would better align the training process with individual needs and capabilities, ensuring an AI SOP posture feedback system can provide a more personalized and effective learning experience.

8 Limitations and Future Work

While our designed AI feedback posture SOP system shows promise in enhancing posture alignment and error correction, several limitations of the current study must be acknowledged. First, the scope of the training was limited to a relatively short duration and a small number of shots per session. To better understand the system's long-term efficacy, future work should include more extensive training periods with a higher volume of shots. This would provide insights into how sustained use of the system impacts both field goal percentages and posture alignment over time.

Another limitation of the current system is its reliance on coaches' input for posture correction feedback, which can introduce subjectivity and variability. To address this, future work could explore the collection of instructional language from various coaches to create a more objective feedback mechanism. By designing and fine-tuning large language models (LLMs) on a dataset with coaching instructions, we could develop an AI-driven system capable of generating precise feedback with less human input. This approach aims to standardize feedback, minimize human error, and ensure that posture correction aligns with established best practices. By enhancing the reliability and scalability of the SOP system, it also opens the door for applications in other training contexts using SOP, such as baseball swings, batting techniques, and boxing movements, which are part of the future work we are currently exploring.

Additionally, the study focused on a single shooting distance, limiting the generalizability of the findings across different shooting distances. Future research should explore the effects of the AI Feedback posture SOP system at varying shooting distances to better understand how posture alignment between basketball coaches and beginner players and field goal performance are influenced. Moreover, the study relied on coach assessments for performance validation, which may carry slight biases or inaccuracies. Future studies should incorporate more objective measures of performance, such as motion capture technology, biomechanical analysis or ball trajectories to validate the system's effectiveness more accurately.

Finally, while the current study primarily focused on posture alignment between basketball coaches and beginner players, it is essential to explore the correlation between posture alignment and field goal performance. Future work should examine how improvements in posture alignment directly correlate with field goal success rates, thereby providing a more holistic evaluation of the AI feedback posture SOP system's impact on basketball shooting performance. This approach will ensure a more integrated understanding of how posture correction contributes to overall skill enhancement in sports training.

9 Conclusion

This study introduces a methodology and framework for designing the AI feedback posture SOP system aimed at enhancing basketball motor learning by bridging coaching knowledge with independent practice. Results show that, first, the system effectively addresses key challenges for beginners, such as misalignment between proprioception and actual posture, uncertainty in corrections, and difficulties in goal-setting. Second, the structured SOP approach integrates coaching knowledge with real-time video and intuitive textual feedback, providing actionable and step-by-step guidance. Third, our user study demonstrates significant improvements in confidence, self-awareness, and effectiveness across training metrics. Lastly, the system offers a scalable and impactful framework that can be implemented on top of existing solutions for skill development, fostering better alignment with coaching standards and enriching the motor learning experience.

Our work presents a comprehensive framework that integrates expert coaching principles with AI-driven SOP feedback, establishing a foundation for future advancements in interactive sports training. To maximize the SOP framework's long-term impact on beginners' skill acquisition, we emphasize the importance of tailored AI feedback and strategically timed technological interventions, including advancements such as LLM implementations. These developments promise to improve system scalability, enhance training precision, and further advance motor learning research.

通过将训练数据与表现相关联，教练们不仅能
不仅能监测进展并获得更深入的见解，还能提供
更有效、数据驱动的教练。

7.2.3 提供主动训练支持以改善平台期下的目标设定与执行。
经过一段时间后进入平台期。B组的多名参与者（B4、
学员 发展 运动 运动 技能 may 经验
B5、B6、

B8和B12）在复杂步骤如步骤06上尤为吃力，尽管能识别问题所在，却难以执行要求的动作。

为此，AI标准操作程序姿势反馈系统应提供选项或提醒，引导学员寻求专家见解，从而明确具体改进领域并优化训练目标，

确保进展不偏离正轨。教练*C6*和*C7*强调，参与者常遇平台期并非因对标准操作程序的概念理解有误，而是体力或协调性需进一步提升。正如*C6*所述：*"*初期我们会引导他们进行简单短程训练，比如增强单手支撑力量以实现*90*度肘角。*[...]* 虽然学员能视觉模仿手腕伸展动作，但身体限制常阻碍其正确执行。当系统缺乏量身定制的建议或标准故障排除技术时，我的介入对解决这类挑战就至关重要。*"*

此外，C4观察到，即使参与者已技术性掌握标准操作程序动作，部分人仍因力量不足而难以成功完成投篮。为提升学习者参与度，该系统可根据专家建议动态推荐适应性调整方案，例如调整投篮距离，

以确保训练有效性并保持动机。这种方法能更好地将训练过程与个人需求和能力对齐，确保AI标准操作程序姿势反馈系统能提供更个性化和有效的学习体验。

8 局限性与未来工作

尽管我们设计的AI反馈姿势标准操作程序系统在提升姿势对齐和错误纠正方面展现出潜力，但必须承认当前研究存在若干局限。首先，训练范围受限于较短的持续时间和每节课较少的投篮次数。为更深入理解系统的长期有效性，未来工作应包含更长的训练期和更高频次的投篮训练。这将提供关于系统持续使用如何随时间影响投篮命中率和姿势对齐的见解。

当前系统的另一个局限在于其对教练的依赖
姿势纠正反馈的输入可能引入主观性和变异性。为解决这一问题，未来工作可以探索收集不同教练的教学语言，以创建更客观的反馈机制。通过在教练指导数据集上设计和微调大型语言模型（LLMs），我们可以开发一个AI驱动系统，能够以更少的人工输入生成精确的反馈。这一方法旨在标准化反馈，减少人为错误，并确保

姿势纠正与既定的最佳实践保持一致。通过提升SOP系统的可靠性和可扩展性，它还为在其他训练情境中使用SOP的应用打开了大门。

如棒球挥棒、击球技术和拳击动作
这些是我们当前正在探索的未来工作的一部分
此外，该研究仅聚焦于单一投篮距离
限制了研究结果在不同投篮距离间的普适性。未来研究应探索AI反馈姿势标准操作程序系统在不同投篮距离下的效果，以更好地理解篮球教练与初学者球员之间的姿势对齐如何影响投篮表现

此外，该研究依赖教练评估进行表现验证，这可能存在轻微偏差或不准确性。未来研究应采用更客观的表现衡量标准

例如动作捕捉技术、生物力学分析或球的轨迹，以更准确地验证系统的有效性。

最后，虽然当前研究主要聚焦于篮球教练与初学者球员之间的姿势对齐，但探索姿势对齐与投篮表现之间的相关性至关重要。未来工作应研究姿势对齐的改善如何直接关联投篮成功率，从而更全面地评估AI反馈姿势标准操作程序系统对篮球投篮表现的影响。这种方法将确保更综合地理解姿势纠正如何促进运动训练中整体技能的提升。

9 结论

本研究提出了一种设计AI反馈姿势标准操作程序系统的方法论与框架，旨在通过将教练知识与独立练习相结合来提升篮球运动学习效果。结果表明：首先，该系统有效解决了初学者的关键挑战，如本体感觉与实际姿势的错位、纠正的不确定性以及目标设定的困难。其次，结构化的标准操作程序方法整合了教练知识、实时视频和直观文本反馈，提供了可操作的分步指导。

第三，我们的用户研究表明，在训练指标方面，信心、自我意识和有效性均有显著提升。最后，该系统提供了一个可扩展且具有影响力的框架，可在现有技能发展解决方案之上实施，促进与教练标准更好地对齐，并丰富运动学习经验。

我们的工作提出了一个综合框架，将专家指导原则与人工智能驱动的SOP反馈相结合，为互动体育训练的未来发展奠定了基础。为了最大化标准操作程序框架对初学者技能获取的长期影响，我们强调定制化人工智能反馈和战略性技术干预的重要性，

包括大型语言模型实施等进步。这些发展有望提升系统可扩展性、增强训练精度，并进一步推动运动学习研究。

Acknowledgments

This research was funded by the National Science and Technology Council (NSTC) under grant numbers NSTC 112-2221-E-007-079-MY3 and NSTC 111-2221-E-007-065-MY3. We extend our sincere gratitude to all participants involved in the user research and the Taiwan Institute of Sports Science consultants for their valuable contributions.

References

[1] Rishabh Bajpai and Deepak Joshi. 2021. Movenet: A deep neural network for joint profile prediction across variable walking speeds and slopes. *IEEE Transactions on Instrumentation and Measurement* 70 (2021), 1–11.

[2] Zixin Cai, Owen Noel Newton Fernando, and Jia Ying Ong. 2022. PoseBuddy: Pose estimation workout mobile application. In *2022 International Conference on Cyberworlds (CW)*. IEEE, 151–154.

[3] Zhe Cao, Tomas Simon, Shih-En Wei, and Yaser Sheikh. 2017. Realtime multi-person 2d pose estimation using part affinity fields. In *Proceedings of the IEEE conference on computer vision and pattern recognition*. 7291–7299.

[4] Chien-Chang Chen, Chen Chang, Cheng-Shian Lin, Chien-Hua Chen, and I Cheng Chen. 2023. Video based basketball shooting prediction and pose suggestion system. *Multimedia Tools and Applications* 82, 18 (2023), 27551–27570.

[5] Robert W Christina and Daniel M Corcos. 1988. Coaches guide to teaching sport skills. (1988).

[6] Master Class. 2024. Stephen Curry Teaches Shooting, Ball-Handling, and Scoring. https://www.masterclass.com/classes/stephen-curry-teaches-shooting-ball-handling-and-scoring. (Accessed on 08/24/2024).

[7] SAVI Coaching. 2022. How to Shoot the Basketball for Beginners [Coaches MUST Watch!]. https://www.youtube.com/watch?v=J6_-SaW_GUE. (Accessed on 08/24/2024).

[8] Bruce Elliott. 1992. A kinematic comparison of the male and female two point and three point jump shots in basketball. (1992).

[9] B Elliott and EJTAJOS WHITE. 1989. A kinematic and kinetic analysis of the female two point and three point jump shots in basketball. (1989).

[10] Kaia Health. 2020. Kaia Motion Coach. https://kaiahealth.com/solutions/msk/for-providers/. 2024-05-8.

[11] Jackie L Hudson. 1985. Prediction of basketball skill using biomechanical variables. *Research Quarterly for Exercise and Sport* 56, 2 (1985), 115–121.

[12] ILoveBasketballTV. 2022. (How To Shoot a Basketball PERFECTLY. https://www.youtube.com/watch?v=nuiPr66rCcw. (Accessed on 08/24/2024).

[13] Pillar Vision Inc. 2020. Noah Shooting System. https://www.noahbasketball.com/. 2024-08-22.

[14] Fajar Awang Irawan and Tania Arlita Safitri Prastiwi. 2022. Biomechanical analysis of the three-point shoot in basketball: shooting performance. *Journal of Physical Education and Sport* 22, 12 (2022), 3003–3008.

[15] Muhammad Syaifullah Irwan and Ms Lismadiana. 2018. The Effect of Exercise Methods and Coordination towards Students' Extracurricular Basketball Skills. In *2nd Yogyakarta International Seminar on Health, Physical Education, and Sport Science (YISHPESS 2018) and 1st Conference on Interdisciplinary Approach in Sports (CoIS 2018)*. Atlantis Press, 198–203.

[16] Lüder A Kahrs, Jörg Raczkowsky, Jürgen Manner, Andreas Fischer, and Heinz Wörn. 2006. Supporting free throw situations of basketball players with augmented reality. *International Journal of Computer Science in Sport* 5, 2 (2006), 72–75.

[17] Ting-Yang Kao, Tse-Yu Pan, Chen-Ni Chen, Tsung-Hsun Tsai, Hung-Kuo Chu, and Min-Chun Hu. 2022. ScoreActuary: Hoop-Centric Trajectory-Aware Network for Fine-Grained Basketball Shot Analysis. In *Proceedings of the 30th ACM International Conference on Multimedia*. 6991–6993.

[18] Kinovea. n.d.. Kinovea. https://www.kinovea.org/. 2024-05-8.

[19] Duane Knudson. 1993. Biomechanics of the basketball jump shot—Six key teaching points. *Journal of Physical Education, Recreation & Dance* 64, 2 (1993), 67–73.

[20] Calvin Ku, Jian-Jia Weng, Yu-Hsin Wang, Dong-Xian Wu, Yi-Min Lau, Wan-Lun Tsai, Te-Cheng Wu, Hung-Kuo Chu, and Min-Chun Hu. 2022. Table tennis skill learning in vr with step by step guides using forehand drive as a case study. In *2022 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. IEEE, 275–282.

[21] Tica Lin, Alexandre Aouididi, Zhutian Chen, Johanna Beyer, Hanspeter Pfister, and Jui-Hsien Wang. 2023. VIRD: immersive match video analysis for high-performance badminton coaching. *IEEE transactions on visualization and computer graphics* (2023).

[22] Tica Lin, Rishi Singh, Yalong Yang, Carolina Nobre, Johanna Beyer, Maurice A Smith, and Hanspeter Pfister. 2021. Towards an understanding of situated ar visualization for basketball free-throw training. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–13.

[23] Dartfish Ltd. [n. d.]. *Dartfish Express*. https://www.dartfish.com

[24] Shengyao Luo, Kim Geok Soh, Yanmei Zhao, Kim Lam Soh, He Sun, Nasnoor Juzaily Mohd Nasiruddin, Xiuwen Zhai, and Luhong Ma. 2023. Effect of core training on athletic and skill performance of basketball players: A systematic review. *Plos one* 18, 6 (2023), e0287379.

[25] Stuart Miller and Roger Bartlett. 1996. The relationship between basketball shooting kinematics, distance and playing position. *Journal of sports sciences* 14, 3 (1996), 243–253.

[26] David R Mullineaux and Timothy L Uhl. 2010. Coordination-variability and kinematics of misses versus swishes of basketball free throws. *Journal of sports sciences* 28, 9 (2010), 1017–1024.

[27] Masato Nakai, Yoshihiko Tsunoda, Hisashi Hayashi, and Hideki Murakoshi. 2019. Prediction of basketball free throw shooting by openpose. In *New Frontiers in Artificial Intelligence: JSAI-isAI 2018 Workshops, JURISIN, AI-Biz, SKL, LENLS, IDAA, Yokohama, Japan, November 12–14, 2018, Revised Selected Papers*. Springer, 435–446.

[28] Victor HA Okazaki, André LF Rodacki, and Miriam N Satern. 2015. A review on the basketball jump shot. *Sports biomechanics* 14, 2 (2015), 190–205.

[29] Victor Hugo Alves Okazaki, André Luiz Félix Rodacki, and Fábio Heitor Alves Okazaki. 2007. Biomecânica do arremesso de jump no basquetebol. *Lect: Educ Fis Deport* 11 (2007), 1–13.

[30] Hiroki Okubo and Mont Hubbard. 2016. Comparison of shooting arm motions in basketball. *Procedia engineering* 147 (2016), 133–138.

[31] Marjansadat Rezaei, Farzaneh Hatami, and Gholamreza Lotfi. 2023. The impact of different attentional focus strategies during modeling on the acquisition and retention of free throws in basketball. *International Journal of Sport Studies for Health* 6, 1 (2023).

[32] H Ripoll, C Bard, and J Paillard. 1986. Stabilization of head and eyes on target as a factor in successful basketball shooting. *Human movement science* 5, 1 (1986), 47–58.

[33] TechSmith. n.d.. Coach's Eye. https://go.coachseye.com/retirement/. 2024-05-8.

[34] Jian-Jia Weng, Yu-Hsin Wang, Calvin Ku, Dong-Xian Wu, Yi-Min Lau, Wan-Lun Tsai, Tse-Yu Pan, Min-Chun Hu, Hung-Kuo Chu, and Te-Cheng Wu. 2022. Assist Home Training Table Tennis Skill Acquisition via Immersive Learning and Web Technologies. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. IEEE, 804–805.

[35] Will FW Wu, Jared M Porter, and Lee E Brown. 2012. Effect of attentional focus strategies on peak force and performance in the standing long jump. *The Journal of Strength & Conditioning Research* 26, 5 (2012), 1226–1231.

[36] Gabriele Wulf and Jiang Su. 2007. An external focus of attention enhances golf shot accuracy in beginners and experts. *Research quarterly for exercise and sport* 78, 4 (2007), 384–389.

致谢

本研究由国家科学及技术委员会（国科会）资助，项目编号为NSTC 112-2221-E-007-079-MY3和NSTC 111-2221-E-007-065-MY3。我们向所有参与用户研究的参与者及台湾运动科学研究所顾问的宝贵贡献表示诚挚感谢。

参考文献

[1] Rishabh Bajpai and Deepak Joshi. 2021. Movenet: A deep neural network for joint profile prediction across variable walking speeds and slopes. *IEEE Transactions on Instrumentation and Measurement* 70 (2021), 1–11.

[2] Zixin Cai, Owen Noel Newton Fernando, and Jia Ying Ong. 2022. PoseBuddy: Pose estimation workout mobile application. In *2022 International Conference on Cyberworlds (CW)*. IEEE, 151–154.

[3] Zhe Cao, Tomas Simon, Shih-En Wei, and Yaser Sheikh. 2017. Realtime multi-person 2d pose estimation using part affinity fields. In *Proceedings of the IEEE conference on computer vision and pattern recognition*. 7291–7299.

[4] Chien-Chang Chen, Chen Chang, Cheng-Shian Lin, Chien-Hua Chen, and I Cheng Chen. 2023. Video based basketball shooting prediction and pose suggestion system. *Multimedia Tools and Applications* 82, 18 (2023), 27551–27570.

[5] Robert W Christina and Daniel M Corcos. 1988. Coaches guide to teaching sport skills. (1988).

[6] Master Class. 2024. Stephen Curry Teaches Shooting, Ball-Handling, and Scoring. https://www.masterclass.com/classes/stephen-curry-teaches-shooting-ball-handling-and-scoring. (Accessed on 08/24/2024).

[7] SAVI Coaching. 2022. How to Shoot the Basketball for Beginners [Coaches MUST Watch!]. https://www.youtube.com/watch?v=J6_-SaW_GUE. (Accessed on 08/24/2024).

[8] Bruce Elliott. 1992. A kinematic comparison of the male and female two point and three point jump shots in basketball. (1992).

[9] B Elliott and EJTAJOS WHITE. 1989. A kinematic and kinetic analysis of the female two point and three point jump shots in basketball. (1989).

[10] Kaia Health. 2020. Kaia Motion Coach. https://kaiahealth.com/solutions/msk/for-providers/. 2024-05-8.

[11] Jackie L Hudson. 1985. Prediction of basketball skill using biomechanical variables. *Research Quarterly for Exercise and Sport* 56, 2 (1985), 115–121.

[12] ILoveBasketballTV. 2022. (How To Shoot a Basketball PERFECTLY. https://www.youtube.com/watch?v=nuiPr66rCcw. (Accessed on 08/24/2024).

[13] Pillar Vision Inc. 2020. Noah Shooting System. https://www.noahbasketball.com/. 2024-08-22.

[14] Fajar Awang Irawan and Tania Arlita Safitri Prastiwi. 2022. Biomechanical analysis of the three-point shoot in basketball: shooting performance. *Journal of Physical Education and Sport* 22, 12 (2022), 3003–3008.

[15] Muhammad Syaifullah Irwan and Ms Lismadiana. 2018. The Effect of Exercise Methods and Coordination towards Students' Extracurricular Basketball Skills. In *2nd Yogyakarta International Seminar on Health, Physical Education, and Sport Science (YISHPESS 2018) and 1st Conference on Interdisciplinary Approach in Sports (CoIS 2018)*. Atlantis Press, 198–203.

[16] Lüder A Kahrs, Jörg Raczkowsky, Jürgen Manner, Andreas Fischer, and Heinz Wörn. 2006. Supporting free throw situations of basketball players with augmented reality. *International Journal of Computer Science in Sport* 5, 2 (2006), 72–75.

[17] Ting-Yang Kao, Tse-Yu Pan, Chen-Ni Chen, Tsung-Hsun Tsai, Hung-Kuo Chu, and Min-Chun Hu. 2022. ScoreActuary: Hoop-Centric Trajectory-Aware Network for Fine-Grained Basketball Shot Analysis. In *Proceedings of the 30th ACM International Conference on Multimedia*. 6991–6993.

[18] Kinovea. n.d.. Kinovea. https://www.kinovea.org/. 2024-05-8.

[19] Duane Knudson. 1993. Biomechanics of the basketball jump shot—Six key teaching points. *Journal of Physical Education, Recreation & Dance* 64, 2 (1993), 67–73.

[20] Calvin Ku, Jian-Jia Weng, Yu-Hsin Wang, Dong-Xian Wu, Yi-Min Lau, Wan-Lun Tsai, Te-Cheng Wu, Hung-Kuo Chu, and Min-Chun Hu. 2022. Table tennis skill learning in vr with step by step guides using forehand drive as a case study. In *2022 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. IEEE, 275–282.

[21] Tica Lin, Alexandre Aouididi, Zhutian Chen, Johanna Beyer, Hanspeter Pfister, and Jui-Hsien Wang. 2023. VIRD: immersive match video analysis for high-performance badminton coaching. *IEEE transactions on visualization and computer graphics* (2023).

[22] Tica Lin, Rishi Singh, Yalong Yang, Carolina Nobre, Johanna Beyer, Maurice A Smith, and Hanspeter Pfister. 2021. Towards an understanding of situated ar visualization for basketball free-throw training. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–13.

[23] Dartfish Ltd. [n. d.]. *Dartfish Express*. https://www.dartfish.com

[24] Shengyao Luo, Kim Geok Soh, Yanmei Zhao, Kim Lam Soh, He Sun, Nasnoor Juzaily Mohd Nasiruddin, Xiuwen Zhai, and Luhong Ma. 2023. Effect of core training on athletic and skill performance of basketball players: A systematic review. *Plos one* 18, 6 (2023), e0287379.

[25] Stuart Miller and Roger Bartlett. 1996. The relationship between basketball shooting kinematics, distance and playing position. *Journal of sports sciences* 14, 3 (1996), 243–253.

[26] David R Mullineaux and Timothy L Uhl. 2010. Coordination-variability and kinematics of misses versus swishes of basketball free throws. *Journal of sports sciences* 28, 9 (2010), 1017–1024.

[27] Masato Nakai, Yoshihiko Tsunoda, Hisashi Hayashi, and Hideki Murakoshi. 2019. Prediction of basketball free throw shooting by openpose. In *New Frontiers in Artificial Intelligence: JSAI-isAI 2018 Workshops, JURISIN, AI-Biz, SKL, LENLS, IDAA, Yokohama, Japan, November 12–14, 2018, Revised Selected Papers*. Springer, 435–446.

[28] Victor HA Okazaki, André LF Rodacki, and Miriam N Satern. 2015. A review on the basketball jump shot. *Sports biomechanics* 14, 2 (2015), 190–205.

[29] Victor Hugo Alves Okazaki, André Luiz Félix Rodacki, and Fábio Heitor Alves Okazaki. 2007. Biomecânica do arremesso de jump no basquetebol. *Lect: Educ Fis Deport* 11 (2007), 1–13.

[30] Hiroki Okubo and Mont Hubbard. 2016. Comparison of shooting arm motions in basketball. *Procedia engineering* 147 (2016), 133–138.

[31] Marjansadat Rezaei, Farzaneh Hatami, and Gholamreza Lotfi. 2023. The impact of different attentional focus strategies during modeling on the acquisition and retention of free throws in basketball. *International Journal of Sport Studies for Health* 6, 1 (2023).

[32] H Ripoll, C Bard, and J Paillard. 1986. Stabilization of head and eyes on target as a factor in successful basketball shooting. *Human movement science* 5, 1 (1986), 47–58.

[33] TechSmith. n.d.. Coach's Eye. https://go.coachseye.com/retirement/. 2024-05-8.

[34] Jian-Jia Weng, Yu-Hsin Wang, Calvin Ku, Dong-Xian Wu, Yi-Min Lau, Wan-Lun Tsai, Tse-Yu Pan, Min-Chun Hu, Hung-Kuo Chu, and Te-Cheng Wu. 2022. Assist Home Training Table Tennis Skill Acquisition via Immersive Learning and Web Technologies. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. IEEE, 804–805.

[35] Will FW Wu, Jared M Porter, and Lee E Brown. 2012. Effect of attentional focus strategies on peak force and performance in the standing long jump. *The Journal of Strength & Conditioning Research* 26, 5 (2012), 1226–1231.

[36] Gabriele Wulf and Jiang Su. 2007. An external focus of attention enhances golf shot accuracy in beginners and experts. *Research quarterly for exercise and sport* 78, 4 (2007), 384–389.