

Article

A Closed Kinetic Chain Task Utilizing an Immersive Virtual Reality-Based Platform Acutely Improves Shoulder Joint Position Sense in Collegiate Baseball Athletes

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Abstract

High-velocity baseball pitches place demands on the shoulder, requiring precise sensorimotor control to maintain joint stability and consistent throwing mechanics. Immersive virtual reality (IVR) has emerged as a platform for sensorimotor training, offering controlled, interactive environments, although its immediate effects on shoulder joint position sense remain unknown in overhead athletes. This preliminary within-subject pilot study evaluated whether a brief IVR-based closed kinetic chain (CKC) task using the ICAROS Lightning device could acutely improve active joint position sense (AJPS) in the dominant arm of collegiate baseball players. Nine male collegiate baseball athletes completed baseline AJPS testing during shoulder internal and external rotation before a 2-min immersive flight simulation task, then repeated AJPS assessment. Absolute angular error was the primary outcome. Following the intervention, AJPS error was significantly reduced in both rotational directions. Mean internal rotation error decreased by 4.22° (95% CI: 3.02° to 5.42°; $p < 0.001$; Cohen's $d_z = 2.70$), while mean external rotation error decreased by 4.73° (95% CI: 3.10° to 6.37°; $p < 0.001$; Cohen's $d_z = 2.23$). These preliminary findings suggest IVR-based CKC exercise acutely improves shoulder joint position sense, which may have implications for restoring proprioception following throwing-induced fatigue. Further validation is warranted in randomized controlled studies with larger, heterogeneous samples in order to determine whether these findings have meaningful effects on throwing performance or recovery.

Keywords: immersive virtual reality; artificial intelligence; shoulder proprioception; active joint position sense; sensorimotor training; closed kinetic chain; overhead athletes; baseball; rehabilitation; intelligent virtual environments



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1. Introduction

The baseball pitch constitutes one of the fastest human physical movements in sport and requires substantial shoulder external rotation during the late cocking phase [1–3]. To tolerate these demands, the rotator cuff musculature must contribute to dynamic stabilization of the humeral head within the glenoid fossa during high-velocity throwing [2,3].

Pitching consistency is clinically important because higher levels of competition are associated with less kinematic variability, and less repeatable mechanics may increase inefficiency and injury risk [4–6]. These observations point to neuromuscular control as a central factor in maintaining both performance and joint stability during repetitive throwing.

Repetitive overhead throwing is also associated with characteristic adaptations in shoulder motion, including increased external rotation and reduced internal rotation in the dominant arm [7–9]. These adaptations may be physiologic in some athletes, but an excessive glenohumeral internal rotation deficit has been associated with increased risk of shoulder and elbow injury in throwers [7,10]. Facilitation of this rotation is primarily accomplished using proprioception, which refers to the ability to integrate afferent input to perceive body position and movement [11,12]. In the shoulder, proprioception includes joint position sense, kinesthesia, and force sense, all of which contribute to joint awareness and neuromuscular control [12,13]. As a clinically used measure of proprioception, active joint position sense (AJPS) evaluates an individual's ability to reproduce a target joint angle without visual input [14]. Since it isolates position sense under controlled conditions, AJPS provides a practical and quantifiable method for assessing proprioceptive function in overhead athletes [11,14].

Interactive immersive virtual reality has emerged as a potentially useful adjunct in musculoskeletal rehabilitation because it can increase engagement via gamification, provide externally directed task goals, and create a more interactive movement environment [13,15,16]. Systematic reviews in orthopedic and shoulder rehabilitation have reported promising yet heterogeneous evidence for virtual reality-based interventions, with benefits often related to engagement, feasibility, and selected functional outcomes rather than uniformly superior clinical results [13,16,17]. External attentional focus has likewise been associated with improved motor performance and neuromuscular efficiency across a broad range of tasks [18]. Immersive virtual reality may also provide a controlled, repeatable, and highly interactive training environment in which users continuously respond to task-linked visual feedback that adapts to their performance. The combination of physical demand and externally driven feedback may create conditions that are particularly favorable for enhancing sensorimotor performance.

The ICAROS Lightning flight simulation device represents one such application that integrates these elements. The ICAROS Lightning device is a novel closed kinetic chain modality in which the athlete assumes a modified prone plank position while controlling a multiaxial platform within an immersive virtual reality environment. This task requires upper-extremity weight-bearing, continuous reactive stabilization, and goal-directed movement control while receiving and responding to immediate visual feedback from the gamified environment. Because user movement directly governs navigation within the virtual environment, the device also functions as an interactive human-in-the-loop sensorimotor system rather than as a passive exercise modality. However, the immediate effects of this type of stimulus on shoulder proprioception in overhead athletes have yet to be elucidated.

Therefore, the purpose of this study was to examine the acute effect of a single ICAROS-based closed kinetic chain session on shoulder joint position sense in the dominant throwing arm of collegiate baseball players. It was hypothesized that this combined sensorimotor stimulus would improve proprioceptive accuracy, demonstrated by a reduction in error during active joint position sense testing following a single session. More broadly, this work aims to clarify whether immersive virtual reality can meaningfully influence short-term sensorimotor performance in overhead athletes.

2. Materials and Methods

2.1. Study Design

This study was designed as a preliminary, hypothesis-generating within-subject pilot investigation to evaluate the acute effects of an immersive virtual reality-based closed kinetic chain intervention using the ICAROS Lightning device (ICAROS GmbH, Planegg, Germany) on shoulder proprioception. A one-group pretest–posttest design was used to assess changes in active joint position sense (AJPS) following a brief dynamic stability intervention in collegiate baseball pitchers.

2.2. Participants

Nine male collegiate baseball players at various Southern California colleges participated in this study at a commercial Strength and Conditioning facility in the San Fernando Valley. Participants were instructed to refrain from exercise before testing on the assessment day. Participants were excluded if they reported significant medical conditions that could limit exercise capacity or affect upper extremity function, throwing-specific conditions such as pathological glenohumeral internal rotation deficit (GIRD), prior use of the ICAROS Lightning device, or a score above the 50th percentile on the Motion Sickness Susceptibility Questionnaire [19]. All exploratory participants provided written informed consent while ethical approval was obtained from the University of California, Los Angeles (UCLA) (IRB: 11-003190). Off-site participants provided written informed consent and single IRB approval (sIRB: BRANY, Melville, NY, USA). Research practices were conducted in accordance with the ethical principles documented in the Declaration of Helsinki. A sample size of $n = 8$ was calculated based on a priori power analysis using results reported from an unpublished exploratory pilot study using eight collegiate aged males of similar design in our research laboratory assuming $\alpha = 0.05$ and $\beta = 0.20$. Nine participants were ultimately enrolled and completed the study.

2.3. Instrumentation

The instrumentation used in this study included the ICAROS Lightning, smartphone inclinometry (InclinoPro, v2.3, Los Angeles, CA, USA), and a laser positioning system. The ICAROS Lightning is a biaxial platform mounted on a single fulcrum point, allowing for rotation along the roll and pitch axes. It includes padded forearm and shin rests, fixed handgrips, and foot supports (Figure 1). The athlete assumes a modified prone plank position. The Pico virtual reality headset (PICO Technology Co., Ltd., Beijing, China) maps the platform's orientation into a virtual environment such that tilting changes the direction of the virtual aircraft. Participants completed a 2-min game of flying through a set of rings on the “Easy” level, which standardized task difficulty across participants and provided an external objective. Sensors on the ICAROS platform detect changes in body positioning, weight distribution, and the speed and directionality of the user's movements. These biomechanical metrics are measured in real-time throughout each session and directly coordinate in-game flight.

Shoulder internal rotation (IR) and external rotation (ER) were measured via smartphone inclinometry, a method that has shown acceptable validity for assessing shoulder range of motion in prior work [20]. The device was aligned along the forearm to approximate the axis of rotation and was calibrated within the application prior to each measurement. To ensure shoulder positioning consistency, two lasers mounted on tripods were positioned anteriorly and laterally to the glenohumeral joint.



Figure 1. ICAROS Lightning interactive immersive virtual reality device.

2.4. Anthropometric Measurements

Each participant's demographic information and anthropometric variables were recorded. Height was measured via precision stadiometer (Seca, Hanover, MD, USA), and body composition was measured using a multi-frequency bioelectrical impedance analyzer (InBody Co., Seoul, Republic of Korea). Participants adhered to standard pre-measurement body composition guidelines [21]. Arm length was measured from the acromion to the distal elbow crease with the elbow fully extended. The dominant throwing arm was recorded.

2.5. Active Joint Position Sense (AJPS) Assessment

A one-group pretest–posttest design was used to assess the acute effect of the ICAROS Lightning device on shoulder AJPS. The AJPS test utilized in this study was based on the method described by Dover and Powers [14], which demonstrated high inter-rater and intra-rater reliability in a healthy university population. Consideration of AJPS as an outcome measure was also informed by broader reviews of shoulder proprioception methodology [11]. The primary outcome measure was absolute angular error (degrees), calculated as the absolute difference between the target position and the participant's actively reproduced position. An exploratory analysis of signed angular error was also performed to characterize the direction of reproduction error, whereby negative values indicated undershooting of the target angle and positive values indicated overshooting. The investigator administering the AJPS assessments was blinded to the study hypothesis and followed an identical standardized assessment protocol for both pre- and post-intervention assessments.

Initially, participants completed a baseline AJPS assessment. In a standing position, the dominant shoulder was aligned according to anterior and lateral laser guides to maintain consistency. Using the smartphone inclinometer, the participant was positioned in the neutral testing position (90° abduction and 90° flexion). Maximum active IR and ER were then collected.

After a 2-min interval, participants closed their eyes while the arm was passively oriented to a target corresponding to 90% of the participants' available ER or IR range. Passive rotation was presented at variable velocities to reduce time-associated cues [14]. Participants were instructed to hold the target position for 3 s, rest for 3 s, and then return to the neutral position. Participants then actively reproduced the target angle, and the

reproduced angle was recorded. This procedure was performed once for internal rotation and once for external rotation.

2.6. Intervention Protocol

Participants were then introduced to the ICAROS Lightning device. After a demonstration, they tested it for one minute, experiencing pitch and roll on command by the researcher to ensure exposure to the full range of device motion. After a 2-min interval, participants put on the VR headset, mounted the ICAROS Lightning, and completed 2 min of the “Easy” level of the ring-navigation game. Participants were instructed to actively engage with the task and control the platform to navigate through the course. The interventional duration of 2 min was intended to serve as a short session with the ICAROS Lightning platform that may serve as an equivalent to a brief warm up or recovery aid. This duration is supported based on the findings of Escamilla and colleagues, who investigated the effects of a one minute stretching and calisthenics drill (i.e., two-out drill) on glenohumeral internal, external, and total rotation deficits after throwing 40 full-effort pitches [22]. The two-out drill, which consisted of 7 stretches and exercises performed in succession, was completed in an estimated 60 s. Notably, after the completion of the two-out drill, glenohumeral internal, external, and total rotational motion levels were restored to pre-pitching values. Therefore, we estimated that a 2 min session with ICAROS would have practical value as a warm up or as a component of a recovery routine.

2.7. Post-Intervention Assessment

Participants then completed a post-test AJPS assessment. The protocol followed the baseline AJPS assessment to reproduce the 90° ER and IR target positions, excluding remeasurement of maximum active IR and ER. All sessions were monitored by researchers under the guidance of the principal investigator.

2.8. Statistical Analysis

All analyses were conducted in R version 4.5.0 (R Foundation for Statistical Computing, Vienna, Austria) using a within-subject (paired) design to evaluate pre- to post-intervention changes in active joint position sense (AJPS) absolute error for internal rotation (IR) and external rotation (ER). An exploratory analysis of signed angular error was also performed to characterize the direction of reproduction error (i.e., undershooting versus overshooting the target angle). All nine participants were included in the paired analyses. Visual inspection of individual change scores indicated consistent reductions in error magnitude for the primary outcome (absolute angular error) without extreme outliers. For the exploratory signed angular error analysis, movement toward 0° was interpreted as reduced directional reproduction error. Given the small sample size and exploratory nature of the study, paired samples *t*-tests were used to assess differences between pre- and post-intervention values. Effect sizes were calculated using Cohen’s *d* to quantify the magnitude of within-subject changes. In addition to null hypothesis testing, 95% confidence intervals (CI) were calculated for mean differences to provide an estimate of precision and to aid in interpretation of the observed effects. Statistical significance was set at $p < 0.05$. Emphasis was placed on effect sizes, confidence intervals, and consistency of individual responses in addition to *p*-values.

3. Results

All nine participants completed the study with mean age, height, and weight of 22.3 ± 1.5 yrs, 184 ± 5.1 cm, and 87.3 ± 12.7 kg, respectively. Paired analyses revealed significant reductions in absolute angular error for both internal and external rotation following the intervention. Internal rotation absolute error decreased by an average of 4.22°

($t(8) = 8.10$, $p < 0.001$), representing a very large effect (Cohen's $d_z = 2.70$), with a 95% CI of 3.02° to 5.42° . External rotation absolute error decreased by an average of 4.73° ($t(8) = 6.68$, $p < 0.001$), representing a very large effect (Cohen's $d_z = 2.23$), with a 95% CI of 3.10° to 6.37° . Mean internal rotation absolute error changed from $8.09 \pm 4.91^\circ$ pre-intervention to $3.87 \pm 4.10^\circ$ post-intervention, while mean external rotation absolute error changed from $6.29 \pm 2.18^\circ$ to $1.56 \pm 0.76^\circ$, respectively.

An exploratory analysis of signed angular error was performed to characterize directional reproduction bias. Internal rotation signed error decreased by an average of 3.33° ($t(8) = 3.16$, $p = 0.013$), representing a large effect (Cohen's $d_z = 1.05$), with a 95% CI of 0.90° to 5.76° . External rotation signed error decreased by an average of 5.11° ($t(8) = 5.96$, $p < 0.001$), representing a very large effect (Cohen's $d_z = 1.99$), with a 95% CI of 3.13° to 7.09° . Mean signed internal rotation error changed from $-6.71 \pm 6.50^\circ$ pre-intervention to $-3.38 \pm 0.74^\circ$ post-intervention, while mean signed external rotation error changed from $-5.84 \pm 2.38^\circ$ to $-0.73 \pm 1.06^\circ$, respectively. As illustrated in Figure 2, individual participant responses generally moved closer to the target angle for both internal and external rotation, with greater magnitude and reduced variability observed for external rotation.

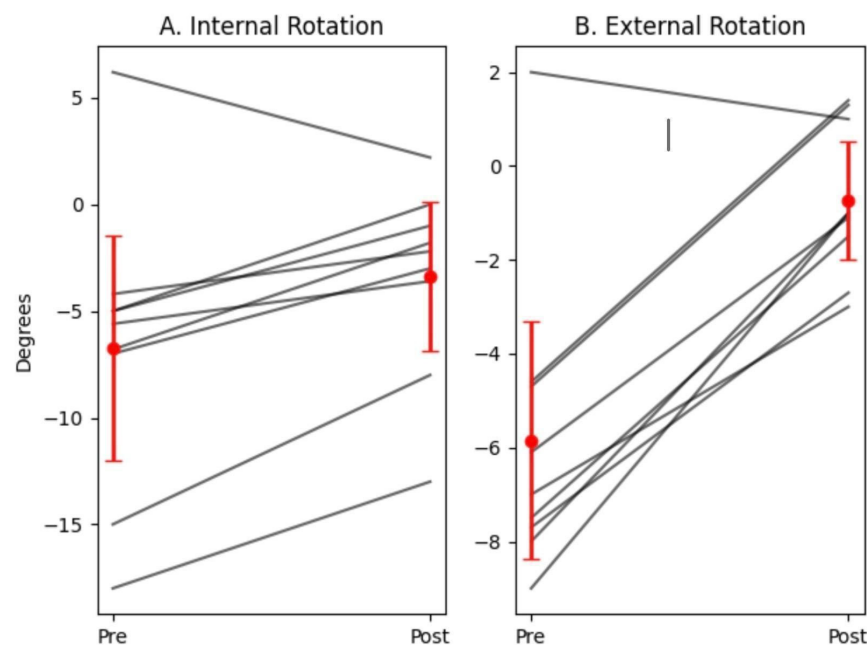


Figure 2. Individual pre- and post-intervention signed angular error values for (A) internal rotation (IR) and (B) external rotation (ER). Each line represents a single participant (grayscale). Negative values indicate undershooting of the target angle, whereas positive values indicate overshooting of the target angle. Group means are overlaid in red with 95% confidence intervals. Signed error generally shifted closer to the target angle following the intervention for both IR and ER, with greater magnitude and more uniform improvements observed during external rotation.

4. Discussion

This study investigated the effect of a novel closed kinetic chain stimulus (ICAROS Lightning) on shoulder AJPSS in the dominant throwing arm of collegiate baseball players. The primary analysis demonstrated significant reductions in absolute angular error for both internal and external rotation immediately following the intervention, indicating improved shoulder position reproduction accuracy. Absolute angular error decreased by 4.22° for internal rotation and 4.73° for external rotation, representing very large effects for both rotational directions. An exploratory analysis of signed angular error further demonstrated that reproduction errors shifted closer to the target angle for both movements, indicating

reduced directional bias following the intervention. The exploratory signed-error analysis demonstrated mean shifts of 3.33° for internal rotation and 5.11° for external rotation, with large and very large effect sizes, respectively. Collectively, these findings support the hypothesis that a single ICAROS-based session can acutely improve shoulder joint position sense while also suggesting reduced directional reproduction bias following the intervention.

These findings are consistent with prior work suggesting that CKC interventions can influence proprioception and neuromuscular control in the upper extremity [23–25]. The larger mean improvement observed in external rotation across both the primary and exploratory analyses is clinically notable, given the relevance of external rotation during the late cocking phase of pitching [1–3]. This pattern may indicate that the intervention meaningfully engaged sensorimotor processes relevant to shoulder position reproduction in a sport-specific range [26,27]. It remains to be determined whether rotational corrections of this caliber (i.e., $3\text{--}5^\circ$) have salient implications on injury risk, performance, or neuromuscular control.

The greater improvement observed in external rotation compared with internal rotation may reflect direction-specific differences in shoulder sensorimotor processing that are not yet fully understood. Prior work has identified directional variation in joint position sense among overhead athletes, but the mechanisms underlying these differences have not been elucidated [26,27]. One possible explanation is that external rotation places unique mechanical demands on capsuloligamentous structures and dynamic stabilizers during the late cocking phase of throwing, potentially heightening afferent sensitivity within this range [28,29]. Repetitive exposure to high-velocity external rotation may also produce sport-specific neural adaptations that influence the accuracy of position reproduction [30]. The present findings support the possibility that proprioceptive responsiveness differs by rotational direction and suggest that external rotation may be particularly sensitive to acute sensorimotor priming interventions [31].

Several mechanisms may contribute to these findings. Proprioception relies on afferent input from muscle spindles, Golgi tendon organs, and joint receptors, which together inform the central nervous system about joint position and movement [11,13]. CKC exercise may enhance dynamic joint stability through co-contraction and increased sensorimotor demand [18,32]. This may have facilitated short-term sensorimotor priming, thereby improving immediate angle-reproduction accuracy. A similar rationale has been proposed in the broader proprioceptive and shoulder rehabilitation literature [12,17,25]. However, these hypotheses remain speculative, as experimental investigation is needed to determine whether neuromuscular facilitation and sensorimotor integration play mechanistic roles in AJPS correction.

The movement configuration used in the present intervention also merits consideration. Although shoulder rehabilitation and sensorimotor training have traditionally emphasized open kinetic chain (OKC) exercise because overhead athletic movements are performed with the distal extremity freely moveable [33], rehabilitation of the overhead athlete has increasingly incorporated kinetic-chain principles that integrate the trunk, scapula, and upper extremity to optimize neuromuscular control and dynamic shoulder function [34,35]. Consistent with these principles, the present intervention employed a CKC task characterized by upper-extremity weight-bearing, continuous reactive stabilization, and coordinated multijoint control. Matched CKC exercises have been shown to elicit greater activation of several shoulder and trunk stabilizers than comparable OKC exercises [36], further supporting the use of CKC as a complementary sensorimotor training approach within upper-extremity rehabilitation [35]. At the same time, CKC configurations may be less representative of the motor demands associated with overhead throwing and

certain shoulder injury mechanisms than task-specific OKC assessments [37,38]. Consequently, the present findings should be interpreted within the context of a CKC-based immersive virtual reality intervention. Future studies directly comparing CKC and OKC interventions of similar intensity will help determine whether improvements in shoulder joint position sense are configuration-specific or reflect broader sensorimotor adaptations.

The present findings have practical implications for athletic preparation and support further investigation into immersive virtual reality systems. A brief IVR-based CKC task may represent a time-efficient strategy to acutely enhance shoulder position sense prior to throwing activity. Because proprioceptive acuity contributes to joint awareness and coordinated movement, interventions that improve AJPS may be useful within broader shoulder preparation programs for overhead athletes [11,14,39]. Interest has grown in regard to VR-based rehabilitation and performance-support environments that combine task engagement with repeated motor exposure [15–17]. Furthermore, as artificial intelligence and adaptive virtual environments have introduced novel frameworks for providing real-time feedback, sensorimotor measures such as active joint position sense could be leveraged as objective performance metrics to optimize physical training. The ICAROS platform collects biomechanical metrics during use of the device that directly affects in-game activity. Although it is important to note that there is a system AI assistant introduced with a newer software version (i.e., Version 2.60), there was no direct usage of this data by the AI assistant to our knowledge. The results of the present study should therefore not be interpreted under the assumption that there was a causal link between AJPS correction and the AI assistant. The AI-related functionalities are a feature of the ICAROS platform but were not the experimental variable investigated in this study. Notwithstanding, future research should utilize the existence of this system's AI assistant to directly and dynamically adjust in-game tasks or difficulty using real-time feedback based on the accessible biomechanical information collected by the ICAROS platform. The measure of AJPS represents a quantifiable sensorimotor outcome that could be incorporated into future adaptive and intelligent virtual reality systems capable of modifying task difficulty, feedback, or training progression based on individual performance.

Several limitations should be acknowledged. First, the participant pool was modest and limited to healthy male collegiate baseball players, which may limit generalizability to other populations. Variability inherent to such a small sample warrants cautious interpretation of these results. Second, the study examined only the acute response to a single session. Third, the outcome measure was AJPS and did not include direct assessment of pitching mechanics, performance, or injury-related outcomes. Fourth, the one-group pretest–posttest design without a comparator condition does not allow for separation of the observed changes from potential repeated-testing effects, general movement preparation, the closed kinetic chain task itself, or the immersive virtual reality component. Although participants completed only a single baseline assessment and one post-intervention assessment within the same session, these potential confounding influences cannot be excluded. Additionally, AJPS was assessed using a single trial per condition to minimize fatigue and testing time; however, this approach may reduce measurement reliability compared to multi-trial averaging and increase the influence of trial-to-trial variability or individual observations on the estimated effect sizes, particularly in a modest sample. Future research should evaluate whether repeated exposure to this intervention produces persistent effects, incorporate appropriate comparator conditions to isolate the independent contribution of immersive virtual reality, utilize multiple AJPS trials with averaged values to improve measurement reliability, prospectively evaluate directional reproduction bias using pre-specified analyses of signed angular error, and determine whether observed changes in AJPS are associated with meaningful sport-specific outcomes and injury prevention. Ad-

ditional outcome measures, such as throwing performance, neuromuscular control, and surface electromyography, should be facilitated in further research. Collectively, these efforts will help determine whether a single ICAROS-based session can acutely improve shoulder joint position sense while further clarifying the contribution of directional reproduction bias to these sensorimotor adaptations.

5. Conclusions

The present study provides initial evidence that a brief immersive virtual reality closed kinetic chain task using the ICAROS Lightning was associated with reduced shoulder joint position sense (AJPS) absolute angular error on immediate post-testing in collegiate baseball players. These reductions were accompanied by very large within-subject effect sizes, suggesting a meaningful acute improvement in shoulder position reproduction accuracy based on a modest sample size. An exploratory analysis of signed angular error further suggested reduced directional reproduction bias following the intervention. Collectively, these findings support continued investigation of IVR-integrated closed kinetic chain exercise as a potential sensorimotor priming modality in overhead athletes and establish a foundation for evaluating sensorimotor outcome measures within future adaptive and intelligent virtual rehabilitation systems. Further research is warranted to determine whether these acute improvements in AJPS translate to meaningful changes in pitching mechanics, performance, injury-related outcomes, rehabilitation applications, and personalized virtual training environments.

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Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy considerations and institutional research policies.

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Abbreviations

The following abbreviations are used in this manuscript:

IVR	Immersive virtual reality
AJPS	Active joint position sense
MER	Maximum external rotation
OKC	Open kinetic chain

CKC	Closed kinetic chain
GIRD	Glenohumeral internal rotation deficit
IR	Internal rotation
ER	External rotation
BIA	Bioelectrical impedance analyzer
CI	Confidence interval
AI	Artificial intelligence
UCLA	University of California, Los Angeles
VR	Virtual reality

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