Research Report

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Association between Head Motion Measured by Wearable Earbuds during Indoor Cycling and Lower Back and Lower Limb Pain in Soccer Players

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Background Indoor cycling exercise is commonly utilized for warm-ups and rehabilitation among soccer players. Individuals with lower back pain exhibit increased trunk motions, such as flexion, lateral leaning, and rotation, while cycling, which can elevate spinal loading. Trunk motion can be estimated using the head motion data measured by wireless earbud sensor.

Purpose The purpose of this study was to compare the range of three-dimensional head motions in soccer players with and without lower back and lower limb (LB & LL) pain, and to assess the correlation between pain intensity and head motion during indoor cycling.

Study design Cross-sectional study

Methods Thirty-one high school soccer players took part in the study, with 16 experiencing LB & LL pain, and 15 without such pain. Pain intensity after the soccer game was evaluated using a visual analogue scale. Wireless earbud sensor was used to measure maximal range of head motion in three-dimensional planes during indoor cycling. The Mann-Whitney U test was utilized to compare head motions between groups. In addition, Spearman correlation coefficients were employed to assess the relationship between pain intensity and head motion.

Results Pain group significantly showed greater range of head motions than the non-pain group in sagittal, frontal and transverse planes ($p<0.05$). Pain intensity was significantly correlated with head motions in each sagittal, frontal and transverse plane ($\rho=0.75$, 0.56 and 0.46, respectively).

Conclusions We found significant differences in the range of 3D head angles during cycling between soccer players with and without pain, as well as a correlation between pain intensity and 3D head angles. These findings highlight the applicability of head angle data, acquired via wireless earbuds, during warm-up cycling for soccer players experiencing LB & LL pain.

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INTRODUCTION

In soccer players, lower back and lower extremity (LB & LL) injuries are prevalent, with back pain affecting approximately 64% of players annually and lower limb injury rates during competitions ranging from 18% to 80%.[1] A previous study has shown a significant correlation between lower back and lower extremity pain among youth soccer athletes.[2] Trunk stability is crucial for soccer players to prevent the LB & LL pain and maintain sufficient dynamic control of their lower limbs during soccer games and to safeguard the lower extremity position against unexpected forces.[3,4] Rehabilitation programs for youth soccer players have emphasized trunk stability and strength focused on the core muscles.[5] In terms of trunk stability, greater lateral trunk displacement in response to sudden trunk force release in an experimental setting is linked to an increased risk of lower extremity injury in athletes with reduced neuromuscular control of the body's core.[6]

Trunk motion and stability can be measured using wearable sensors, providing a non-invasive and practical method to monitor movement patterns and potential implications for pain and injury.[7] Inertial measurement unit (IMU) wearable sensors were attached to one or more of the following regions to measure trunk motion and balance during dynamic sports activities: the head, L1, T12, L5/S1, sacrum, and pelvis.[8,9] However, IMU wearable sensors attached to the torso have not been widely adopted in real environment when comparing smartwatches or wireless earbuds. To measure trunk movements using commercial wearable sensors, a head-worn earbud is more effective than a wrist-worn smartwatch, which suffers from wrist movements and motion noise.[10] Recently, wireless earbud-type IMU sensor was used for assessing the trunk stability during home fitness activities, because earbud was commonly used for listening the music during treadmill walking and indoor cycling.[11] Wireless earbud sensor can estimate the trunk motion and be used to compare trunk stability during home-fitness activities, as the head and trunk are biomechanically linked.[11,12] A previous result confirmed that the head angle measured by the earbud-IMU sensor had a fair correlation with trunk motion measured by 3D motion analysis during home fitness activities.[11]

The earbud-type IMU sensor can compare the angle of trunk motion between groups with good and poor trunk stability, as well as classify groups with and without LB & LL pain during indoor home fitness activities. Specifically, when assessing the trunk motion using wireless earbuds during treadmill walking, the poor trunk stability group had significantly greater lateral oscillation of the center of mass than the good trunk stability group.[13] The individuals with and without LB & LL pain could be discriminated using mediolateral head motion data measured by wireless earbud sensor during single leg standing and fast walking in treadmill. During indoor cycling, the poor trunk stability group also exhibited significantly more asymmetrical mediolateral head motion compared to the good trunk stability group.[12]

Although indoor cycling is widely used among soccer players for both warm-up routines and rehabilitation, there has been no study to compare the estimated trunk motions using wireless earbud sensor between soccer players with and without LB & LL while indoor cycling. If soccer players can assess their trunk instability during the warm-up period while performing indoor cycling with wireless earbuds, they can engage in additional trunk stability training and better manage LB & LL pain. The purpose of the present study using wireless earbuds is to (1) compare the differences in the range of 3D head motion during cycling between soccer players with and without LB & LL pain, and (2) investigate the association between the intensity of LB & LL pain and the range of head motion across three-dimensional planes during indoor cycling in soccer players. We hypothesized that there would be a significant difference in the range of 3D head motion during indoor cycling between soccer players with and without LB & LL pain, and a significant association between pain intensity and the range of 3D head motion.

METHODS

Participants

A total of thirty-one high school male soccer players, with an average age of 17.77±0.88 years, participated in this study. The mean height was 175.42±5.53 cm, and the mean weight was 67.58±6.58 kg. All participants were members of an elite high school soccer team registered with the National Football Association. On average, participants engaged in 135.71±40.40 minutes of soccer exercise daily. They were divided into two groups based on their reported pain levels after soccer games: a pain group (comprising 16 players with visual analogue scale (VAS) scores for LB & LL pain ≥3 cm) and a non-pain group (consisting of 15 players with scores <3 cm) (Table 1).[14] The results for the highest pain region and intensity are as follows: the highest VAS scores were reported in the ankle and foot by 7 participants, followed by the lower back in 6 participants, and the knee in 3 participants. The exclusion criteria for both groups included severe LB & LL pain that hindered indoor cycling, chronic pain excluding LB & LL pain, acute musculoskeletal pain, and disorders related to the neurological, cardiopulmonary, vestibular, or psychological systems. All participants or their guardians provided consent to participate in this study and were informed about the procedures. This study received approval from the University Institutional Review Board.

Instrumentation

1) Wireless Earbud-Type IMU Sensor

3D head motion during indoor cycling was captured using a high-resolution inertial measurement unit (IMU; BNO080; CEVA Technologies, Rockville, USA) housed within a wireless earbud (QCY-T6; Dongguan Hele Electronics Co., Ltd., Dongguan, China), which included a triaxial accelerometer and triaxial gyroscope. The moderate-

Table 1. Participant characteristics

Variables	Pain group (N=16)	Non-pain group (N=15)	*p*
Age (years)	17.50±0.89	18.06±0.80	0.09
Height (cm)	176.25±6.60	174.53±4.15	0.38
Weight (kg)	68.25±6.88	66.87±6.42	0.60
Exercise duration (min per a day)	136.88±38.07	134.17±45.02	0.67
Pain intensity after soccer game (cm)*	6.13±1.50	0.40±0.83	<0.01

Data are expressed as mean±standard deviation.
* 10 cm visual analogue scale scores.

to-very-strong validity of the IMU sensor has been demonstrated through comparison with a 3D motion analysis system during workout activities.[11] The IMU data were gathered at 100 Hz and the acceleration outputs were transmitted via Bluetooth to a self-developed mobile app (DDoARi, Republic of Korea). This app provided real-time calculations for the 3D head angle. Prior to the calculation, the accelerometer output underwent filtration using a low-pass filter at 5 Hz. A one-second automatic off calibration was conducted prior to the measurement to standardize the different initial static head and torso postures for each participant. During this calibration period, 100 data samples were collected while the participant remained stationary on the indoor cycle, grasping the cycle's handle.

Procedure

The experiment took place at the training gym where soccer players were practicing. The experimental procedure consisted of two sessions that included the following:

1) Measurement of pain intensity after soccer game

Pain intensity measurements were conducted at the end of the competitive season. Before measuring the range of 3D head motion, examiner A, who was blinded to the other examiner, administered a self-reported questionnaire addressing LB & LL pain intensity after soccer game using 10 cm VAS scores, anthropometric characteristics and exercise duration (Table 1). Participants were asked to rate their maximum pain using a VAS scale among specific areas: (1) low back, (2) hips, (3) knees, and (4) ankle-foot regions. A drawing was used to identify these anatomical areas.[15]

2) Measurement of 3D head angle during cycling

The wireless earbud was worn. The IMU sensor is built into the left wireless earphone. The IMU sensor within the wireless earbud recorded the 3D head motion during indoor cycling. Each participant adjusted the cycle seat height to their preferred comfort. Participants held the front handlebars with both hands and fixed their gazes on the cycle's dashboard (Figure 1). Before data collection, the participants were allowed 1 min to become familiar with the self-selected speed. To ride the cycle at a self-selected speed, the participants were instructed, "Ride the cycle at your most comfortable pace for warm-up". Examiner B requested the participants to focus only on the cycle's dashboard in front while riding the cycle. If the gaze shifted away from the cycle dashboard to look at another area, it was considered a failure, prompting a rerun of the experiment. While the participants cycled 1 min at a self-selected speed on the indoor cycle, 3D head motion data was recorded via mobile app by examiner B, who was blinded to the examiner A.

Statistical analysis

Data analysis was also performed by an individual who was blind to the examiners. The highest VAS score among the low back, hips, knees, and ankle-foot regions was used for analysis. The head angle data analysis utilized the mid-

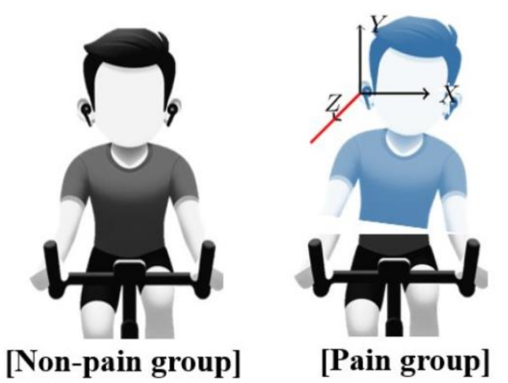

Figure 1. Measurement of 3D head motion using wireless earbuds during indoor cycling in soccer players with and without lower back and lower limb pain.

dle 40 seconds of the 1-minute cycling session. The maximum head angle in each of the sagittal, frontal and transverse planes during cycling was calculated for analysis. The normality of the data was assessed using the Shapiro-Wilk test, which indicated that all variables were not normally distributed. Head angles were compared using the Mann-Whitney U test between pain and non-pain group in each 3D plane. Spearman correlation coefficients were used to assess the relationship between pain intensity and the head angle in each of the three-dimensional planes. The interpretation of correlation coefficients followed Swinscow's classification: 0.00–0.39 indicated a very weak to weak correlation, 0.40–0.59 a fair to moderate correlation, 0.60–0.79 a good correlation, and 0.80–1.0 a strong correlation.[16] A post-hoc power analysis was conducted. All statistical analyses were conducted using Google Colab. The significance threshold was set at $p<0.05$.

RESULTS

Comparison of 3D head angle during cycling between groups

The data for 3D head angles are compared between the LB & LL pain and non-pain group in Table 2. Maximal head angles in all 3D planes during cycling were greater in the LB & LL pain group compared to the control group ($p<0.05$).

Correlation between pain intensity and head angle during cycling

The correlations between LB & LL pain intensity and maximal head angle during cycling ranged from 0.46 to 0.75 (Figure 2). A significant good correlation was present between LB & LL pain intensity and sagittal head angle ($\rho=0.75$, $p<0.01$). And there was a significantly fair to moderate correlation between LB & LL pain intensity and frontal head angle ($\rho=0.56$, $p<0.01$). Also, the correlation level was fair to moderate between pain intensity and transverse head angle ($\rho=0.46$, $p<0.01$).

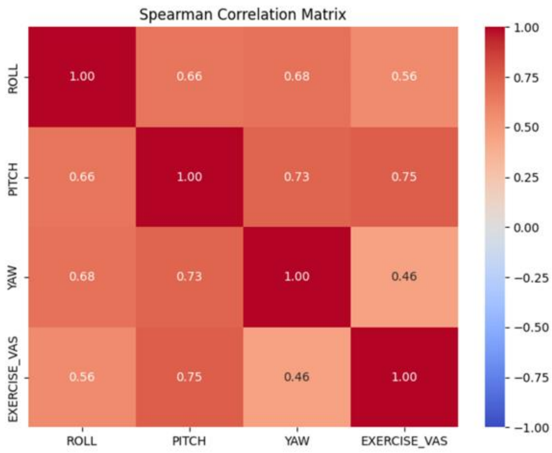

Figure 2. Correlation between head motion during cycling and pain intensity.
* Roll corresponds to lateral flexion around the x-axis, pitch corresponds to flexion and extension around the y-axis, and yaw corresponds to rotation around the z-axis. Exercise_VAS refers to the pain intensity evaluated after the soccer game using a 10-cm visual analogue scale.

Post-hoc power analysis

When comparing the 3D head angles during cycling between groups, our study achieved a power (1-β) of 0.96 in the sagittal plane, 0.90 in the frontal plane, and 0.67 in the transverse plane, with observed effect sizes of 1.39, 1.20, and 0.90, respectively. For the correlation analysis between pain intensity and head angle during cycling, we found that our study achieved a power (1-β) of 1.00 in the sagittal plane, 0.95 in the frontal plane, and 0.80 in the transverse plane, with corresponding effect sizes of 2.27, 1.35, and 1.04. These results indicate strong statistical power in detecting differences and relationships in our sample, supporting the robustness of our findings.

DISCUSSION

The current study found that soccer players in the pain

Table 2. Comparison of maximal head angle during cycling

Maximal head angle	Pain group (N=16)	Non-pain group (N=15)	*p*
Sagittal plane (Pitch)	16.25±9.80	6.08±3.37	<0.01*
Frontal plane (Roll)	8.26±5.44	3.41±1.76	<0.01*
Transverse plane (Yaw)	9.06±5.79	4.87±3.19	0.04*

Data are expressed as mean±standard deviation.
* $p<0.05$.

group demonstrated greater maximal head angles in all three dimensions during indoor cycling compared to those without pain, with significant positive correlations identified between pain intensity and head motion. These findings demonstrate the feasibility of using earbud-type wearable sensors to indirectly assess trunk motion during warm-up cycling in relation to pain intensity. In digital healthcare settings, application-based data for self-analysis and self-management is essential for creating personalized exercise programs.[17] The wireless earbud wearable sensor enables soccer players with LB & LL pain to independently identify compensatory trunk motion and trunk instability during the warm-up cycling period before training sessions. By providing a practical method for monitoring trunk motion in real-time, wireless earbud-type IMU sensors allow soccer players experiencing LB & LL pain to independently tailor their rehabilitation programs.

The results revealed that maximal head angles in all three dimensions during cycling were significantly greater in the LB & LL pain group compared to the non-pain group (Table 2), suggesting that soccer players experiencing pain may demonstrate compensatory movement patterns while cycling. Similarly, previous research has shown that cyclists with non-specific chronic back pain exhibit greater compensatory lumbar flexion, or a combination of lumbar rotation and flexion, during cycling.[18,19] Additionally, thoracic lateral flexion and pelvic lateral tilt during cycling have also been identified as contributors to chronic back pain.[19] These findings suggest that back pain is associated with altered motor control, including compensatory lumbar and thoracic movements. Therefore, training to regain control over the trunk during cycling could be crucial for the rehabilitation and prevention of back pain in cyclists.[18,19] In line with this, for soccer players with LB & LL pain, if excessive head motions across the three planes are observed during warm-up cycling, rehabilitation programs should focus on minimizing these compensatory trunk movements, which can be indirectly measured using wireless earbuds during warm-up cycling. Compensatory movements during cycling may also extend to soccer-related activities like running and sprinting, as flexion and extension of the hip and knee involved in cycling are similar to those used in the game. As a result, athletic trainers can design LB & LL pain management programs that prioritize minimizing trunk compensations during soccer performance.

The significant correlations found between LB & LL pain intensity and maximal head angles during cycling, particularly the strong correlation with sagittal head motion (ρ=0.75, p<0.01), suggest a clear relationship between pain levels and compensatory trunk motion. In line with this finding, a previous literature review showed people with lower back pain had greater amounts and longer durations of lumbar flexion while cycling than healthy individuals.[20] The fair to moderate correlations in the frontal (ρ=0.56, p<0.01) and transverse planes (ρ=0.46, p<0.01) further indicate that pain affects not only forward and backward trunk motion but also lateral stability and rotational control. Likewise, a previous study demonstrated that greater asymmetry in frontal head motion during indoor cycling, as measured by wireless earbuds, was associated with poorer trunk muscle endurance.[21] These results emphasize the importance of addressing trunk stability measured by wireless earbud in soccer players experiencing LB and LL pain, as reducing compensatory trunk motions during cycling may help mitigate trunk instability and pain. Future rehabilitation protocols should incorporate exercises specifically targeting trunk stability, such as dynamic trunk stability training and motor control training, to reduce pain-related movement and improve functional capacity. These interventions could play a pivotal role in the recognition and recovery of altered motor control of the trunk during cycling, and in helping with pain management.

Despite the valuable insights provided by the current study, several limitations should be noted. First, neck pain should be considered as one of the exclusion criteria when recruiting participants, although all participants in this study had no neck pain. Since neck instability is a common characteristic in individuals with chronic neck pain,[22] further studies are needed to investigate the relationship between head motion during cycling and neck pain. Second, this study relied solely on estimated trunk motion through head motion, highlighting the importance of trunk stability and pain during cycling for soccer players. However, trunk stability can be influenced by various factors such as balance, proprioception, and neuromuscular coordination. Future regression research should explore which trunk stability-related factors, including head motion, influence the pain in soccer players. Finally, the cross-sectional nature of this study precludes establishing a cause-and-effect relationship between trunk compensatory movements and pain. Longitudinal studies are needed to determine whether reducing compensatory trunk motion through visual and auditory feedback via wireless earbuds can effectively mitigate pain and improve soccer performance over time.

CONCLUSIONS

This study demonstrates significant differences in 3D head angles during indoor cycling between soccer players with LB & LL pain and those without pain. The findings highlight the feasibility of using earbud-type wearable sensors to assess compensatory trunk motion related to pain intensity. Notably, significant positive correlations, ranging from good or fair to moderate level, were identified between pain intensity and 3D head angles, underscoring the relationship between pain levels and compensatory trunk motion. These insights indicate a need for tailored rehabilitation programs for soccer players with pain, aimed at improving trunk stability through intuitive wearable technology, such as wireless earbud. Overall, this study paves the way for integrating digital healthcare technologies in sports rehabilitation through user-centered design, eliminating the need for soccer players to perform specific movement tests to confirm their trunk stability, as indoor cycling is a common warm-up activity they engage in before matches or training sessions.

Key Points

Question Is there a difference in head motion during indoor cycling between soccer players with lower back or lower limb (LB & LL) pain compared to those without pain?
Is there an association between head motion during indoor cycling and pain intensity after the soccer game?

Findings Soccer players with LB & LL pain significantly showed greater range of head motions in 3D planes than players without LB & LL pain. Pain intensity was positively associated with head motion in 3D planes during cycling.

Meaning Head motion data obtained from wireless earbuds during cycling could be useful for managing soccer players with LB & LL pain, as indoor cycling is a common warm-up activity performed before matches or training sessions.

Article information

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Author contributions

Conceptualization: KN Park.
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Data analysis: SH Kim.
Project administration: KN Park.
Interpretation of data: SH Kim.
Writing – original draft: KN Park.
Writing–review&editing: SH Kim, KN Park.

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