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ORIGINAL

Kinematic Analysis of Back Somersault Pike According to Skill Level in Platform Diving

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Objective: The purpose of this study was to investigate kinematic differences in back pike somersault in platform diving according to skill level and to apply the findings to improve performance.

Method: Korean divers participating in this study were divided into a skilled group (age: 21.6±4.16 y, height: 1.68±0.03 m, weight: 62.0±3.94 kg, career: 12.6±5.13 y) and a less-skilled group (age: 20.6±2.7 y, height: 1.72±0.05 m, weight: 64.8±6.76 kg, career: 12.2±2.49 y) and an independent t-test was performed to analyze differences between groups at the moment of takeoff.

Results: The two groups showed significant differences in displacement and velocity of center of mass (COM), takeoff angle, hip joint angle, knee joint angular velocity, and hip joint angular velocity at the takeoff (p<.05), and significant differences in displacement of COM, hip joint, and ankle joint during flight (p<.05).

Conclusion: For a successful back pike, the COM should rise quickly in the vertical direction and the hip joint angle and angular velocity should increase. To improve performance, the back pike turn should be practiced on the ground before an attempt on a 10-m platform, to stretch the ankle and knee joints and enable quick flexion of the hip joint when turning in flight.

Keywords: Platform diving, Back pike, Somersault, Kinematics

INTRODUCTION

Like swimming, diving has a long history. Diving initially came from an over-water training of gymnasts to help safely perform a somersault and it has developed into a sport over the time. A diving competition consists of two main events-platform and springboard-and competitive athletes use highly-advanced skills in the three elements of a dive: takeoff, flight, and entry.

Although diving in Korea had fallen short of international standards, it has advanced significantly since the early 2000s, with the introduction of dives with a high degree of difficulty (DD) and systematic training methods. To accomplish this, a world-class training facility was built and a Chinese coach was recruited (Korea Institute of Sport Science [KISS], 2010). With improved facilities and technical advances, Korean diving performance has seen remarkable improvements, with one bronze medal in the 2010 Asian Games in Guangzhou, one silver and four bronze medals in the 2014 Asian Games in Incheon, and one gold, one silver, and two bronze medals in the 29th Universiade in Taipei.

Unlike springboard diving, which utilizes the elasticity of the board, platform diving is performed on firm ground. Platform diving techniques are divided into six groups depending on the set position and direction of the somersault. Group 1, forward, is a technique in which the diver faces the water and uses a forward approach and hurdle, while group 2, back, is a technique in which the diver stands with the back to the water and executes a backward press and takeoff. Group 3, reverse, is a technique in which the diver uses a forward approach and hurdle but rotates backwards, and group 4, inward, is a technique in which the diver executes a backward press and takeoff but rotates toward the diving board. Group 5, twist, involves twisting around a vertical axis, and group 6, arm stand, begins in a handstand position. Based on these six groups, diving position is further classified into four types (straight, pike, tuck, and free) depending on the somersault position during flight. In the straight position, the diver maintains the trunk and lower extremities straight without bending. In the pike position, the diver bends at the waist with the legs extended straight and hips flexed. In the tuck position, the diver bends the hips and knees and pulls them as close to the body as possible. The free position is a combination of the straight, tuck, and pike positions.

In a diving competition, each athlete must perform all six groups, with one of four positions chosen for each group. The DD is determined by the combination of groups and somersaults. The perfection of an athlete's takeoff, flight, and entry postures are scored according to the DD (KISS, 2010; Federation International de Natation [FINA], 2015); in order to obtain a high score, the athlete must perform the takeoff, flight,

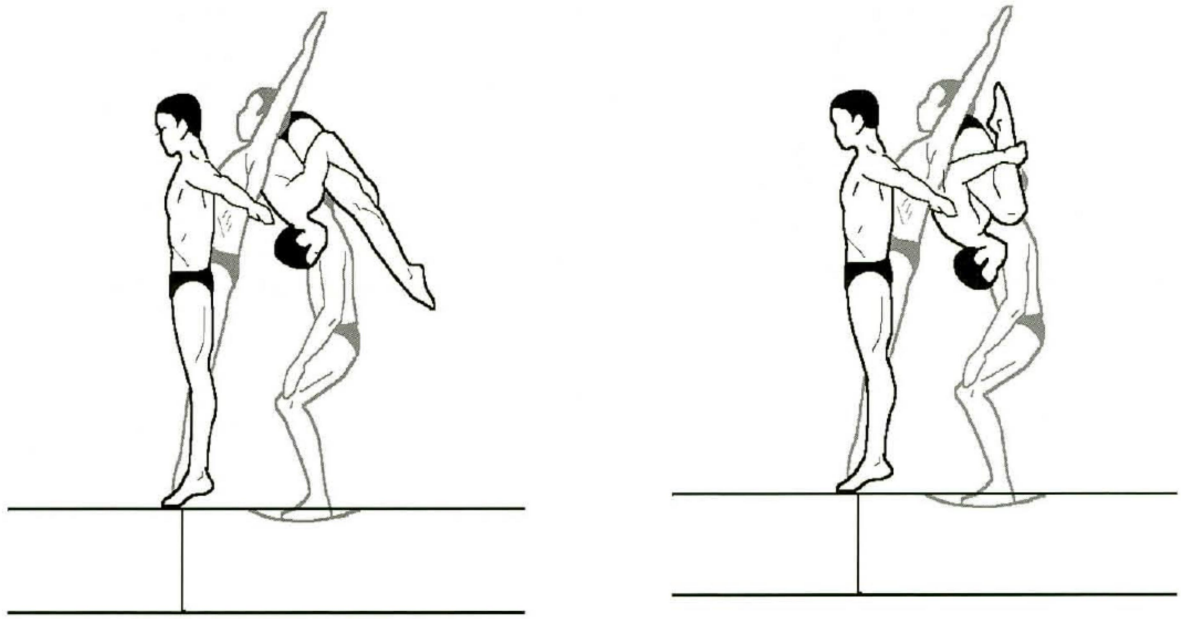

Figure 1. Back pike (left) and back tuck (right) position (KISS, 2010).

and entry routines without a mistake (Lee, 2006).

In a platform competition, most elite athletes choose a 3½ somersault pike or tuck, which have a high DD, for the back group. The back 3½ somersault pike has the highest degree of difficulty-thereby the possibility for a high score-among back positions that can be performed on a platform. An athlete who performs the back 3½ somersault pike can earn up to 9 points more than one who performs the back 3½ somersault tuck (Figure 1). This score gap has a major impact on the outcome of the competition, as it can change the performance rankings. However, the pike position requires faster somersaults velocity and greater flexibility than the tuck position, which demands sufficient takeoff height and technical competence. Athletes without such qualities reportedly have difficulty executing the pike position (Jeon, 2013; Lee, 2008).

Lee (2008) and Miller et al. (1989) argued that a successful back pike dive on the platform requires sufficient angular velocity toward the direction of the somersault, i.e., to the posterior, during takeoff, and that fast body rotation can be achieved by holding the trunk and lower limbs close and bending the hip while extending the lower limbs. Hamill et al. (1986) investigated the differences in angular momentum in relation to the number of somersaults in the pike position and reported that angular momentum increases with the number of somersaults. Further, Miller et al. (1990) stated that during a back takeoff on a 10-m platform, the vertical velocity of the center of body mass decreases as the number of somersaults increase, and that the back pike requires a greater horizontal distance than the back tuck. Lee (2008) analyzed the back 2½ somersault pike on a 5-m platform from the point of the takeoff to the preparation for entry and reported that athletes must straighten out the upper body as much as possible for effective somersaulting.

However, these studies involved subjects with low skill levels, who cannot perform the back 3½ somersault pike, which is a popular dive performed by platform divers in international meets. Moreover, these studies have not performed a kinematic analysis of the lower limb joints to describe the takeoff in the back-pike position. Furthermore, these studies have not taken differences associated with varying athletic performance into consideration, thereby hindering the application of the findings to training programs designed to improve performance of low tier athletes.

In the takeoff phase in a platform dive, the athlete acquires sufficient height and rotation velocity to perform high-level techniques. Previous studies have reported that athletes perform a smooth somersault by securing the time needed to perform their techniques in this phase (Lee, 2006; Lee, 2008; Kang & Nam, 2010; Hue & Nam, 2012). Therefore, many studies have reported that takeoff is a highly-important phase that directly influences performance in platform diving (McCormick, Subbaiah, & Arnold, 1982; Koschorreck, & Mombaur, 2009, 2012). Successful takeoff requires divers to lower their center of mass by bending the knees and hips when preparing for the jump, then quickly extend the ankles, knees, and hips at the subsequent takeoff (An & Jang, 2001; Kwon, 2011; Lee, 2008; Hamill, Richard, & Golden, 1986; Miller, Jones, Pizzimenti, Hennig, & Nelson, 1989, 1990). In addition, a perfect first rotation following a successful takeoff is an important component that ensures a successful back 3½ somersault pike.

Therefore, for a successful performance based on a perfect takeoff, divers must enhance their skills through repeated practice on an actual platform (Pyun, 2010), but technical training on a platform is practically difficult for Korean athletes due to temporal and spatial limitations as well as substantial physical burdens imposed on the athletes. As a result, Korean athletes at the national team level mostly undergo ground training using a training mat, and ground training accounts for 60% of the entire diving training program. Ground training resembles actual diving, while also enabling immediate feedback and repetitive training,

and is reportedly important for mastering difficult skills and performing dives safely (KISS, 2010). Back pike training-one of the most popular ground training programs-consists of one somersault on the ground and landing on the feet. Athletes strive to refine performance on an actual platform based on the feedback they receive during ground training.

Platform diving is a classic sport that involves movement against gravity. Competitive platform diving comprises two events at 5 m and 10 m, and movement from platform takeoff to flight entry (one somersault after takeoff) is known to be a determinant of dive performance (KISS, 2010, Miller, Jones, Pizzimenti, Hennig, & Nelson, 1989, 1990). By the same token, the back-pike somersault on the ground is an important move that may determine the success of a platform dive.

In this context, this study aims to compare and analyze the back-pike somersault during ground training according to skill level in Korean athletes, ultimately to contribute to improvement of performance of low-tier athletes.

METHODS

1. Participants

Ten currently active male divers with at least seven years of experience were enrolled in this study. The participants were divided into two groups. The skilled group (age: 21.6±4.16 y, height: 1.68.8±0.03 m, weight: 62.0±3.94 kg, career: 12.6±5.13 y) comprised five athletes who have been members of the national team and who are capable of successfully performing a back pike with DD of 3.2 or higher. The less-skilled group (age: 20.6±2.7 y, height: 1.72±0.05 m, weight: 64.8±6.76 kg, career: 12.2±2.49 y) comprised five athletes who have been national team candidates and who can attempt but have difficulty successfully performing a back pike with DD of 3.2 or higher. After providing adequate information about the procedure and purpose of this study, informed consent was obtained from all participants prior to the experiment.

2. Measurements

To analyze the back-pike somersault in relation to skill level, seven infrared cameras (Oqus 300, Qualisys, Sweden) were used at a sampling rate of 200 Hz.

Prior to the experiment, all participants underwent adequate warm-up and wore swim suits. Then, 67 reflective markers were placed on the participants to model 13 segments (e.g., head, trunk, pelvis, and left and right upper and lower limbs) (Figure 2). After the reflective markers were placed, the participants performed 15 trials of the back-pike somersault in an environment equivalent to that of ground training. All participants had one-minute breaks between trials to reduce fatigue. Data from 10 stable trials were used for the analysis.

3. Data processing

Raw data from the reflective markers were collected using Qualisys Track Manager (Qualisys, Sweden). Two-dimensional data collected from seven infrared cameras were converted to three-dimensional coordinate values via the nonlinear transformation (NLT) technique. Visual 3D (C-motion, USA) was used to compute the variables used for this study, and data were processed with a 2nd Butterworth low-pass filter at a cutoff frequency of 10 Hz to reduce random errors during the experiment (Kwon, 2011). Variables for analysis were displacement of center of mass (COM) and velocity of COM at takeoff. With reference to the global coordinate system, the anterior direction was defined as negative and the posterior direction was defined as positive. Further, the projection angle of the COM with reference to the toe was defined as the takeoff angle. Left lower limb joint angle and angular velocity were calculated. Joint angles were defined as follows. The joint formed by the trunk and femur was defined as the hip joint, the joint formed by the femur and calf was defined as the knee joint, and, the joint formed by the calf and foot was defined as the ankle joint. Flexion of the knee and hip joints and dorsiflexion of the ankle joint were defined as positive values, while extension of the knee and hip joints and plantarflexion of the ankle joint were defined as negative values. The back somersault pike motion was divided into four events for an effective analysis (Figure 3).

Figure 2. Marker attachment points

4. Statistical analysis

The differences in the displacement and velocity of the COM, lower limb joint angle, and angular velocity during the back-pike somersault according to skill level were verified using the independent *t*-test. Statistical significance was set at α=.05.

RESULTS

1. Displacement of the center of mass

Vertical displacement of the COM was significantly greater at E4 in the skilled group compared to the less-skilled group (p<.05, Figure 4).

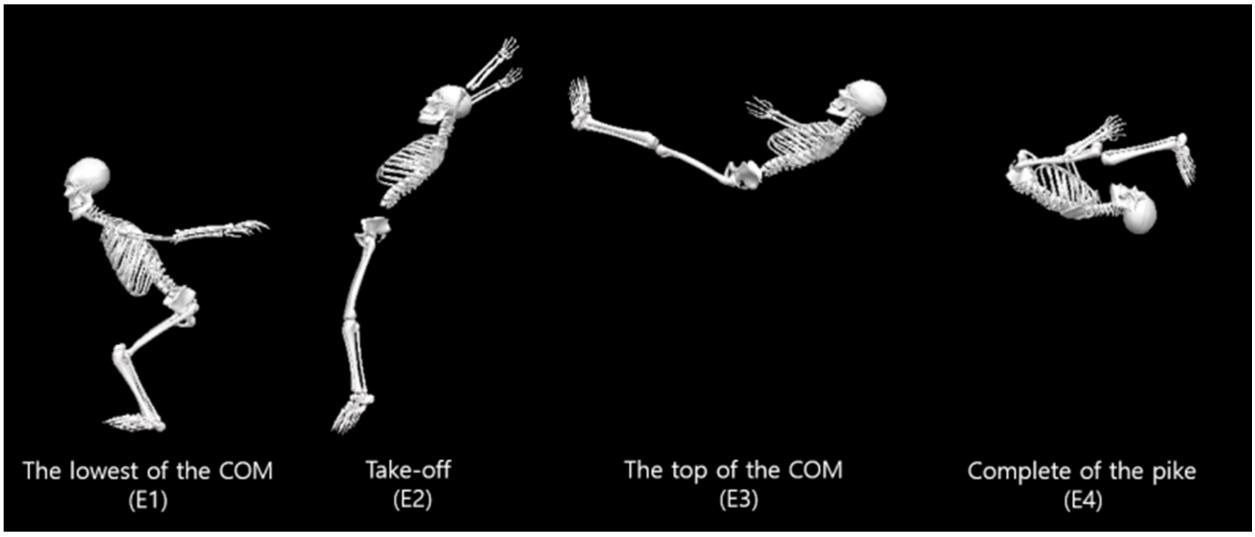

Figure 3. Events setup for back somersault pike

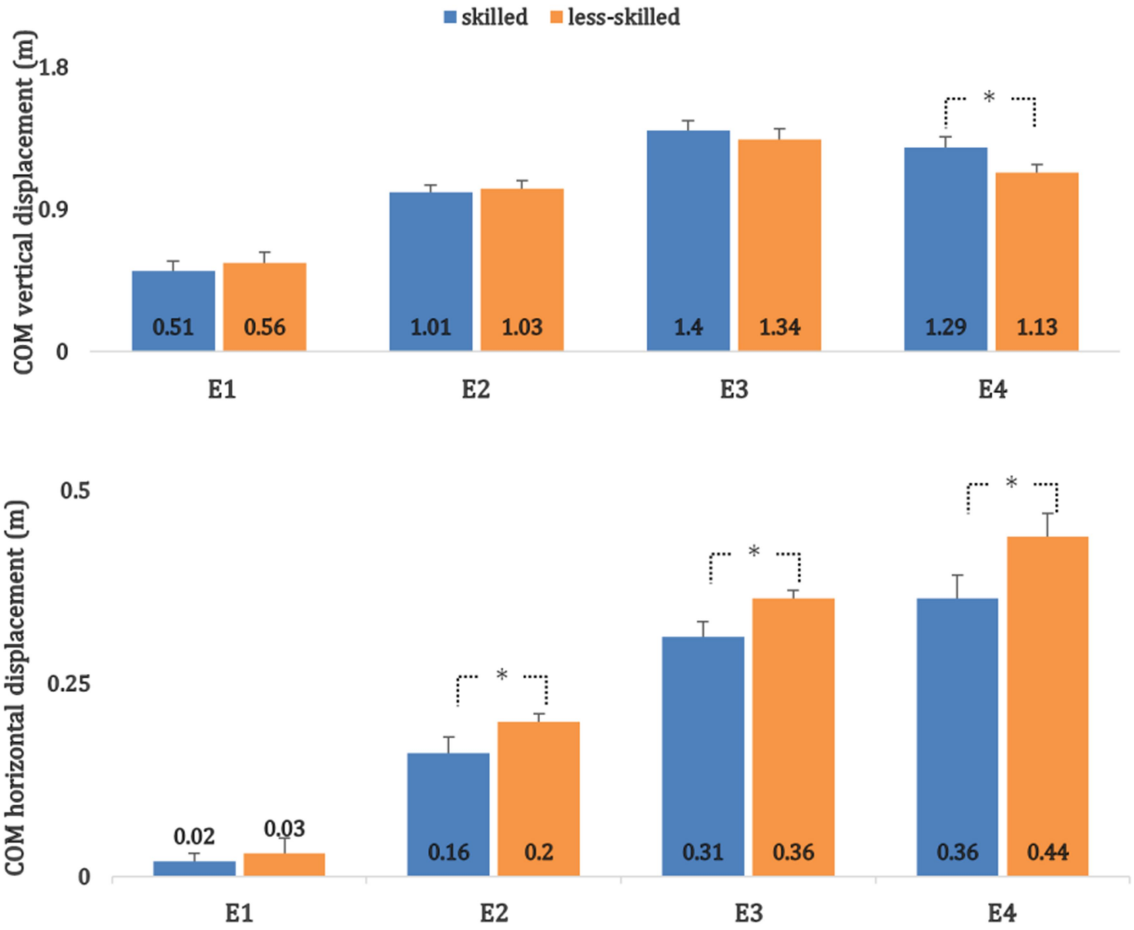

Figure 4. COM displacement in back pike somersault

There were no significant differences in other events. The skilled group had significant anterior horizontal displacement of the COM compared to the less-skilled group in all events except E1 ($p < .05$, Figure 4).

2. COM takeoff velocity and angle

At takeoff, the skilled group had significantly slower posterior velocity and faster vertical velocity compared to the less-skilled group ($p < .05$,

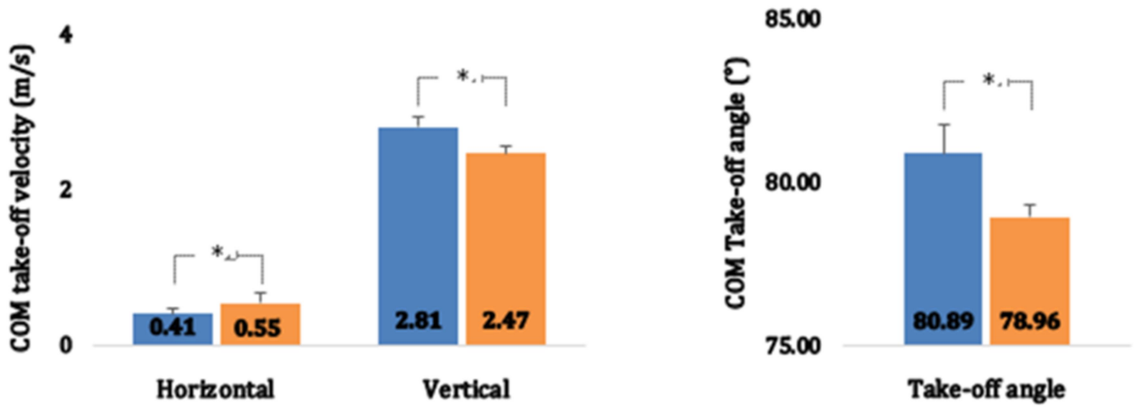

Figure 5. COM takeoff velocity and angle

Figure 5). Further, the skilled group had a significantly larger takeoff angle than that of the less-skilled group ($p < .05$, Figure 5).

3. Lower limb joint angle

During the back-pike somersault, the skilled group had significantly less ankle dorsiflexion and knee flexion at E4 compared to the less-skilled group ($p < .05$, Figure 6). On the other hand, the skilled group had significantly greater hip extension and flexion angles at E2 and E3 compared to the less-skilled group ($p < .05$, Figure 6).

4. Lower limb joint angular velocity

During the back-pike somersault, the skilled group had significantly faster knee and hip angular velocities at E2 compared to the less-skilled group ($p < .05$, Figure 7).

DISCUSSION

Diving techniques are becoming increasingly difficult as new training methods and analyses advance technical and physical skills. The most difficult back group on the platform is the back 31/2 somersault pike, with a DD of 3.6. Due to inadequate technical skill, however, only a minority of elite athletes attempt to perform the back 3½ somersault pike in Korea. In this context, we conducted this study to analyze kinematic differences in the back-pike somersault according to skill level, in order to improve technical skills in Korean platform divers.

Appropriate preparatory position is an important component of an effective takeoff (KISS, 2010). Athletes lower their COM by bending their knees and hips to prepare for a fast takeoff (Kim, 2003).

The findings of this study showed that the two groups did not significantly vary in COM displacement at E1, when the body's COM is at the lowest point; however, at E2, the moment of takeoff, skilled athletes displaced their COM 20% farther forward (toward the platform) compared to the less-skilled athletes ($p < .05$, Figure 4). This result suggests that although both groups assumed effective postures to prepare for takeoff, the skilled group performed the subsequent stage for takeoff faster than the less-skilled group.

The moment of takeoff is when the athletes achieve sufficient height and rotation velocity required to perform the dive, by rapidly extending their bent lower limb joints. This is a critical point in a dive because the extension posture and speed have an impact on the height of takeoff and rotation speed (Lee, 2006; Lee, 2008; Kang & Nam, 2010; Hue & Nam, 2012). At takeoff, divers gain time for rotation by increasing their COM through rapid extension of the ankle, knee, and hip joints, and adjust the speed of rotation by tilting the upper body rearward (Hamill et al., 1986). In general, less-skilled divers tend to focus more on the rotation than on the takeoff. In other words, they move the upper body before finishing in order to stretch out the lower limb joints, and this upper body movement leads to excessive posterior COM velocity (Oh & Lee, 1995; An & Jang, 2001; Lee, 2006). The findings of this study showed that skilled athletes had 13.77% faster vertical velocity and 24.55% slower horizontal velocity at takeoff, compared to the less-skilled athletes ($p < .05$, Figure 5). That is, skilled athletes seem to reach sufficient height by emphasizing vertical movement at takeoff while less-skilled athletes fail to reach sufficient height by focusing on movement toward the platform rather than on vertical movement.

To reach the maximum takeoff height during a back pike, the lower limb joints must be extended as much as possible (KISS, 2010).

In this study, skilled athletes had 8.16% greater hip joint angle and 17.1% and 33.92% faster extension speed at the hip and knee, respectively, at takeoff, compared to the less-skilled athletes ($p < .05$, Figure 6-7). Extension of the lower limb joints is based on explosive power, and the above results for extension speed are attributable to the differences in explosive power in relation to skill level.

Flight moves are performed based on the takeoff height and rotation speed, and athletes must complete the position and number of rotations they had chosen before entry into the water. If the 3½ somersault is chosen for the back group, the athlete attempts the pike and tuck positions. In the tuck position, the athlete somersaults with the knees and hip joints bent, and in the pike position, the athlete somersaults with only the hip joints bent and lower limb joints extended straight. Fast somersaulting is possible in the tuck position, because it is easy to lower the moment of inertia by holding the body close to the axis

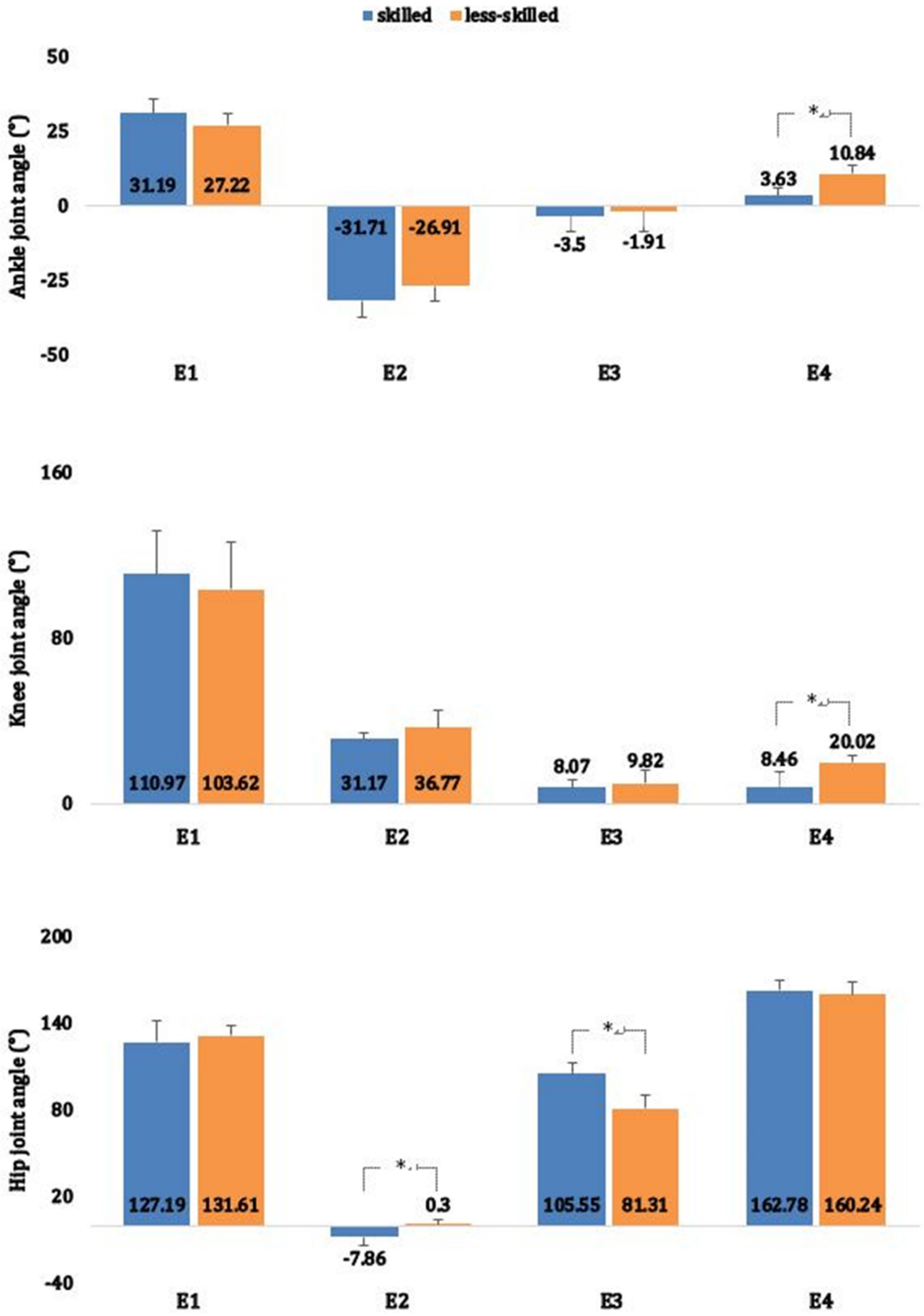

Figure 6. Left lower extremity joint angles in back pike somersault

of rotation (Lee, 2006). However, somersaulting is difficult in the pike position because the knee and ankle joints must be extended straight, which increases the moment of inertia; hence, the pike somersault is classified as a difficult technique. A successful pike somersault requires flexibility to hold the body close to the lower limbs while maintaining good extension of the lower limbs, and repeated training is essential to increase explosive power immediately following takeoff. Despite the fact that all participants of this study were members or candidates of

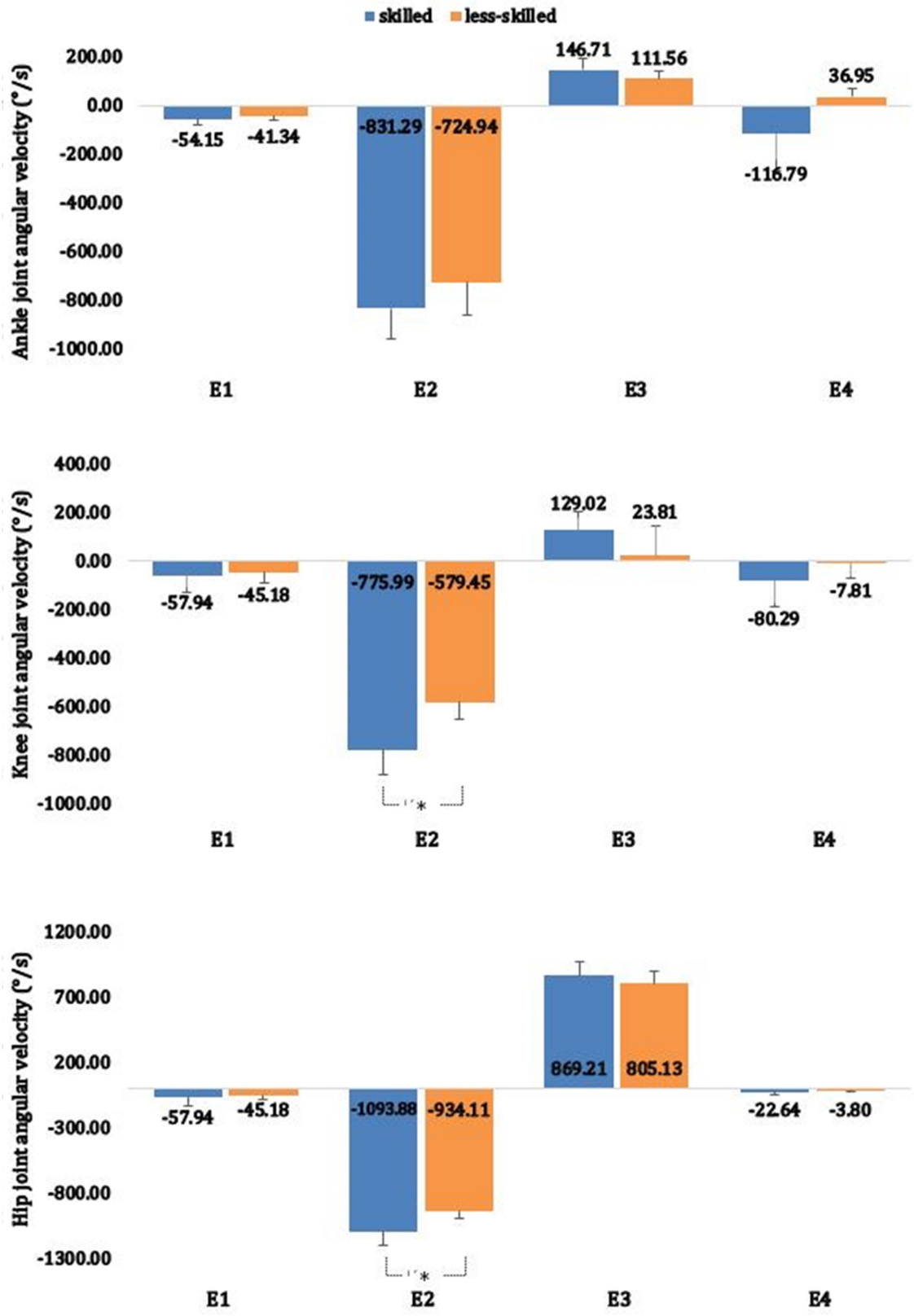

Figure 7. Left lower extremity joint angular velocity in back pike somersault

the national team with adequate flexibility and explosive power, the less-skilled group had 7.21° greater ankle dorsiflexion and 11.56° greater knee flexion at the completion of the pike compared to the skilled group ($p < .05$, Figure 6).

Points are deducted when an athlete shows knee flexion or ankle dorsiflexion during the back pike (FINA, 2015). Any problems with these

moves should be corrected through repeated training, particularly through ground training due to the high physical burden posed by platform training. Although skills acquired through repeated training are reported to lead to improved performance (Pyun, 2010), skills learned in incorrect and ineffective postures would have relatively little contribution, further emphasizing the importance of correct posture during ground training. Therefore, based on the findings of this study, repetitive ground somersault training should focus on correcting athletes to increase their COM vertically and increase lower limb joint angle and angular velocity at takeoff and rapidly bend their hip while extending ankle and knee joints immediately after takeoff. Such training would contribute to improving diverse' performance in the back pike on a 10-m platform.

This study analyzed the kinematic differences of the back-pike somersault in relation to skill level and suggested implications for repetitive ground training program. However, one limitation of this study is that it performed the analyses in the ground training setting; this should be addressed in future studies by investigating the actual movements on a 10-m platform dive.

CONCLUSION

This study aimed to provide data to help less-skilled divers improve performance in the back-pike somersault. Ten current male professional divers with at least seven years of experience were divided into skilled and less-skilled groups to analyze differences in COM displacement and velocity, and in lower limb joint angle and angular velocity at takeoff, in the back-pike somersault.

A successful back pike somersault requires rapid vertical elevation of the COM and an increase in the joint angle and angular velocity at takeoff, as well as stretching out the ankle and knee joints and rapid bending of the hip joint immediately after takeoff. Correcting these postures and techniques through repeated ground training would help athletes improve back pike performance in 10-m platform diving.

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