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ORIGINAL

Effects of Counter-rotation Position on Knee/Hip Angulation, Center of Mass Inclination, and Edging Angle in Simulated Alpine Skiing

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Objective: To investigate rotation movement of segment for performing each position and its effect on knee/hip angulation, COM inclination, and edging angle changes.

Method: Twelve Alpine skiers (age: 25.8±4.8 years, height: 173.8±5.9 cm, weight: 71.4±7.4 kg, length of career: 9.9±4.6 years) participated in this study. Each skier was asked to perform counter-rotation, neutral, and rotation positions.

Results: Shank and thigh were less rotated in the counter-rotation position than in other positions, whereas the trunk and pelvis were more counter-rotated ($p<.05$). Hip angulation, COM inclination, and edging angle were significantly greater in the counter-rotation position than in other positions ($p<.05$).

Conclusion: Our finding proved that the counter-rotation position increases hip angulation, COM inclination, and edging angle. Consequently, we suggest that skiers should perform counter-rotation of the trunk and pelvis relative to the ski direction in the vertical axis for the counter-rotation position. Further analysis will continue to investigate the effects of the counter-rotation position in real ski slope with kinetic analysis.

Keywords: Alpine ski, Counter rotation position, Angulation, Edging angle

INTRODUCTION

Alpine skiing is a sport of sliding down snow-covered mountains; therefore, turning techniques for controlling speed and direction have been continuously and extensively developed. In addition, biomechanical studies aimed at the development of turning techniques have been frequently conducted.

The turning and sliding speed of skis are determined by the reaction force and the friction force generated between the snow surface and the ski. These forces vary based on the skier's center of mass (COM), up and down, left and right position, slope, and edging angle of the ski (Federolf et al., 2008; Supej et al., 2013). Therefore, the change in the skier's posture has a direct effect on the change of the external force required for the turn to occur, and because of this, there has been a great interest in alpine ski research (Yoneyama, Kagawa, Unemoto, Iizuka, & Scott, 2009).

For alpine skiing, both legs are equipped with a ski, which is divided into an inner and an outer ski based on the direction of the turn. Therefore, when a skier performs a turn, the nature of the turn depends on how much he/she uses the inner or outer ski. Based on the study conducted by Kim et al. (2014); Kröll, Wakeling, Seifert and Müller (2010); Stricker, Scheibera, Lindenhofera and Müller (2010); and Vaverka, Vodickova and Elfmark (2012), although intermediate skiers are more loaded on the inner ski, expert skiers are more loaded with external ski and the muscle activity of the quadriceps femoris was also greater in the outer legs, emphasizing the use of outside skis. Thus, the edging of the outer ski has a direct effect on the form of turning through changes in snow friction.

The edging angle of the outer ski determines the radius of the turn. In the case of skidding turns, slippage occurs on the side of the ski, and at this time, a larger edging angle results in a larger snow surface friction; hence, a shorter radius turn is created. In addition, in the case of carving turns, depending on the degree of bending of the skis of the side cut, the radius of the turn is determined; hence, a larger edging angle would result in more bending of the ski, eventually decreasing the radius of turn. Thus, for an alpine ski race that passes through a gate with a limited radius and for a recreational alpine skiing that involves a turn depending on the slope or terrain, successful turning depends on the ability to adjust the edging angle and the edging angle determined by the movement of the skier (Federolf et al., 2008; Federolf, Luthi, Roos, & Dual, 2010; Heinrich, Mössner, Kaps, & Nachbauer, 2010, 2011; Müller et al., 1998; Yoneyama et al., 2009).

Skiers require a larger edging angle to turn with a smaller radius, and to accomplish this, the COM is tilted more towards the inside of the turn. Also, greater COM inclination shows in the steering phase after fall-line (Müller et al., 1998; Spörri, Kröll, Schwameder, Schiefermüller, & Müller, 2012). It also requires a larger edging angle in the carving turn, which depends on the speed and bending of the ski compared with the basic parallel turn using the skidding, indicating a greater COM inclination during carving turn (Kim et al., 2014). COM inclination to the inside of the turn for edging is the result of the combined the joint movements, and these movements are called angulation (Lind & Sanders, 2004). The angulations are divided into knee and hip angulations, which are defined as knee and hip angles projected on a plane perpendicular to the direction of ski (Supej, 2010). A greater edging angle similar to the COM inclination shows in the steering phase after fall-line (Supej, Hébert-Losier, & Holmberg, 2015).

Generally, in alpine skis, the position where the upper body is directed outward with respect to the direction of the turn is referred to as a counter-rotation position, and the neutral and rotation positions are referred to as the neutral and rotation positions, respectively (LeMaster, 2010; Lind & Sanders, 2004). Among them, the counter-rotation position increases the COM inclination to increase the edging angle, and it is preferred to increase knee and hip angulation (Greenwald, Senner, & Swanson, 2001; Müller et al., 1998). Nevertheless, no quantitative study has been conducted on understanding how the counter-rotation position occurs through the movement of any segment and their effects on the knee or hip angle, COM inclination, and edging angle; hence, it depends on empirical knowledge.

Because of the experimental difficulties and characteristics of the sport, such as high-speed and wide range of motion, as well as environmental factors, such as cold and sloping snow, kinematic studies of alpine skiing have been conducted through the studies using a ski simulator (Koo, Lee, Kweon, Hyun, & Eun, 2014; Lee, Roh, & Kim, 2016; Nam & Woo, 2007), or using a robot (Federolf, Roos, Lüthi, & Dual, 2010; Mössner et al., 2014; Yoneyama et al., 2009) or through the studies that simulate Alpine skiing in a laboratory setting to generalize the results to actual situations (Böhm & Senner, 2008; Demšar, Duhovnik, Lešnik, & Supej, 2015; Nedergaard et al., 2014). The purpose of this study was to investigate the differences of segments rotation movement between 3 different positions and their effects on knee and hip angulation, COM inclination and edging angle changes.

METHODS

1. Participants

The subjects of this study were six instructors from Korea Ski Instructors Association and six alpine ski racer from the Korea Ski Association who can ideally perform counter-rotation, neutral, and rotation position. All subjects were selected as adult men (age: 25.8±4.8 years, height: 173.8±5.9 cm, body weight: 71.4±7.4 kg, length of career: 9.9±4.6 years) without musculoskeletal abnormalities. After adequate explanation about the experimental procedure before participating in the experiment to all participants, the experiment was conducted only with skiers who agreed to participate.

2. Measurements

To simulate the skiing position, the reference axis was defined by

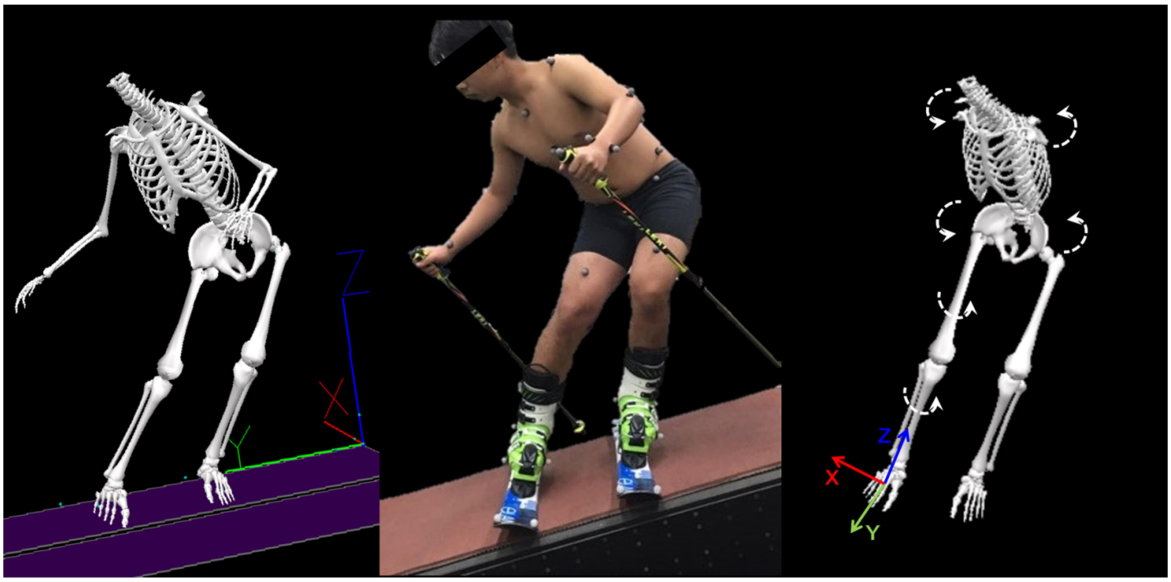

Figure 1. Experimental setup and definition of rotation angle for simulated alpine skiing. The X- and Y axes indicate the direction of the ski and centrifugal force, respectively. The 15° sloped surface was covered with a rubber material, providing enough friction between surface and ski edge. Rotation angles were defined as the segment orientation angle relative to ski orientation angle on the vertical axis.

setting the X axis to the ski direction and the Y axis to the direction where the centrifugal force occurred at an inclination of 15°.

The surface of the slope was then covered with a rubber material to provide sufficient friction between the edges of the ski (Figure 1). Each participant performed enough preparatory exercises and posture exercises, and then put on their own ski and boots. To model the 12 segments and skis, 37 reflective markers were attached to the left, right, upper, and lower legs, trunk, pelvis. Each skier performed a turn in the left direction, and assumed that the reaction force generated by the slope was the reaction force generated between the ski and the snow surface. In addition, the counter-rotation, neutral, and rotation positions were performed to perform edging and COM inclination required to cope with this reaction force. For the kinematic analysis between three different positions, eight infrared cameras (Oqus 300+, Qualysis, Sweden) were used and the sampling rates were set to 100 Hz and controlled using the Qualysis Track Manager ([QTM], Qualysis, Sweden) program.

3. Data processing

The marker data of all the skiers collected through the infrared camera were analyzed using Visual3D (C-motion, USA). A second-order Butterworth low-pass filter was used to reduce the effect of noise, and the cut-off frequency was set to 6 Hz.

Alpine skiing uses two skis on both legs, but most alpine skiing studies are based on outside skis because most skiers use the outside skis to guide the direction of the turn (Kim et al., 2014; Kröll et al., 2010; Stricker et al., 2010; Vaverka et al., 2012). In the present study, the rotation angle of the trunk, pelvis, thigh, and shank of the legs was defined as the rotation angle based on the orientation angle of the ski on the vertical axis to analyze the rotation movement of each segment in each position. In addition, Knee and hip angulations were defined the knee and hip angles projected on a plane perpendicular to the direction of ski. The inclination of the whole body COM with respect to the vertical axis of the outer ski center of mass (outer-ski COM) was defined as the COM inclination (Supej et al., 2015). The edging angle was defined as the anteroposterior axis movement of the ski.

4. Statistical analysis

For each variable, one-way analysis of variance (ANOVA) with repeated measures was used to test for significant differences in kinematic factors based on counter-rotation, neutral, and rotation position. Bonferroni correction was used for the post test. The significance level was set to α=.05.

RESULTS

1. Segment rotation angle

The shank rotation angle was 4.00±3.69°, 7.08±0.77°, and 8.64±1.36° in the counter-rotation, neutral, and rotation positions, respectively ($F_{2,33}$=13.368, p=.000), showing significant differences among the groups. In the post-test, the rotations position showed a more significant rotation than the counter-rotation position (p=.001) and neutral position (p=.010) as shown in Figure 2. The thigh rotation angle was 6.26±10.31°, 11.35±1.78°, and 13.48±3.66° in the counter-rotation, neutral, and rotation positions, indicating a significant difference among positions ($F_{2,33}$=6.728, p=.005). In the post-test, the rotation position was significantly rotated compared with the counter-rotation position (p=.019) and compared with the neutral position (p=.042) (Figure 2).

The pelvis rotation angle was -26.65±10.92°, 3.86±6.30°, and 21.63±9.93° in the counter-rotation, neutral, and rotation positions, respectively, and a significant difference was found between positions ($F_{2,33}$=729.005, p=.000). Post-test showed significant counter-rotation in the counter-rotation position compared with the neutral (p=.000) and rotation position (p=.000). In addition, the rotation position was found to be significantly rotated compared with the neutral position (p=.000, Figure 2). The trunk rotation angle was -54.34±19.03°, 1.94±7.66°, and 43.04±7.09° in the counter-rotation, neutral, and rotation positions, respectively, and a significant difference was found between positions ($F_{2,33}$=515.833, p=.000). In the post-test, the counter-rotation position was significantly reversed compared with the neutral (p=.000) and rotation position (p=.000). In addition, the rotation position was found to be significantly rotated compared with the neutral position (p=.000, Figure 2).

2. Knee and hip angulations

Knee angulation showed no significant difference among positions ($F_{2,33}$=2.103, p=.146). In contrast, the hip angulations showed a significant difference between the positions of -35.97±4.61°, 3.68±3.80°, and -14.67±3.04° in the counter-rotation, neutral, rotation positions ($F_{2,33}$=878.222, p=.000). In the post-test, the counter-rotation position was significantly larger than the neutral (p=.000) and rotation positions (p=.000). In addition, the neutral position was significantly larger than the rotation position (p=.000, Figure 2).

3. COM inclination

The COM inclination was 29.42±6.71°, 26.69±6.28°, and 26.24±6.52° in the counter-rotation, neutral, and rotation positions, respectively, and no significant difference was found between the positions ($F_{2,33}$=14.609, p=.000). In the post-test, the counter-rotation position was significantly larger than the neutral (p=.001) and rotation position (p=.008) (Figure 2).

4. Edging angle

The edging angle was 27.72±2.61°, 15.74±4.98°, and 9.42±3.51° in the counter-rotation, neutral, and rotation positions, respectively, and no significant difference was found between positions ($F_{2,33}$=164.124, p=.000). In the post-test, the counter-rotation position was significantly larger than the neutral (p=.000) and rotation position (p=.000). In addition, the neutral position was significantly larger than the rotation position (p=.000, Figure 2).

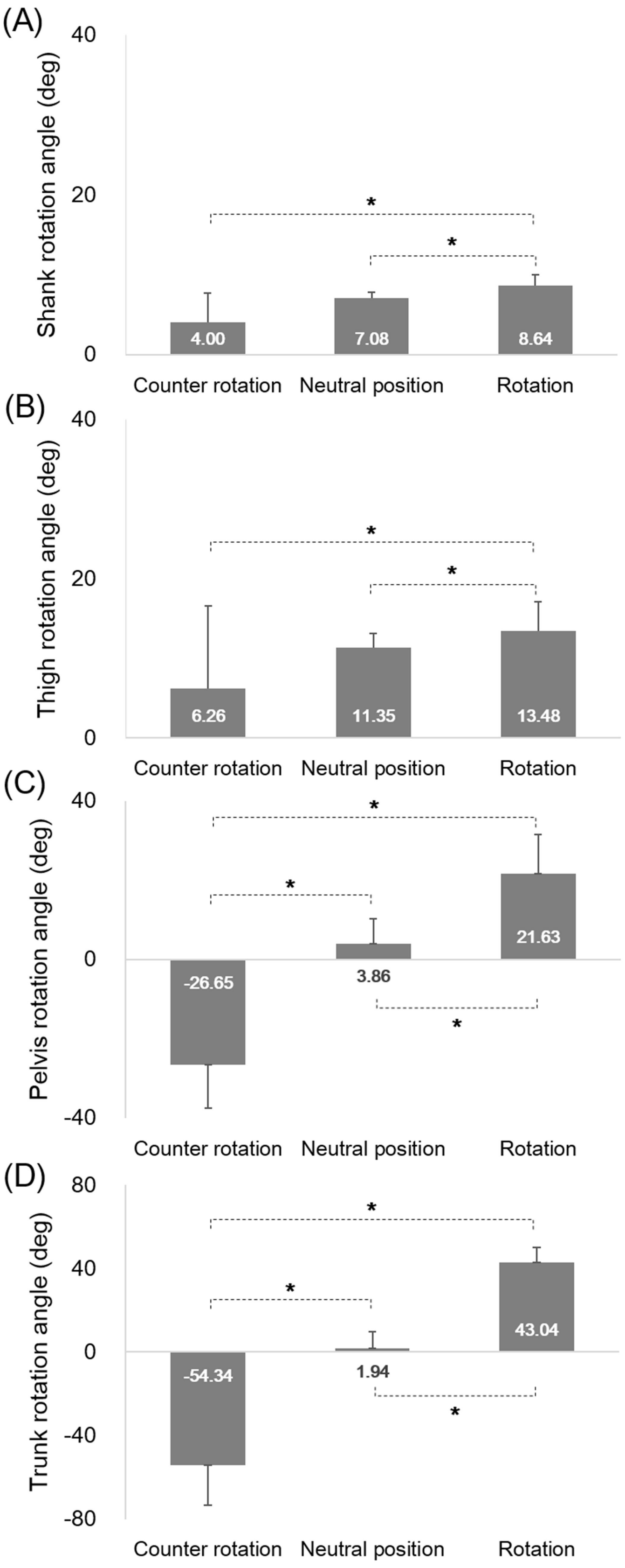

Figure 2. Rotation angle of the outer (A) shank, (B) thigh, (C) pelvis and (D) trunk between three different positions (counter-rotation, neutral, and rotation positions). Statistical significance effects were calculated using one-way repeated ANOVA with Bonferroni correction. Asterisk indicates a statistical difference between three conditions.

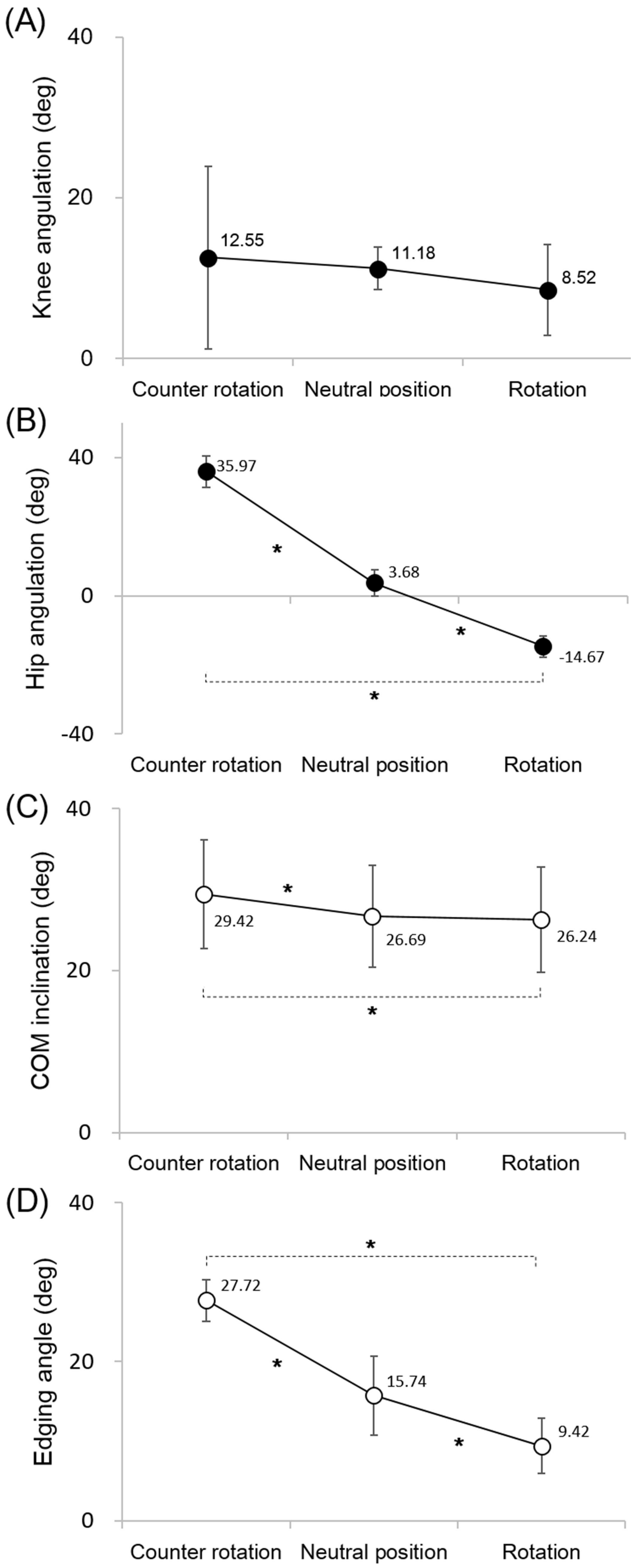

Figure 3. (A) Knee and (B) hip angulations, (C) COM inclination, and (D) edging angle between three different positions (counter-rotation, neutral, and rotation positions). Statistical significance effects were calculated using one-way repeated ANOVA with Bonferroni correction. Asterisk indicates a statistical difference between three conditions.

DISCUSSION

Alpine skiing is a sport that focuses on controlling the speed and direction of skiing, and various techniques have been developed to control skiing through the movement of skiers. Among them, recreational skiers (intermediate and expert levels) and racing athletes try to create a larger edging angle by increasing the COM inclination using knee and hip angulations to perform faster speeds and shorter radius turns (Federolf et al., 2010; Mössner et al., 2014). At this time, most skiers prefer counter-rotation position for greater variation of angulation, COM inclination, and edging angle (LeMaster, 2010, Lind & Sanders, 2004). Therefore, the purpose of this study was to analyze the difference of segmental movements between the counter-rotation, neutral, and rotation positions through the alpine ski simulation and to investigate the effect of this on knee and hip angulation, COM inclination, and edging angle changes.

In alpine skiing, leg, hip, and upper-body rotations are used to impart torque to the ski using segment rotation (LeMaster, 2010). The leg rotation involves in rotating the outer leg in the inner direction of the turn while rotating the upper body in the outer direction. It is used as a main technique for performing a skidding turn in modern skiing because the torque is generated in the direction wherein the turn is made to generate the steering angle of the ski larger. In contrast, upper-body and hip rotations are the actions of turning the upper body or pelvis inward of the turn to pivot the ski inward. This is a classic turning technique used for skidding or lateral projections and also a technique to avoid in modern skiing. The results of this study showed that the counter-rotation position rotated less in the lower leg and the lower femur compared with the other positions, whereas the pelvis and trunk were more inversely rotated than the skiing direction. Therefore, in performing the skidding turn, the trunk and the pelvis are rotated together with the legs, so that the torque is generated by using the counter-rotation position, wherein only the leg rotation is performed, rather than the rotation or neutral position wherein the upper-body and hip rotations occur simultaneously (LeMaster, 2010). In addition, in modern skiing, most skiers prefer the carving turn, which has a faster speed and a faster turn between each turn, except for a few special situations, such as edging at steep slopes that require a very short radius or braking. Skidding turns use the friction between the ski and the snow as a centripetal force, whereas carving turn relies on ski bending, which requires more edging angle than skidding turns. Therefore, the skier must increase the edging angle through the counter-rotation position using the reverse rotation of the segment, rather than the neutral position, wherein increasing the edging angle or the rotation position, wherein the edging angle is limited, is difficult (Lind & Sanders, 2004).

The knee and hip angulations are defined by the knee and hip joint angles appearing on the plane projected perpendicular to the ski direction, and this is an action that has a direct effect on the edging angle because it is similar to the motion of the ski's frontal plane (LeMaster, 2010; Supej, 2010; Supej et al., 2015). In general, the angulation of the skier is used to adjust the edging angle of the ski. If a large edging angle is required, such as when performing a turn at a steep slope with a high acceleration or a low turn radius, the skier must slide to create a larger angulation (Howe, 2001; Lind & Sanders, 2004; Supej et al., 2015). Knee angulation is an action that cranks the knee inward without changing the COM. Due to the nature of the hinge joint, excessive knee angulation is an action that should be avoided in modern skiing because knee flexion occurs irrespective of the action of increasing the edging angle. In contrast, hip-induced movement is the movement of the femoral head inside the turn without the movement of the COM, and it is believed to be a more important action than knee angulation because it can transmit forces to the inner edge of the outer ski (LeMaster, 2010). The current study showed that no difference was found in knee angulations between positions, but hip angulation was significantly increased in counter-rotation position. This is because knee angulation changes with the radius of the slope or turn (Howe, 2001; Supej et al., 2015); hence, the influence by the counter-rotation position is considered to be small. Conversely, hip angulation is affected not only by the radius of the slope or turn, but also by the counter-rotation position. Therefore, the skier must slide by increasing the hip angulation through the counter-rotation position to effectively transmit force to the inner edge of the outer ski, which is in contact with the snow surface and acts on the reaction force (Federolf et al., 2010; Federolf et al., 2010; Mössner et al., 2014).

COM inclination is used to generate centripetal force or to counteract centrifugal forces in most sports, such as biking, skating, etc. In addition to that, COM inclination is performed to increase the edging angle in alpine skiing, and the higher the steeper slope, the faster the skiing speed, or the shorter the radius, the more the turn it will be (Howe, 2001; Kim et al., 2014; Spörri et al., 2012). The results of this study showed that the COM inclination was significantly increased in the counter-rotation position. Therefore, because the counter-rotation position tilts the COM more toward the inside of the turn, counteracting the centrifugal force while generating a larger centripetal force may be advantageous by increasing the edging angle.

The edging angle is defined as the slope of the horizontal slope of the ski slope. The larger the edging angle is, the greater the reaction force generated between the ski and the slope, and the greater the deflection of the ski, which is considered an important factor, will be (Brown, 2009; Federolf et al., 2010; Federolf et al., 2010). To adjust the edging angle, the alpine skier tilts the COM to the inside of the turn, or uses knee and hip angulations. In this study, the angle of the body increased by >12°; whereas the COM inclination increased by <3°, and hip angulation increased by >32°. This requires a counter-rotation position to increase hip angulation (Lind & Sanders, 2004); hence, the counter-rotation position is speculated to be very useful for making a large edging angle despite the small COM movement. Therefore, a skier not only tilts the COM toward the inside of the turn when the slope is steep and when the slider speed is fast and the radius is short, he/she has to increase the edging angle by increasing the hip angulation through the counter-rotation position.

In this study, we performed alpine ski simulations in a laboratory setting to investigate the effect of the counter-rotation position and its effect. Therefore, the limitations of this study are as follows: (1) the process of interaction between the snow and ski is simplified, (2) not taking into account the characteristics of initiation and steering phase in dynamic skiing, (3) the difference in slope or skiing speed of various slopes could not be considered. In addition to conducting research on the effects of counter-rotation position in dynamic situations, if the kinetic analysis is used to investigate the reaction force and torque between the ski and snow, it will be a great help to generate the quantitative guidelines necessary for the improvement of the alpine ski performance and development of training.

CONCLUSION

The aim of this study was to investigate the movement of the segments on the vertical axis based on the counter-rotation, neutral, and rotation position in the laboratory setting, and the effects of these on the knee and hip angulation changes, COM inclination, and edging angle changes. For this purpose, 12 skiers participated in the experiment, and the alpine ski was simulated at a 15° slope. When the counter-rotation position was performed, the thigh and shank were significantly rotated, and the trunk and pelvis were significantly reversed. In addition, the hip angulation, COM inclination, and edging angle significantly increased in the counter-rotation position. Based on the results of this study, to increase the edging angle, making a counter-rotation position using the trunk and pelvic counter-rotation to increase the hip angulation and COM inclination is necessary. Future experiments and kinematic analysis should be conducted to quantify the change of force required for the skier's movement and rotation.

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