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Effect of Walking Speed on Lower Extremity Internal and External Rotation While Turning 90 Degrees

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국문요약

90도 회전 시 보행속도가 하지의 내외 회전에 미치는 효과

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회전(turning)은 보행 중 방향을 바꾸는 운동 기술(motor skill)이고, 회전 전략(turning strategy)은 회전을 완수하는데 사용되는 일반적 행동 전형(generalized movement pattern)이다. 회전에 대한 보행속도의 영향은 분명하지 않다. 이 연구의 목적은 보행속도의 돌기 전략에 대한 영향을 분석하고 보행속도의 하지 내외 회전(internal and external rotation)에 대한 영향을 분석하는 것이다. 건강한 젊은 성인 15명이 이 연구에 자발적으로 참여하였다. 맥리플렉스 측정 장치(MacReflex measurement system)가 동작 분석(motion analysis)을 위해 사용되었다. 각각의 자원자들은 보행 중 90도 왼쪽으로 회전을 10회씩 완수하였다. 각각의 시도마다 보행속도를 다르게 하기 위해서 세 가지의 다른 요구들(slow, regular, fast)이 임의적으로 주어졌고 각각의 실제 보행속도가 자원자의 무게 중심 변화에 따라 구해졌고 요구별 평균이 구해졌다. 회전 안쪽 발의 스핀(inside foot spin)은 보행속도가 증가함에 따라 증가했지만, 회전 바깥쪽 발의 스핀(outside foot spin)은 보행속도와 상관이 없었다. 하지의 내외 회전은 보행속도와는 상관이 없었지만, 같은 쪽 발의 스핀과는 역관계가 있었다. 회전은 발 스핀이 있는 돌기와 발 스핀이 없는 돌기로 구분되는 것이 합당한 듯 하다. 제한된 시간과 공간 내에서 스핀은 보행속도가 빨라질수록 몸의 전방 운동량(forward momentum)에서 몸의 전방 운동량(forward momentum)으로의 전환이 스핀이 없는 회전 시보다 효율적이다. 고관절의 내외 회전 근육들은 회전 전략에 상관없이 회전되는 동안 몸의 역학(body mechanics)을 조절하는데 중요한 역할을 맡고 있는 것으로 보인다. 앞으로 회전 시 몸의 생체 역학적 그리고 신경 근육적 기전들(biomechanical and neuromuscular mechanisms)을 밝히는 연구들이 필요하다.

핵심단어: 내외 회전; 동작분석; 보행 속도; 회전.

Introduction

No one has to run but everyone has to turn for performing activities of daily living. Turning is classified as one of the unsafe moments during ambulation in the elderly (Tinetti et al, 1986). It increases the biomechanical demand more than straight walking (Perry, 1992). However, straight walking on level surfaces has been the basic task used in the majority of studies on human locomotion. Limited studies (Andrews et al, 1977; Hase and Stein, 1999; Patla et al, 1991) exist on activities other than straight walking, such as, turning.

Turning is a motor skill of changing direction while walking, and the turning strategy is the generalized movement pattern used to complete the turning. The course of turning consists of decelerating the forward momentum, rotating the body, and stepping out toward the new direction (Hase and Stein, 1999). Based on the interaction between muscle tension and mechanical demand, several deceleration mechanisms are generally used to decrease the forward moment (Hase and Stein, 1999). An extension synergy of the forward lower extremity and reduced push-off power in the other lower extremity are the fundamental deceleration mechanisms during the same step cycle (Hase and Stein, 1999). Once the walking speed is decelerated, rotational movements of the locomotor unit, formed by the two lower limbs and pelvis, occur in the transverse plane to turn the body toward a new direction (Perry, 1992). Rotating the upper body on one hip joint and spinning of the whole body on the floor are the main strategies to rotate the body around the longitudinal axis in the transverse plane.

Adjustment of gait is required to alter the direction of locomotion (Patla et al, 1991). Turning has been defined as a basic strategy to avoid an obstacle in the path (Patla et al, 1991). While changing direction, the following changes were found through the ground reaction force study: 1) an increase in mediolateral impulse components; 2) an increase in the braking impulse component for anterior-posterior and vertical impulse components; and 3) a decrease in both horizontal and vertical push-off impulse components (Patla et al, 1991). Patla and his associates concluded that changing direction while walking normally must be planned in the previous step (Patla et al, 1991). This plan must occur regardless of the magnitude of the change in direction of locomotion in order to reduce the acceleration of the body center of mass toward the landing foot (Patla et al, 1991). Changing direction within the same step was not limited by reaction time, but by the inability of the muscles to rotate the body to the new direction (Patla et al, 1991).

Hase and Stein (1999) defined the spin and step turning strategies in their study on turning the body 180 degrees. In the spin turn, the body spins on the floor around the ball of one foot, and in the step turn, both feet continue to step and each hip can serve as the axis for part of the turn (Hase and Stein, 1999). Andrews and his colleagues (1977) described the spin turn as the crossover cut and the step turn as the sidestep cut for turning 90° during human running. It was found that the step turn is an easier strategy for subjects to use when turning 180° because it has a broader base of support and separates the deceleration and the turn while maintaining the walking rhythm (Hase and Stein, 1999). The timing of a tactile signal during a gait cycle was believed to be a determinant for the selected turning strategy. It was found that the step turn was preferred if the center of gravity (CoG) had already passed the supporting foot when the tactile signal was given. The walking speed was eliminated as a possible factor that influencing the choice of turning strategy by assuming that all of their subjects walked at similar speeds. However, it is unclear whether the same turning strategy would be used at various walking speeds.

Hip is the best example of the ball-and-socket joints in the body, which provides stability and mobility (Hollinshead and Jenkins, 1991). Rotation of the hip in the transverse plane occurs as the contralateral lower extremity swings forward in preparation for the next step while straight walking (Norkin and Levangie, 1992). An average of 13° of hip internal and external rotation occurs during a normal gait cycle (Nordin and Frankel, 1989). In straight walking, external rotation of the hip occurs during the swing phase of the limb, and internal rotation occurs during the stance phase (Levens et al, 1948; Nordin and Frankel, 1989; Johnston and Smidt, 1969). The rotation of the hip minimizes the drop of the center of gravity and the energy expenditure during the double support period by lengthening the lower extremities (Norkin and Levangie, 1992). While turning without spin, the internal rotation of the inside hip may be increased and the external rotation of the outside hip may be increased during the ipsilateral single limb support period. If the body is spinning on the floor, the hip internal and external rotation may differ from when the body is turning without spinning. The hip internal and external rotation while turning has not been clearly determined.

Turning 90° is one of most functional activities and is more frequently required than turning to any other angle in activities of daily living. However, there has been little interest in this motor skill and normative data are unavailable. This study is the first effort to determine the generalized locomotion pattern while turning 90° at various walking speeds and to assess the amount of lower extremity internal and external rotation in the transverse plane. The purpose of this study was to analyze the effect of walking speed on the turning strategies used and on the amount of lower extremity internal and external rotation while turning 90° in healthy young adults. The following were hypothesized:

1) The turning strategies used will differ at the various walking speeds while turning 90°.
2) The amount of lower extremity internal and external rotation will be related to the walking speed while turning 90°.
3) The amount of lower extremity internal and external rotation and the turning strategies used will be related while turning 90°.

Methods

Subjects

Seven female and eight male volunteer subjects without any history of neuromuscular or musculoskelektal disease, disorder, or condition participated in this study. Their ages ranged from 22 to 32 years. Two out

Table 1. Descriptive statistics of height and weight of subjects

	N	Mean	Standard Deviation	Maximum	Minimum	Range
Height (inch)	15	66.74	3.04	74.00	61.80	12.20
Weight (pound)	15	136.01	22.40	185.00	110.00	75.00

of fifteen subjects were left-hand dominant (13.3%). The characteristics of subjects who participated in this study are shown in Table 1.

The subjects were recruited from New York University and from the adjacent communities on a voluntary basis. Prior to participation, all subjects signed a written consent form, indicating that they had been informed about the nature of this study. A participation questionnaire was completed by each subject to obtain information regarding the age and any previous medical history. If subjects fulfilled the criteria, they were selected as candidates for this study. They received a brief physical examination, which included measurement of height, weight, active range of motion of both hips, and manual muscle testing of the hip internal and external rotators bilaterally. All subjects were asked to bring their own sneakers. Dark-colored tight shorts and a sleeveless black T-shirt were provided to each subject to increase the visibility of the markers and to minimize the artifacts from the vibration of the markers.

Equipment

The MacReflex measurement system[1] was used in this study to detect the instant location of the markers on the subject's body and on the floor. The only system that can possibly capture all the data from human movement is an imaging measurement system because of its complexity (Winter, 1990). Three-dimensional motion analysis shows the body's true spatial motions and is closer to the reality of the movement (Barlett, 1997). Furthermore, the intersegmental angles could be calculated accurately without viewing distortions in three-dimensional motion analysis (Barlett, 1997). The MacReflex measurement system was found to offer a flexible and easily operated solution for recording of movements with a high resolution (Josefsson et al, 1996). The system included five cameras, five video processors, five camera-to-video processor cables, five video processor-to-monitor cables, twenty-one markers, a calibration frame, and a Macintosh computer. Camera units emitted invisible infrared light to detect the reflective markers in the image[2]. Video processors calculated the center of each marker and sent the coordinates to the computer. In this study, spherical, 3.6-centimeter-diametered, passive retro-reflective markers were used. The sampling rate of 60 ㎐ and the exposure

1. Qualisys Inc. Glastonbury, CT

2. Qualisys Inc. MacRefelx User Manual. Version 3.0 Glastonbury, CT. 1995.

time of 0.25 ㎳ were selected. Calibration of the MacReflex measurement system was done at the beginning of each session with the calibration frame from the manufacturer. All setting procedures were recorded on videotape for reproduction. The MacReflex software (version 3.0)[3] was used for collecting and digitizing the data. The CyanLab software (version 1.0)[4] was used for obtaining the instant center of gravity (CoG) of whole body at sampling rate of 60 ㎐ and for smoothening raw data by the butterworth filter with cut-off frequency of 10 ㎐. Microsoft Excel (version 2000)[5] was used for processing the data. The SPSS (version 9.0)[6] was used for the statistical analysis.

Procedures

Eighteen spherical, 3.6-centimeter-diametered, passive retro-reflective markers were attached by using a double-sided adhesive tape. The markers were attached bilaterally on greater tubercles and lateral epicondyles of the humeri, styloid processes of the ulnae, greater trochanters and lateral condyles of the femurs, lateral malleoli, heel and toe ends of the shoes and unilaterally on the glabella of the frontal bone and mental protuberance of the mandible bone of the skull (Fig 1). When necessary, the hair around the location of makers was shaved to avoid detachment of the marker during the test. Each spot on the skin was marked with a water-soluble pen to assure replacement of the marker on the same spot if a marker detached. The cameras were positioned as shown in Figure 2. An adhesive color tape was used to mark the exact location of the camera mounting tripod.

Before starting the data collection, subjects performed five practice trials to familiarize them with the test procedure. A two-minute rest period was allowed after the practice trials. As soon as the researcher said, ready, set, go, the subjects were asked to walk along the 7-meter path without looking down. Strings from the ceiling to the floor indicated the point at which the turn was to occur (Fig 2).

Turning 90° only to the left was performed based on the results of previous studies (Andrews et al, 1977; Hase and Stein, 1999; Patla et al, 1991) in which the characteristics of the both side turns were symmetric. After turning 90°, the subjects were asked to continue walking as fast as they did prior to turning until the researcher said, stop. Two sets of five trials were performed with different walking speeds in a randomized order to avoid the effect of fatigue. A two-minute rest period was allowed between the sets.

To vary the walking speed at each trial, one of the three commands (slow, regular, fast) was given in a randomized order. For each command, at least three trials were performed. Each subject performed a total of ten trials. The center of gravity (CoG) of the whole body was calculated based on the dislocation data of all body segments at a sampling rate of 60 ㎐. Walking speed was calculated based on the temporal dis-

3. Qualisys Inc. Glastonbury, CT
4. CyanSoft Inc.
5. Microsoft Inc.
6. SPSS Inc. Chicago, IL

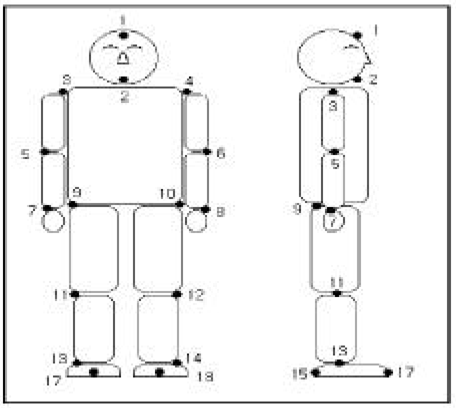

Fig 1. The location of markers in the frontal and sagittal views.

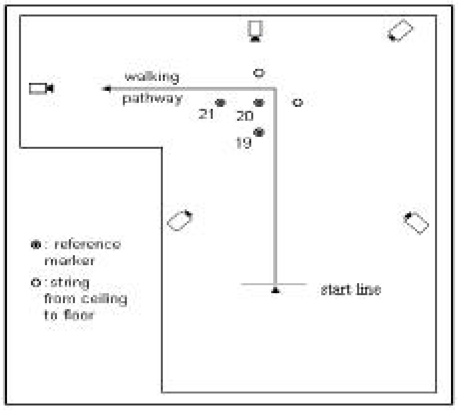

Fig 2. The location of the camera and the walking pathway in the superior view.

location of the center of gravity while it was passing the predetermined zone, which was located just before the turning point (Fig 3). The zone, where the walking speed was measured, was predetermined to obtain the velocity of the center of gravity just before turning. The walking speeds were averaged within commands for each subject.

The amount of foot spinning on the floor was measured by the amount of change in angles between the foot line (from heel to toe markers) and the reference line (from marker 19 to marker 20) on the floor during the ipsilateral single limb support period (from contralateral toe off to contralateral heel contact) while turning. The single limb support period was determined based on the velocity of the markers on the contralateral heel (marker 15 and marker 16) and the contralateral toe ends (marker 17 and marker 18). The accuracy of measuring the stance phase from the kinematic data by a motion analysis system was found to be sufficient in comparison

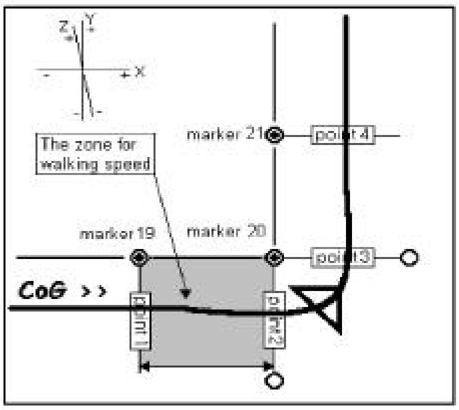

Fig 3. Schematic diagram of the center of gravity pathway and the zone where the walking speed was measured. The universal coordinate is displayed in the upper left corner.

to the measurement by a force plate system (Peham et al, 1999). The advantage of this method was that the temporal parameters of gait could be obtained without using an additional device, such as, a footswitch (Peham et al, 1999).

Lower extremity (LE) rotation was measured by the change in the angle between the hip line (from left greater trochanter marker and right greater trochanter marker) and the foot line (from heel marker to toe marker) during the ipsilateral single limb support period while turning (Fig 4). While this was not the direct measurement of hip joint rotation in the transverse plane, it was considered as a representative measure of hip rotation in the transverse plane because the other lower extremity joints (knee and ankle) allow very limited ranges of rotational motion in the transverse plane during ipsilateral single limb support. The range of motion of the flexed hip is 90° in external rotation and 70° in internal rotation (Nordin and Frankel, 1989). As the hip is extended, the range of rotational motion in the transverse plane decreases because of the limiting force of the adjacent ligaments (Nordin and Frankel, 1989). The range of rotation at the knee joint increases as the knee is flexed, reaching a maximum at 90° of flexion: external rotation ranges from zero to approximately 45° and internal rotation ranges from zero to approximately 30° (Nordin and Frankel, 1989). With the knee in full extension, rotation is almost completely restricted by the interlocking of the femoral and tibial condyles (Nordin and Frankel, 1989). The interlocking of the knee occurs because the medial femoral condyle is longer than the lateral condyle (Nordin and Frankel, 1989). Rotation of the ankle and foot in the transverse plane is inherently limited by the orientations of their structure (Nordin and Frankel, 1989). Lower extremity internal and external rotation in the transverse plane is predominantly produced by rotation at the hip joints. The lower extremity rotation increased with hip external rotation and decreased with hip internal rotation (Fig 4).

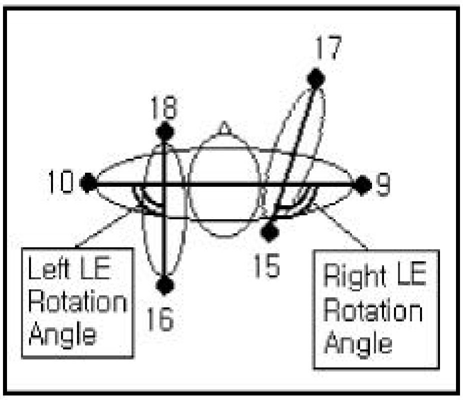

Fig 4. Schematic diagram of the lower extremity (LE) rotation angles in the transverse plane.

Statistics

The paired t-test was used to determine the difference between the amounts of inside and outside foot spin while turning. The Pearson product moment correlation coefficient was used to determine the relationships: between the amount of foot spin while turning and the walking speed; between the amount of lower extremity internal and external rotation while turning and the walking speed; and between the amount of foot spin and the amount of lower extremity internal and external rotation while turning 90°. The regression equation was calculated to determine the nature of the relationship, as needed.

Table 2. Descriptive statistics of foot spin while turning

(degree)	N	Minimum	Maximum	Mean	Standard Deviation	Skewness	
						Statistic	Standard Error
Left spin	45	.29	59.66	15.64*	15.50	1.44	.35
Right spin	45	-2.95	23.87	5.33*	6.46	1.50	.35
Both side spin	45	-1.86	73.01	20.97	18.08	1.07	.35

*p<.001

Results

Effect of walking speed on foot spin

The distributions of all walking speeds are shown in Figure 5. The mean was 1.69 ㎧ with a standard deviation of .20 ㎧ and the distribution was close to the normal curve. The maximum walking speed was 2.03 ㎧ and the minimum was 1.27 ㎧.

The descriptive statistics for each foot spin while turning are displayed in Table 2 and the distributions are shown in Figures 6, 7 and 8. All spins were positively skewed because of their concentrations in the lower ranges and their long tails in the higher ranges. The mean of the inside foot spin was 15.64 with a standard deviation of 15.50. The mean of the outside foot spin was 5.33 with a standard deviation of 6.46. The mean of the total spin of both feet in a single trial was 20.97 with a standard deviation of 18.08. During the left turn, spinning of the left (inside) foot happened more frequently than spinning of the right

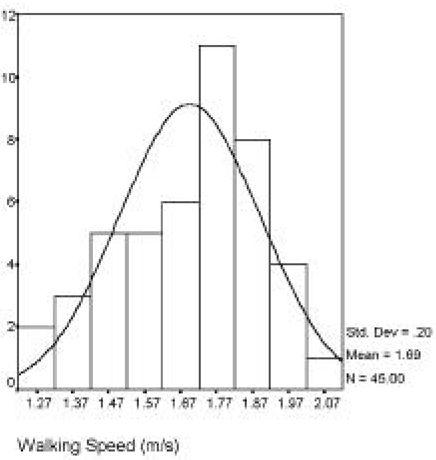

Fig 5. Histograms of the walking speed. Normal curve is illustrated for comparison.

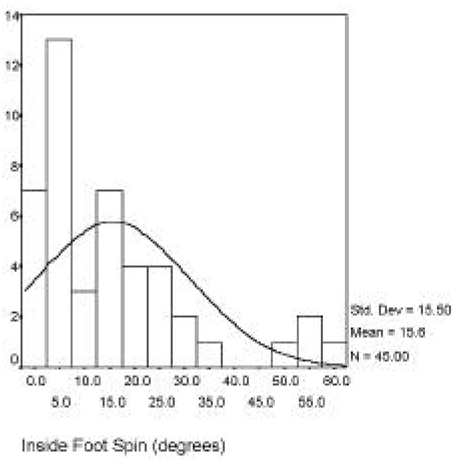

Fig 6. Histograms of the inside (left) foot spin. Normal curve is illustrated for comparison.

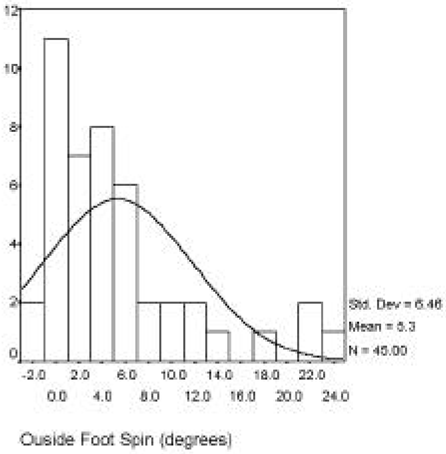

Fig 7. Histograms of the outside (right) foot spin. Normal curve is illustrated for comparison.

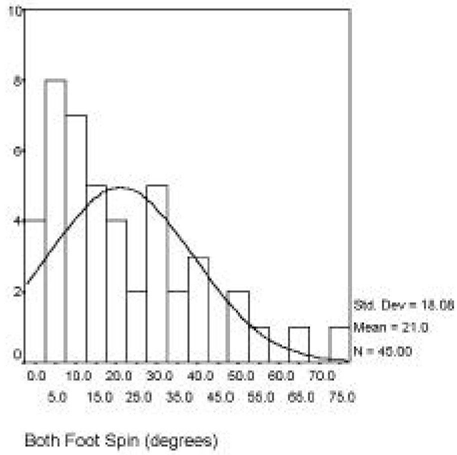

Fig 8. Histograms of the both feet spin in a single trial. Normal curve is illustrated for comparison.

(outside) foot. The number of spins greater than 5, which were considerable spins in this study, was 31 on the inside foot spin (68.9 %) and 17 on the outside foot spin (37.8 %). The mean of the left (inside) foot spin was greater than that of the right (outside) foot spin (t=4.50, p<.001).

The Pearson correlation coefficient (R) between walking speed and amount of inside (left) foot spin was .44 (p=.002). Walking speed and amount of outside (right) foot spin were not statistically significantly correlated (R=.12, p=.419). The Pearson correlation coefficient (R) between walking speed and amount of both side spin in one trial was .43 (p=.004). The correlations are demonstrated in Figure 9.

The regression equation between the amount of inside foot spin in a trial and the walking speed was:

Amount of inside foot spin

= 35.08 (walking speed) - 42.79

The regression equation was statistically significant (F(1,44)=10.56, p=.002) and walking

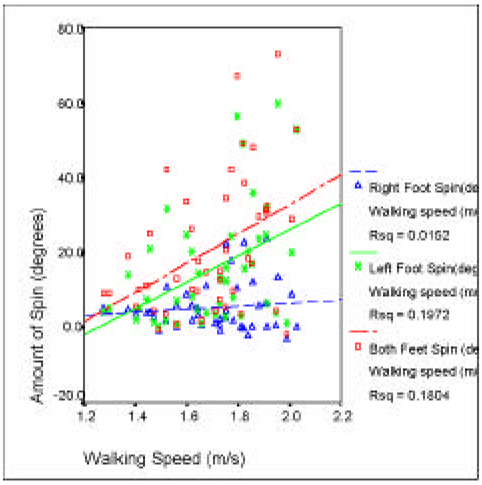

Fig 9. Scatter plot for the relationship between the walking velocity and each foot spin. Each line represents the regre-ssion equation between two variables. Squared correlation coefficients (Rsq) are displayed to determine the accuracy of predictions based on the regression equations.

Table 3. Descriptive statistics of the inside (left) and outside (right) lower extremity (LE) rotation while turning

(degree)	N	Minimum	Maximum	Mean	Standard Deviation
Inside LE rotation	45	-58.95	-7.99	-37.25	14.19
Outside LE rotation	45	-11.24	28.37	9.07	10.98

speed accounted for 19.7% of inside foot spin variance (Fig 9). The slope (B-weights) (p=.002) and the constant (p=.022) of the regression equation were statistically significant. A unit (1㎧) increase in the walking speed was associated with an increase in inside foot spin by 35.08° on average. Because the standardized coefficient in a univariated regression equation with a single predictor is equal to the correlation coefficient, one standard deviation (.20㎧) change in the walking speed was related to a .44° standard deviation (15.50°) change in the amount of inside foot spin on average.

Effects of walking speed and foot spin on lower extremity rotation

LE rotation was measured in the transverse plane during ipsilateral single support period while turning. The descriptive statistics of each LE rotation while turning are displayed in Table 3 and the distributions are demonstrated in Figures 10 and 11. The mean for inside (left) LE rotation while turning was -37.25° with a standard deviation of 14.19° and the mean for outside (right) LE rotation while turning was 9.07° with a standard deviation of 10.98°.

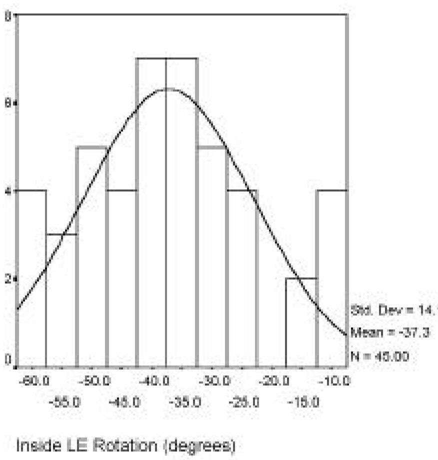

Fig 10. Histograms of the inside (left) lower extremity (LE) rotation. Normal curve is illustrated for comparison.

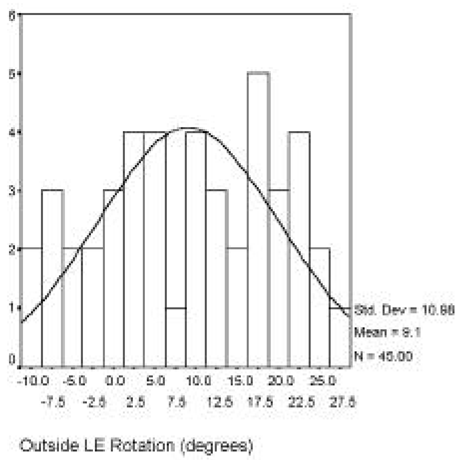

Fig 11. Histograms of the outside (right) lower extremity (LE) rotation. Normal curve is illustrated for comparison.

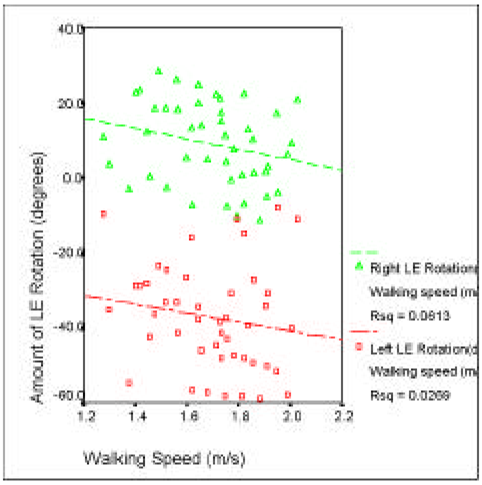

Fig 12. Scatter plots for the relationship between the walking velocity and each side lower extremity (LE) rotation. Each line represents the regression equation between two variables. Squared correlation coefficients (Rsq) are displayed to determine the accuracy of predictions based on the regression equations.

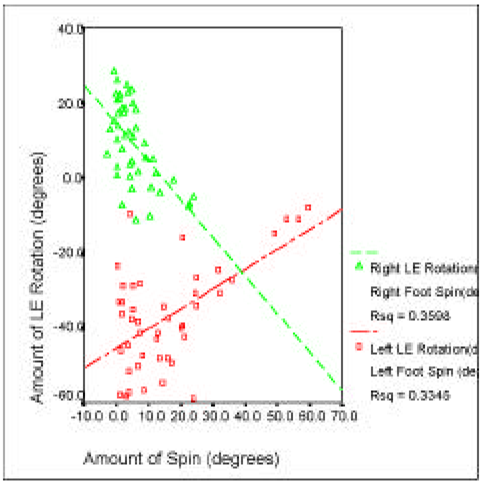

Fig 13. Scatter plots for the relationship between each lower extremity (LE) rotation and each foot spin. Each line represents the regression equation between two variables. Squared correlation coefficients (Rsq) are displayed to determine the accuracy of predictions based on the regression equations.

The Pearson correlation coefficient between each LE rotation and walking speed revealed no statistically significant relationship (for right p=.101, for left p=.281). Left (inside) LE rotation correlated with the amount of inside foot spin (R=.59, p<.001). Right (outside) LE rotation correlated with the amount of outside foot spin (R=-.60, p<.001). The correlations are demonstrated in Figure 12 and 13.

Discussion

The purpose of this study was to analyze the effect of walking speed on the turning strategies and on the amount of lower extremity internal and external rotation while turning 90 degrees in healthy young adults. The following were hypothesized:

1) The turning strategies used would differ at the various walking speeds while turning 90°.
2) The amount of lower extremity internal and external rotation would be related to the walking speed while turning 90°.
3) The amount of lower extremity internal and external rotation and the turning strategies used would be related while turning 90°.

The step strategy without a foot spin was used predominantly during the slow speed trials. The frequency and magnitude of inside foot spin increased as walking speed increased, but outside foot spin was not correlated with walking speed. The amount of lower extremity internal and external rotation while turning 90° was not correlated with walking speed. The amount of lower extremity internal and external rotation and the amount of spin of both feet were negatively correlated while turning 90°.

Step strategy vs spin strategy

To complete turning 90° during walking, a spin and/or a step strategy of turning may be used. In the spin strategy, the whole body rotates on the floor around the ball of one foot. In the step strategy, the upper body (head, neck, both upper extremities, and trunk) and contralateral lower extremity rotate on one hip joint. The step strategy seemed to be more dominant than the spin strategy since only twelve out of forty five trials (26.6%) used a very small amount of spin (less than 5° of both feet spin). The trial completed by using only the spin strategy without the step strategy was rare (the maximum of both feet spin in one trial was 75°). Hase and Stein (1999) found the step strategy was easier than the spin strategy due to larger base of support and a separation of the components of deceleration and turn. Even in spin turns, the amount of foot spin varied from trial to trial. The step and spin strategies were supplementary to each other rather than exclusive. Based on results of this study, it seems to be more reasonable to classify turns into the turns with a foot spin and the turns without a foot spin.

Inside spin vs outside spin

In left turns, spinning on the left (inside) foot happened more frequently and to a greater degree than on the right (outside) foot. In the case of inside foot spin, the direction of the foot spin was the same as the direction of turning. In the case of outside foot spin, the direction of the foot spin was opposite to the direction of turning. If a person turned 90° to the left, the turning direction of the body during inside foot spin was to the left and forward, and the turning direction of the body during outside foot spin was to the right and backward. An extra force was needed to spin the body in the opposite direction of the turn during outside foot spin. This might be the reason why inside foot spins occurred more frequently.

Effect of walking speed on foot spin

Hase and Stein (1999) eliminated the walking speed as an influencing factor in deciding turning strategies by assuming all the testing velocities were similar. However, according to the results of this study, the walking speed before turning was one of the major influencing factors on the amount of inside (left) foot spin while turning. This finding indicated that the turning strategy might vary according to the walking velocity tested. The relationship between the walking speed and the amount of outside (right) foot spin was not statistically significant. The positive relationship between the walking speed and the amount of the inside foot spin may be explained with Newton's laws of motion. According to the law of acceleration (second law of motion), momentum (G) is defined as

$$G = m \times V$$

where m = mass, V = walking speed (Enoka, 1998). When the walking speed is increased, greater forward momentum of the body occurs. The step strategy has a limited capacity to transform forward momentum of the body into rotational momentum in a short period of time because of the position of the center of gravity (anterior to turning foot) and limited range of internal rotation of hip. If the forward momentum of the body exceeded the capacity of a step strategy (rotating the upper body on a hip joint) to transform forward momentum into rotational momentum, increased forward momentum of the body could be transformed into rotational momentum by taking another step or by spinning on the floor around the longitudinal axis of the inside foot to complete the turn. Taking another step while turning, however, would require more time and space to complete the turn. The spin strategy could decelerate the walking speed and turn the body at the same time, because spinning occurs while the center of gravity is passing the turning foot from posterior to anterior (Hase and Stein, 1999). Because of this advantage with the spin strategy, spinning on the inside foot is more effective than taking another step to transform increased forward momentum into rotational momentum in a limited time and space. Spinning on the outside foot would make it more difficult to handle increased forward momentum because the direction of spinning is opposite to the direction of turning and to the direction of walking. Other possible influencing factors on the amount of spin during turn may be the angle of turning, the amount of friction between the shoes and the floor, individual ability to maintain balance during spin, and individual preference.

Effects of walking speed and foot spin on lower extremity rotation

In the case of walking straight, lower extremity rotation in the transverse plane was found to have a negative value because the hip rotates internally during ipsilateral single support period. In the case of the turn without a foot spin, inside LE rotation generally decreased as the upper body rotated internally on the inside hip, and outside LE rotation generally increased as the upper body rotated externally on the outside hip during the ipsilateral foot spin. LE rotation was independent of walking speed (Fig 12), but it was affected by the amount of ipsilateral foot spin (Fig 13). There was a positive linear relationship between the amount of inside (left) LE rotation and the amount of inside (left) foot spin. The amount of outside (right) LE rotation was negatively correlated with the amount of outside (right) foot spin. These results need to be carefully interpreted. In this study, internal LE rotations were defined to have negative values with respect to external LE rotations (Fig 4). The positive relationship between inside LE rotation and inside foot spin meant that the amount of inside LE internal rotation was decreased or the inside LE rotation angle was maintained more with the greater amount of inside foot spin while turning. The inside hip was locked to deliver the rotational moment from the body and the outside LE to the inside LE during the inside foot spin. In the same way, the negative relationship between outside LE rotation and outside foot spin meant the outside LE rotated less externally with outside foot spin than without a foot spin by locking the outside hip to transfer the rotational moment to the outside LE. By locking its rotational movement, the hip joint served as a solid axis to transfer the rotational momentum of the body to the ipsilateral LE in the spin strategy. In this situation, inside hip external rotators and outside hip internal rotators needed to contract eccentrically or isometrically against the rotational moment of the body to lock hip rotation for transferring the rotational moment from the body to the appropriate LE though the hip joint. In spin turns, the whole body could rotate on the floor as one solid unit by locking the turning hip joint. In other words, turning 90° was completed by spinning of the foot rather than by rotating the body on the hip as the amount of LE rotation was decreased.

The function of the hip internal and external rotators has not received the same focused attention as have the hip abductors and extensors in activities of daily living. The hip abductors produce the main force to prevent the center of gravity from dropping during the ipsilateral single support period while walking (Nordin and Frankel, 1989). The hip extensors are the major muscle group used for faster walking or to ascend stairs (Johnston and Smidt, 1969). According to the results of this study, hip internal and external rotators seemed to be essential for completing the turn while walking regardless of the turning strategy used. In the step strategy, they rotated the body on the ipsilateral hip as they contracted concentrically. In the spin turn, they locked the hip joint to transfer the rotational momentum of the body to the ipsilateral lower extremity by contracting isometrically or eccentrically. These findings suggested that the therapeutic exercise for the hip internal and external rotators should be enhanced for patients in hip rehabilitation programs to prepare for their performance during activities of daily living.

Possible limitation of this study were that: 1) hip rotation in the transverse plane was designated by the angle between the pelvis and foot by assuming that amount of the rotation of knee and ankle in the transverse plane was negligible; 2) foot spin during the double support period was not included in the amount of foot spin; and 3) a limited sample size was used.

For the further studies, it might be meaningful to analyze the sequence of segmental body rotation including eye movements while turning and to study the function of arm movements while turning. Electromyographic study of the hip rotators and paraspinal muscles would also be important to determine their function in turning. Determining the amount of rotational moment of the lower extremities in turns with or without a foot spin would be beneficial for patients specially with lower extremity amputation. Study with subjects from different age groups would also valuable to find out the relationship between the turning strategy and aging.

Conclusion

Inside foot spin increased with increased walking speed, but outside foot spin was not related to walking speed. Spinning on the inside foot seemed more effective than taking another step to turn the body quickly with high speed walking. Lower extremity internal and external rotation was not related to walking speed, and it was negatively related to the amount of inside and outside foot spin. As the amount of foot spin increased, hip rotation in the transverse plane decreased to transfer the rotational momentum to the ipsilateral lower extremity. The hip internal and external rotators seemed to have an important role in controlling the body mechanism while turning regardless of the turning strategy used. Increased therapeutic exercise for the hip rotators in hip rehabilitation programs is recommended. Further study is needed to analyze the biomechanical and neuromuscular mechanisms of the body while turning.

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