LOWER LIMB KINETIC CHARACTERISTICS OF THE SIDE-HOP TEST IN HEALTHY INDIVIDUALS

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The purpose of this study was to investigate the relationship between the kinetics of lower limb joints and the side-hop test (SHT) time in healthy individuals and to clarify the factors that may influence performance on the SHT. Twenty male athletes performed the SHT. The SHT time and lower limb joint torque (hip, knee, and ankle) were calculated to explore the relationship between the two variables. The relationship between the SHT time and joint torque was found specifically at the medial and lateral contact phases of the SHT. These results suggest that hip joint function may be important in the medial contact phase. In the knee joint, it was suggested that the load at the frontal plane of the knee joint increases with shorter SHT time. We have provided these results for researchers/clinicians who consider the performance characteristics related to shorter times in the SHT.

KEYWORDS: assessment, ankle sprain, functional performance test

INTRODUCTION: The side-hop test (SHT) is a commonly used test to assess functional performance in individuals with lateral ankle sprains. The test requires a subject to hop medially/laterally using one leg 10 times across two parallel 30-cm-wide lines as fast as possible (Docherty et al., 2005). Since the SHT has high validity in discriminating between individuals with and without chronic ankle instability (CAI) (Rosen et al., 2019), researchers have investigated the kinematic and kinetic characteristics, especially in the ankle joint. In a previous study, it was demonstrated that the mean ankle joint inversion angle in healthy individuals was 27 ± 3.8 °, with a peak inversion angle of 13 ° at the end of medial ground contact and peak eversion angle was 14 ° in the middle of the same phase (Yoshida et al., 2011). In addition, a study comparing the biomechanical characteristics of three single-leg jump performance tests—rebound drop jump test, repetitive jump test, and SHT—in healthy athletes showed that the SHT showed the greatest range of motion in the ankle and knee joints in the frontal plane compared to those in the other jump tests (Nariai et al., 2017). The kinematic characteristics of the SHT in healthy subjects have been established; however, the kinetic characteristics, such as the joint torque of the lower limb joint, are unclear. To effectively use the SHT in the field, it is important to understand the kinetic characteristics of the SHT from a dynamic perspective. Therefore, this study aimed to investigate the relationship between the kinetics of lower limb joints and the SHT time in healthy individuals and to clarify the factors that may influence performance on the SHT.

METHODS: Competitive collegiate soccer players [male, 20; age, 20.25 ± 1.41 years; height, 172.77 ± 4.79 cm; body mass, 67.10 ± 5.16 kg, mean ± standard deviation (SD)] participated in this study. The subjects did not have any functional instability in the ankle joint at the time of measurement. The Cumberland Ankle Instability Tool and a questionnaire on ankle joint history were used to assess ankle joint functionality.
The SHT was conducted in an indoor laboratory. The subjects were allowed to practice the task before data collection. The test leg was the leg used to kick the ball when playing soccer, and all participants performed the test using their right leg. During the trials, the subjects wore their familiar indoor shoes. The subjects stood on a single leg and initiated the SHT by hopping

laterally with the start signal. The SHT times were measured using a manual stopwatch and recorded to the nearest 0.01 s. If the supporting leg stepped on the inside of the line more than twice, free leg touched the ground, or hands left the hips, the trial was considered a failure trial, and the SHT was performed until three successful trials were recorded. There was a 1 min rest time between trials to minimize the effects of fatigue.

Two force plates (9287C, Kistler) and a 10-camera three-dimensional motion analysis system (Vicon MX+, Vicon Motion System) were used to measure the kinetics [ground reaction force (GRF)] and kinematics (joint angles) data during the task. Standard inverse dynamics analysis was conducted to calculate the net internal torque normalized by body mass at the hip, knee, and ankle joints. For the hip joint, flexion and adduction were positive, and extension and abduction were negative; for the knee joint, flexion and varus were positive, and extension and valgus were negative; for the ankle joint, dorsiflexion and inversion were positive, and plantar flexion and eversion were negative. Following the methods of a previous study (Yoshida et al., 2018), we used the force plate data to divide the SHT into two phases (Figure 1): medial hop contact phase (MC, the medial ground contact phase), and lateral hop contact phase (LC, the lateral ground contact phase). Ground contact was defined as the moment when the vertical component of the GRF exceeded 20 N. Toe-off was defined as the point at which the GRF reduced to below 20 N. Of the 10 round trips performed in the SHT, a total of 8 round-trip sections, excluding the first and tenth round trips, were analyzed for peak joint torque. The data obtained from these sections were averaged and adopted as the data for one trial. Finally, the data obtained by averaging three successful trials were treated as the data of one subject.

Spearman's rank correlation was used to examine the relationship between the SHT time and net joint torque of the lower limbs. IBM SPSS statistics, version 25 package (IBM), was used for statistical processing, and the statistical significance level was set at less than 5%.

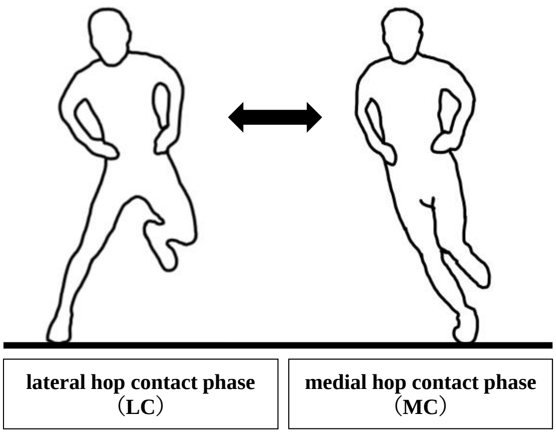

Figure 1: Phase of the SHT

RESULTS: The SHT time was 6.99 ± 0.85 s (mean ± SD). The lower limb peak

Table 1: Peak joint torque in the sagittal and frontal planes of the lower limb joints

Peak Hip Joint Torque (Nm/kg)				
	Flexion	Extension	Adduction	Abduction
MC	2.10 ± 0.70	-1.52 ± 0.52	0.60 ± 0.17	-1.17 ± 0.28
LC	1.28 ± 0.58	-2.41 ± 0.38	1.05 ± 0.24	-3.46 ± 0.47
Peak Knee Joint Torque (Nm/kg)				
	Flexion	Extension	Varus	Valgus
MC	0.63 ± 0.23	-0.26 ± 0.16	0.09 ± 0.04	-0.32 ± 0.12
LC	0.96 ± 0.25	-1.46 ± 0.34	0.46 ± 0.08	-1.29 ± 0.24
Peak Ankle Joint Torque (Nm/kg)				
	Dorsiflexion	Plantar Flexion	Inversion	Eversion
MC	0.06 ± 0.01	-0.05 ± 0.24	0.01 ± 0.02	-0.04 ± 0.01
LC	0.04 ± 0.01	-2.79 ± 0.38	0.33 ± 0.09	-0.10 ± 0.04

Values are presented as mean ± SD.

MC; medial hop contact phase LC; lateral hop contact phase joint torque for each phase of the SHT is shown in Table 1, and the correlation between the SHT time and lower limb peak joint torque is shown in Table 2. Significant correlations are shown in Figure 2 as scatter plots. Significant correlations were found between hip flexion (r = -.677, p < 0.01), extension (r = .653, p < 0.01), and abduction (r = .666, p < 0.01) torque in the MC phase. Significant correlations with knee flexion torque were observed in both the MC (r = -.517, p < 0.05) and LC (r = -.605, p < 0.01) phases, and a significantly correlation with knee valgus torque was found only in the MC phase (r = .692, p < 0.01). Significant correlations with ankle eversion torque and the SHT time were observed in both the MC (r = .453, p < 0.05) and LC (r = .514, p < 0.05) phases.

Table 2: Correlation between the SHT time and lower limb peak joint torque

Peak Hip Joint Torque				
	Flexion	**Extension**	**Adduction**	**Abduction**
MC	**-.677****	**.653****	**-.411**	**.666****
LC	**-.398**	**.215**	**-.433**	**-.317**
Peak Knee Joint Torque				
	Flexion	**Extension**	**Varus**	**Valgus**
MC	**-.517***	**.364**	**-.078**	**.692****
LC	**-.605 ****	**-.053**	**-.338**	**.168**
Peak Ankle Joint Torque				
	Dorsiflexion	**Plantar Flexion**	**Inversion**	**Eversion**
MC	**-.299**	**-.403**	**-.275**	**.453***
LC	**-.090**	**.284**	**.277**	**.514***
MC; medial hop contact phase				*** :p<0.05**
LC; lateral hop contact phase				**** :p<0.01**

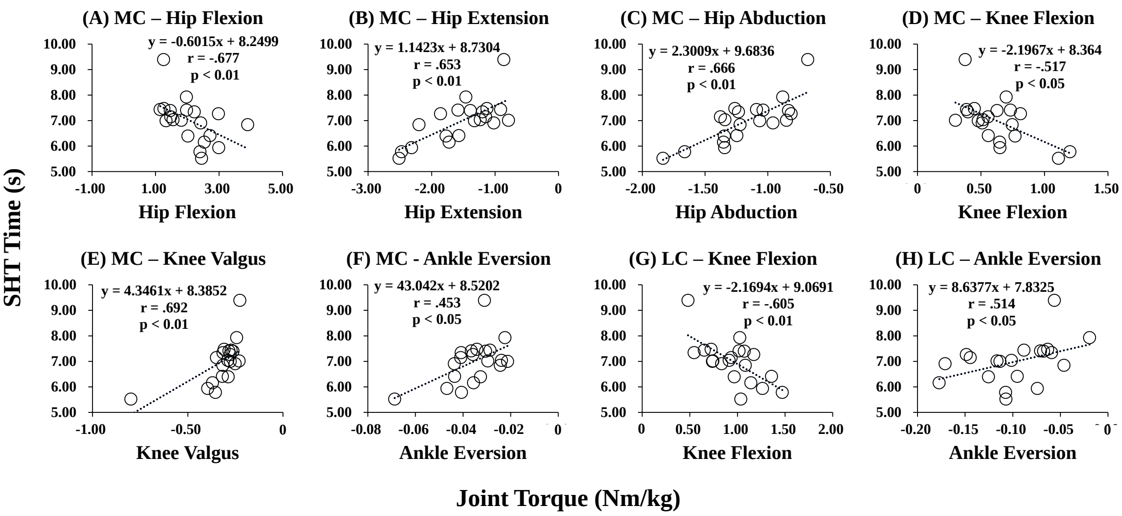

Figure 2: Relationship between the SHT time and lower limb peak joint torque

DISCUSSION: In a previous study investigating kinematics during the SHT, the mean SHT time was 7.29 ± 0.58 s in healthy subjects (Yoshida et al., 2011). On the other hand, our results showed a shorter time in competitive collegiate soccer players, which suggests that caution should be exercised when assessing the SHT time in a "high-intensity" population to compare the results of previous studies.

In each phase of the SHT, there were specific relationships between the peak torque of the three lower limb joints and time (Table 2, Figure 2). Larger correlations were found in the hip

joint than in the other joints, and this is the finding that is emphasized in this study. In particular, there were relationships between the SHT time and hip flexion, extension, and abduction torque only in the MC phase (Figure 2A, B, C), suggesting that the hip joint function in the MC phase enables participants to perform the SHT faster. Controlling the center of gravity (COG) to perform the SHT faster is important. Although the parameters related to the COG are not shown in this study, it is thought that the large hip flexion and abduction torque reduce the displacement of the COG in the vertical and lateral directions, thus resulting in a shorter SHT time. In addition, it has been reported that hip abduction torque contributes to maintaining trunk uprightness during sidestepping (Inaba et al., 2013). In other words, the hip abduction torque may elevate and stabilize the pelvis during single-leg movements in a narrow basal plane. Regarding the hip extension torque, previous studies have demonstrated that flexion of the lower limb joints is necessary to absorb energy during landing and that hip extension force contributes more to energy absorption in soft landings compared to that in stiff landings (DeVita et al., 1992). Therefore, the hip extension torque is thought to contribute to the absorption of the impact of landing after moving from the LC to MC phase.
In the knee joint, correlations with knee flexion torque were observed in both the MC (Figure 2D) and LC (Figure 2G) phases. In addition, there was a correlation with knee valgus torque in the MC phase (Figure 2E), suggesting that the knee valgus torque increases when the SHT is performed rapidly, which may be related to the increased load on the frontal plane at the knee joint.
In the ankle joint, there were significant correlations with ankle eversion torque in both the MC (Figure 2F) and LC (Figure 2H) phases. The SHT involves a movement performed mainly in the frontal plane, and a previous study has demonstrated that the mean angle of inversion and eversion of the ankle joint during the SHT in healthy subjects was 27 ± 3.8 ° (Yoshida et al., 2011). In light of the above, since a large ankle inversion and eversion angle is required to perform the SHT, it is thought that the ankle eversion torque works to fix the ankle joint so that an unstable inversion position is not caused. Meanwhile, if the ankle eversion torque is not sufficiently recovered after an ankle sprain, fast performance on the SHT may be difficult.

CONCLUSION: In this study, we investigated the kinetic characteristics of the SHT in healthy athletes. In particular, it was found that hip function contributes significantly to fast performance on the SHT. The results of this study provide insight into the movement characteristics of faster SHT performance in healthy subjects and basic knowledge for future studies to assess athletes who have sustained sports-related injuries such as ankle sprains, CAI, and anterior cruciate ligament reconstruction.

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