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ORIGINAL

Three-dimensional Kinematics of Knee Joint in a Complete Gait Cycle: A Comparative Study between Handball Players and Non-athletes

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Objective: The purpose of this study is to investigate whether the athletic knee show greater rotation and translation movement than non-athletic knee during the treadmill walking with their preferred speed in a complete gait cycle.

Method: Thirty young and healthy male subjects participated in the study, fifteen handball players (mean age: 19.6 ± 1.4 years old, mean weight: 85 ± 11.9 Kg, mean height: 179.8 ± 4.7) and fifteen non-athletes (mean age: 22.8 ± 1.2 years old, mean weight: 74.5 ± 8.6 Kg, mean height: 175 ± 5.9). Three-dimensional positional coordinate of lower limb during treadmill walking were analyzed.

Results: There were significant differences (t (22.014)=1.585, p=0.127 in the range of internal and external rotation with mean value for handball player (M=14.4513, SD=2.3839) was higher than non-athletes (M= 13.3327, SD=1.337). The magnitude of the difference in the means (mean difference=1.11867, 95% CI: -0.34489 to 2.5822) was significant. There were also significant differences (t (17.956)=1.654, p=0.116 in the max abduction and adduction with mean value for handball player (M=5.7160, SD=2.49281) was higher than non-athletes (M=4.5773, SD=0.94667). The magnitude of the difference in the means (mean difference=1.138, 95% CI: -0.30805 to 2.58539) was significant. At significance level 0.05.

Conclusion: Finding of this study suggest that to understand the actual characteristic of knee motion studies have to be done in different walking and running trial at variable speed.

Keywords: Knee, Movement, Rotation, Translation, Kinematics, Gait cycle

INTRODUCTION

Knee joint is the biggest joint of the human body having both mobility and stability. Rotational and translational movement of the knee occurs in six degrees of freedom. Rotational movements flexion/extension, abduction/adduction and internal/external occurs in sagittal plane, frontal plane and transverse plane respectively. There are three translational movement of tibia with respect to femur, proximal/distal translation, medial/lateral translation and anterior/posterior translation. (Andriacchi, Alexander, Toney, Dyrby & Sum, 1998). In an athletic endeavour most of the injuries are associated with lower extremities with knee being predominant (Van Mechelen, 1992). Actual characteristics of tibiofemoral movement helps to understand the complex mechanics of the knee (Akbarshahi et al., 2010) and also quantify the human gait characteristics (Levine, Richards & Whittle, 2012).

Different methods and systems have been implemented to study the knee joint kinematics, however the motion pattern of the tibiofemoral joint itself are still discussed controversially (Postolka et al., 2020). Most of the studies on knee kinematics in sagittal plane are widely described and accepted while the studies on transverse and frontal plane have reported fluctuating ROM (Clément et al., 2018). Only few studies have focused on the translation movement in the knee joint (Dennis et al., 2001; Gray et al., 2019; Komistek, Dennis & Mahfouz, 2003; Koo & Andriacchi, 2008; Kozanek et al., 2009; Liu et al., 2021; Postolka et al., 2020). Optical motion capture system, sensors and fluoroscopic analyses are being used to study the knee kinematics. Very few researches have been done to study knee kinematics in six degrees of freedom by using Opti track motion capture system. On the other hand, studies are only confined to stance phase or swing phase of the gait cycle, only number of studies has studied knee kinematics in complete gait cycle.

It is a well-known fact that athletic knee is more robust than the non-athletic knee and various studies had been performed to measure the knee strength of athletes. Most of the studies has compare the athletes and non-athletes' knee in different jumping and squatting event. Further many comparative studies have been done to study knee kinematics in healthy and unhealthy knee. To our knowledge there are not any studies which has compare the knee kinematics in six degrees of freedom for athletes and non-athletes during treadmill walking.

Handball is a fast and dynamic game in which player performs the repeated accelerations, sprints, jumps, shots, rapid change of direction, and a high number of physical confrontations with opponent players. (Michalsik, Aagaard & Madsen, 2015). Handball players perform at least 48,000 throwing motions in season of practice and competition (Almeida et al., 2013). In all these events active participation of knee is essential with rotational and translation movement.

Thus, the objective of this study is to investigate whether the athletic knee show greater rotation and translation movement than non-athletic knee during the treadmill walking with their preferred speed. Further this study also wants to compare the 3D knee kinematics of handball player and the non-athletes during treadmill walking with their preferred speed in different event of complete gait cycle.

METHODS

1. Participants

Thirty male participants of Kangwon National University, Samcheok campus voluntarily participated in the study: fifteen handball players (mean age: 19.6±1.4 years old, mean weight: 85±11.9 Kg, mean height: 179.8±4.7) and fifteen non-athletes (mean age: 22.8±1.2 years old, mean weight: 74.5±8.6 Kg, mean height: 175±5.9). Participants had no previous history of medical injury that could affect the natural gait. The participants were trained to walk on treadmill and were explained about the experimental procedure and purpose of the study. Participants walked on treadmill with their preferred speed, handball player (4.44±0.45 km/h) and non-athletes (2.64±0.64 km/h).

2. Experimental equipment

Kinematic data were collected using Opti-track motion capture system (motive 2.1.1) with six cameras (prime X 13). Camera calibration and ground plane setting were performed using CW-500 calibration wand kit and calibration square CS-400 respectively. Treadmill was setup in the capture area for the walking. Retro-reflective markers were attached to motion capture suit classic bilaterally to the greater trochanter, lateral and medial plateau, lateral and medial femoral epicondyle, lateral and medial malleolus, anterior superior iliac spine, posterior superior iliac spine, 1^{st} and 5^{th} metatarsal and the heel. The suit is breathable and markers can be attached to any of the Velcro friendly surfaces for custom marker set and skeleton.

3. Procedure

Preliminary phase of experiment started by introducing the subjects about the experiment, equipment and the way of performing. Subjects were made familiar to walk on treadmill wearing experimental suit. Cameras were adjusted in the designated areas such that they can capture each and every marker attached in the body of the subjects and the camera frame rate was set to 120 Hz. Any external noise or disturbances were removed. After that camera calibration was performed by repeatedly moving calibration wand kit in the capture area. Then after ground plane was set by using the calibration square. Afterwards retroreflective markers were placed in the bony land marks of the body. Afterwards static posture file was collected to define the position and orientation in the space of the body segment. Then the process of data capture began for which each subject walked on treadmill with their preferred speeds.

4. Data collection and analysis

Three-dimensional coordinate of the retroreflective markers attached to the lower extremity joints were obtained after labelling and gap filling of the trajectories of markers. Smoothing feature available in the edit tools of the software (Opti-track motion capture system) was used to remove the disturbances in the data by applying the cut off frequency of 6 Hz. Smoothing feature applies a noise filter (Butterworth 4^{th} low-pass filter). For quantifying gait cycle at first position time graph of heel and toe marker were analyzed. All data processing, analyzing and script coding were performed in MATLAB (MATLAB R2021a).

5. Events and phases

For the study of rotational and translational movement in a complete gait cycle, we divided the walking in eight events and 7 phases which is illustrated in (Figure 1).

1) Events

(1) Event1 (E1): when heel of the right foot contacts the floor
(2) Event2 (E2): flat foot condition of the right foot
(3) Event3 (E3): when femur of the right leg is in vertical position
(4) Event4 (E4): heel off of the right foot
(5) Event5 (E5): toe off of the right foot
(6) Event6 (E6): maximum flexion of the right knee
(7) Event7 (E7): when tibia of the right leg is in vertical position
(8) Event8 (E8): Terminal contact by the heel of the right foot

2) Phases

(1) Phase1 (P1): E1 ~ E2

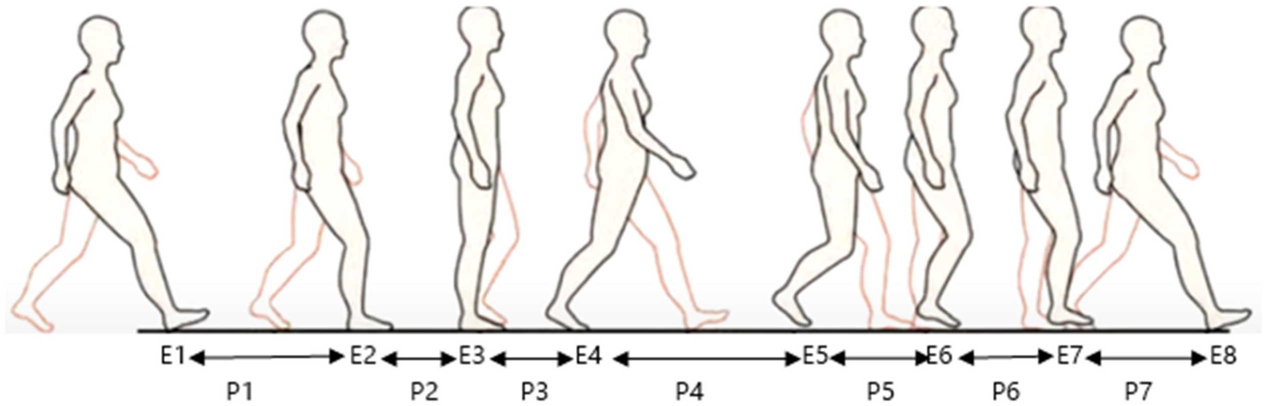

Figure 1. Definition of event and phase.

(2) Phase2 (P2): E2 ~ E3

(3) Phase3 (P3): E3 ~ E4

(4) Phase4 (P4): E4 ~ E5

(5) Phase5 (P5): E5 ~ E6

(6) Phase6 (P6): E6 ~ E7

(7) Phase7 (P7): E7 ~ E8

TOTAL: from initial contact of the right heel to the terminal contact of the right heel. As a whole E1 to E4 represents the stance phase and E5 to E8 represents the swing phase of gait cycle.

6. Statical analysis

To determine the significant difference in dynamic knee motions between the handball player and non-athletes' group Independent samples *t*-test was performed. Level of significance was set to 0.05. Statical analysis was done by using (IBM SPSS statistics 25).

RESULTS

Max value, min value and ROM in the complete gait cycle were calculated for the rotation movement of the knee joint which are presented in (Table 1). Average rotation movement in a complete gait cycle at different event are presented in (Figure 2, Figure 3, and Figure 4).

As we can see in (Table 1) the max value for flexion and extension is slightly higher for the handball player than the non-athletes. However, there are very small differences in abduction/adduction and internal/external rotation movement.

Max value, min value and ROM in the complete gait cycle were calculated for the translation movement of the knee joint which are presented in (Table 2). Average translation movement in a complete gait cycle at different event are presented in (Figure 5, Figure 6, Figure 7).

As we can see in (Table 2) Max, Min and ROM for different translatory movement of tibia with respect to femur shows the slight difference of 2 mm to 3 mm for handball player and non-athletes.

Result of independent samples *t*-test for the rotation movement of the knee joint is presented in (Table 3) shows that there were significant differences (t (22.014)=1.585, p=0.127 in the range of internal and external rotation with mean value for handball player (M=14.4513, SD=

Table 1. Average max and min values and ROM of rotation movement of the knee joint

Rotational movements (mean ± Sd) in (degrees)		Handball player	Non-athletes
Flexion (+) / Extension (−)	Max	64.95±2.4	60.93±2.9
	Min	1.14±3.8	1.17±4.12
	ROM	62.38±2.37	60.73±3.45
Abduction (+) / Adduction (−)	Max	5.71±2.49	4.57±0.94
	Min	-3.73±1.31	-4.35±1.36
	ROM	10.18±1.96	9.1±2.09
Internal (+) / External (−)	Max	9.61±2.61	8.31±2.38
	Min	-3.66±3.33	-3.31±4.02
	ROM	14.45±2.38	13.33±1.33

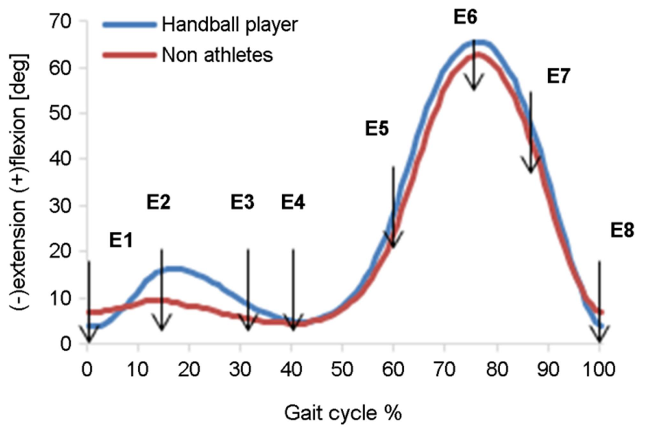

Figure 2. Average flexion and extension of knee joint at different event in a complete gait cycle

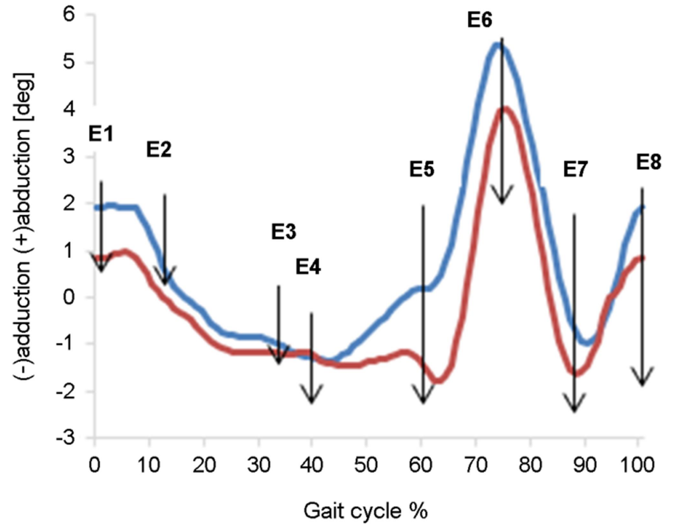

Figure 3. Average abduction and adduction of knee joint at different event in a complete gait cycle

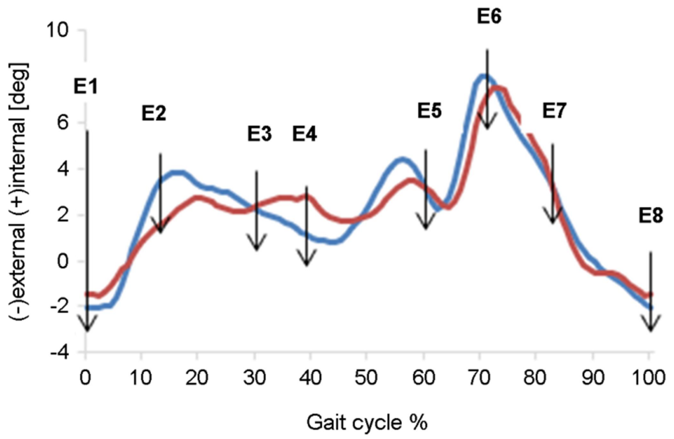

Figure 4. Average external and internal rotation of knee joint in a complete gait cycle.

Table 2. Average max and min values and ROM of translation movement of the knee joint

Translation movement (mean ± Sd) (mm)		Handball player	Non-athletes
Proximal (+) / Distal (–)	Max	23.4±3.26	21.23±2.81
	Min	-8.75±2.72	-5.93±4.08
	ROM	27.73±3.73	24.38±3.38
Anterior (+) / Posterior (–)	Max	11.47±3.34	10.64±2.75
	Min	-4.39±3.56	-4.19±2.84
	ROM	15.38±2.44	12.60±2.68
Lateral (+) / Medial (–)	Max	8.46±2.63	6.27±2.19
	Min	-5.96±2.36	-6.18±2.07
	ROM	12.43±2.09	10.88±1.39

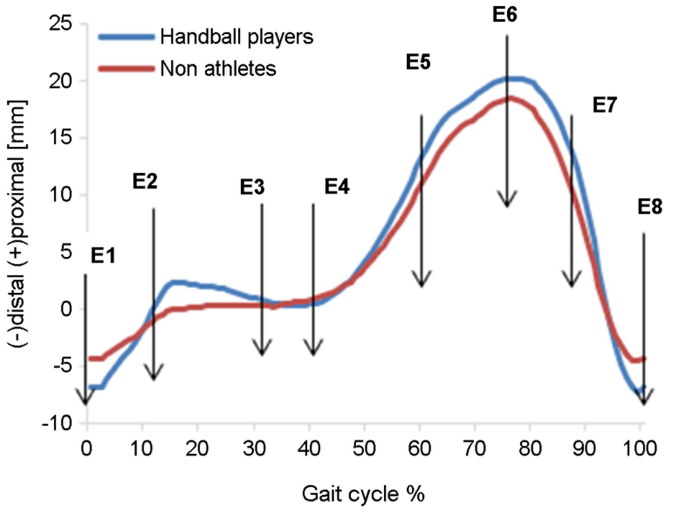

Figure 5. Average distal and proximal translation of tibia with respect to femur at different event in a complete gait cycle

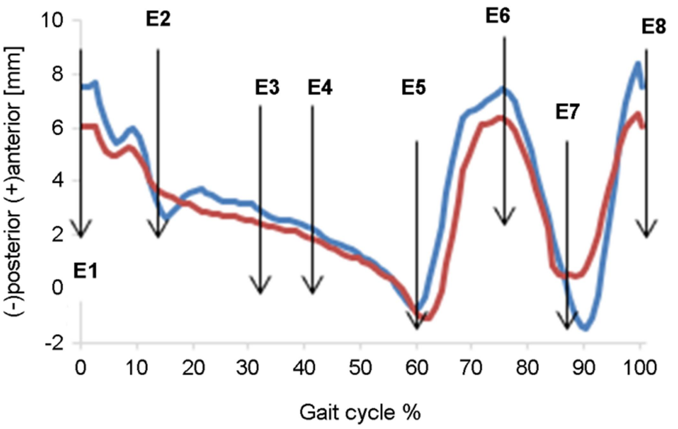

Figure 6. Average posterior and anterior translation of tibia with respect to femur at different event in a complete gait cycle

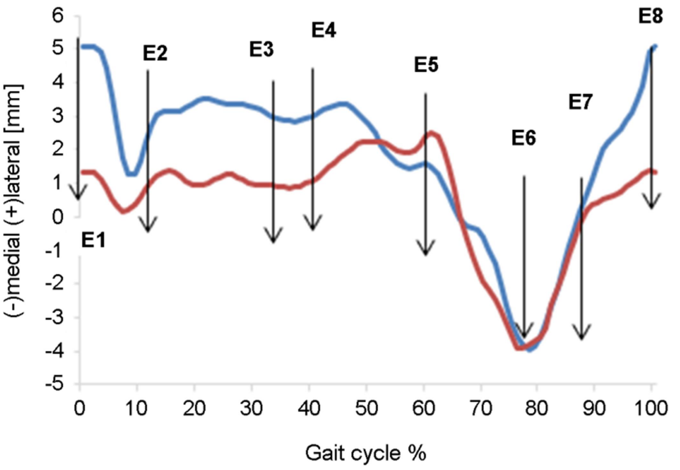

Figure 7. Average medial and lateral translation of tibia with respect to femur at different event in a complete gait cycle

Table 3. Result of independent samples *t*-test for the rotation movement of the knee joint

		F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence interval of the difference	
									Lower	Upper
Max flexion or extension	EVA	.403	.531	4.025	28	.000	4.02133	.99905	1.97487	6.06780
	EVNA			4.025	26.963	.000	4.02133	.99905	1.97132	6.07135
Min flexion or extension	EVA	.774	.387	-.019	28	.985	-.02733	1.45498	-3.00772	2.95305
	EVNA			-.019	27.850	.985	-.02733	1.45498	-3.00844	2.95378
ROM during flexion and extension	EVA	3.451	.074	1.523	28	.139	1.64867	1.08247	-.56868	3.86602
	EVNA			1.523	24.838	.140	1.64867	1.08247	-.58147	3.87880
Max internal and external rotation	EVA	.284	.598	1.426	28	.165	1.30267	.91338	-.56831	3.17364
	EVNA			1.426	27.758	.165	1.30267	.91338	-.56905	3.17438
Min internal and external rotation	EVA	.702	.409	-.259	28	.797	-.35000	1.34906	-3.11343	2.41343
	EVNA			-.259	27.064	.797	-.35000	1.34906	-3.11775	2.41775
ROM during internal and external rotation	EVA	5.823	.023	1.585	28	.124	1.11867	.70574	-.32697	2.56430
	EVNA			1.585	22.014	.127	1.11867	.70574	-.34489	2.58222
Max abduction and adduction movement	EVA	8.566	.007	1.654	28	.109	1.13867	.68849	-.27164	2.54897
	EVNA			1.654	17.956	.116	1.13867	.68849	-.30805	2.58539
Min abduction and adduction movement	EVA	.019	.890	1.259	28	.219	.61467	.48837	-.38571	1.61504
	EVNA			1.259	27.966	.219	.61467	.48837	-.38577	1.61510
ROM during abduction and adduction	EVA	.173	.681	1.455	28	.157	1.07933	.74195	-.44048	2.59915
	EVNA			1.455	27.871	.157	1.07933	.74195	-.44080	2.59946

Note: EVA (Equal variance assumed), ENVA (Equal variance not assumed)

2.3839) was higher than non-athletes (M=13.3327, SD=1.337). The difference of magnitude (mean difference=1.11867, 95% CI: -0.34489 to 2.5822) was significant. There were also significant differences (t (17.956) =1.654, p=0.116 in the max abduction and adduction with mean value for handball player (M=5.7160, SD=2.49281) was higher than non-athletes (M=4.5773, SD=0.94667). The difference of magnitude in the means (mean difference=1.138, 95% CI: -0.30805 to 2.58539) was significant.

Result of independent samples *t*-test for the translation movement of the tibia with respect to femur is presented in (Table 4). No significant differences were found in translation movement at significance level 0.05. There were slight differences of 2 mm to 3 mm for Max, Min and ROM for different translatory movement of tibia with respect to femur however no significant difference was found during statical analysis.

DISCUSSION

In this study we calculate the rotation and translation movement of the knee joint and compare the knee kinematics of handball player and non-athletes during treadmill walking with the preferred speed in a complete gait cycle. In this study subjects walked in treadmill as it allows ambulation within small area and facilitates the use of static camera and monitoring equipment (Alton, Baldey, Caplan & Morrissey, 1998). Preferred walking speed of the subject in our study in agreement with the study (Mohler, Thompson, Creem-Regehr, Pick & Warren, 2007).

We divided the walking in eight different events and seven different phases as illustrated in (Figure 1) and studied the knee movement in individual event. Division of walking in events and phases had made the study easier to understand the actual characteristics of knee movements in stance and swing phase of gait cycle. Rotational movement are presented in (Table 1, Figure 2, Figure 3 and Figure 4). Maximum values of rotational movement were observed in E6. Flexion and extension of the knees were noticeable in E2, E5, E6 and E7. Previous studies (Gray et al., 2019) had reported two flexion and two extension peaks during the stance phase but the particular event was not described. However, in this study we had clearly explained the peaks in flexion and extension. Result of *t*-test in (Table 3) shows the comparison between means of rotational movement of two groups. Significant differences were found in ROM of internal and external rotational and

Table 4. Result of independent samples *t*-test for the translation movement of the knee joint

		F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence interval of the difference	
									Lower	Upper
Max proximal and distal translation	EVA	.598	.446	1.946	28	.062	2.16800	1.11424	-.11443	4.45043
	EVNA			1.946	27.403	.062	2.16800	1.11424	-.11667	4.45267
Min proximal and distal translation	EVA	.411	.527	-2.220	28	.035	-2.81400	1.26770	-5.41076	-.21724
	EVNA			-2.220	24.367	.036	-2.81400	1.26770	-5.42831	-.19969
ROM in proximal and distal translation	EVA	.375	.545	2.574	28	.016	3.34713	1.30031	.68357	6.01070
	EVNA			2.574	27.734	.016	3.34713	1.30031	.68242	6.01185
Max lateral and medial translation	EVA	.297	.590	2.475	28	.020	2.19133	.88534	.37780	4.00486
	EVNA			2.475	27.112	.020	2.19133	.88534	.37512	4.00754
Min lateral and medial translation	EVA	.322	.575	.272	28	.788	.22067	.81120	-1.44101	1.88234
	EVNA			.272	27.526	.788	.22067	.81120	-1.44230	1.88363
ROM in lateral and distal translation	EVA	3.882	.059	2.397	28	.023	1.55780	.64986	.22662	2.88898
	EVNA			2.397	24.367	.025	1.55780	.64986	.21763	2.89797
Max anterior posterior translation	EVA	1.316	.261	.743	28	.464	.83100	1.11889	-1.46094	3.12294
	EVNA			.743	27.011	.464	.83100	1.11889	-1.46473	3.12673
Min anterior posterior translation	EVA	.736	.398	-.168	28	.868	-.19800	1.17885	-2.61276	2.21676
	EVNA			-.168	26.690	.868	-.19800	1.17885	-2.61811	2.22211
ROM during anterior posterior translation	EVA	.538	.469	2.969	28	.006	2.78467	.93776	.86375	4.70559
	EVNA			2.969	27.771	.006	2.78467	.93776	.86303	4.70630

max abduction and adduction between handball player and the non-athlete group. This may be the result of high load torsional activities such as cutting and pivoting during training and game play (Muaidi, Nicholson & Refshauge, 2009). Sports such as handball require a high-level coordination, postural control strength and flexibility associated with the lower extremity and knee is directly involved in such activities. While passing and receiving the ball, cutting movements and quick changes of direction are required at that time rotation of the leg is essential.

Translational movement are presented in (Table 2, Figure 5, Figure 6 and Figure 7). Maximum proximal translation was observed in E6 whereas distal translation was found maximum in E1 and E6. Distal translation was found higher in handball player than non-athletes. Posterior translation was found maximum in E5 for non-athletes and in E7 for handball player. Small difference was found in the medial /lateral translation in E1 and E8. In spite of differences in the translation movement no significant difference was found during the statical analysis. The result of independent samples *t*-test in (Table 4) shows no significant difference for translation movement of tibia between the two groups of the study. The anterior posterior translation of the tibia with respect to femur in our study is found to be consistent with previous studies (Iwaki, Pinskerova & Freeman, 2000; Pinskerova et al., 2004), however in this study we are able to focus the movement at the particular event in the gait cycle which is one of the merit of this study. The magnitude of the overall translation are comparable Previous studies (Liu et al., 2021; Postolka et al., 2020) which has accessed to knee movements in six degree of freedom using motion capture system and fluoroscope. However, in the use of fluoroscope subjects have to get expose in the harmful radiation for the longer period of time.

Variety of approaches had been used to study the knee kinematics however in this study we approach to knee movement in 6 degrees of freedom with the use of motion capture system only. Further we studied the athletes and non-athletes' knee in different event of a complete gait cycle.

CONCLUSION

We calculate rotation and translation movement of knee during the complete gait cycle using motion capture system. Comparison of calculated movements between handball player and non-athletes shows Significant difference in the ROM of internal-external rotation and max abduction and adduction. Active involvement of handball players knee during game and training session may be the result of such difference. In this study dominant knee at a single speed was investigated. The result of this study may not be applicable to other athletes rather than handball player. In order to understand the actual characteristic of knee motion future studies have to be done in different walking and running trial at variable speed.

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