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Investigating the landing kinetics factors and preparatory knee muscle activation in female handball players with and without dynamic knee valgus while performing single leg landing

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Abstract

Study aim: to examine the differences in landing kinetics factors (LKF) to assess the whole body stability and preparatory muscle activation (PMA) in female handball players with and without dynamic knee valgus.
Material and methods: Twenty-four professional female handball players (11 with (DKV) and 13 without (Control) dynamic knee valgus) were asked to perform three trials of a single-leg landing. LKF and surface EMG were recorded. Initial contact knee valgus angle (IC KVA), vertical ground reaction force (vGRF), confidence ellipse area of center of pressure (CEA), time to stability (TTS) and EMG from 100 ms prior to ground contact were used in the data analyses.
Results: Multivariate analyzing of LKF showed significant differences between two groups ($p = 0.001$) while for PMA the result was not significant ($p = 0.361$).
Conclusion: Altered landing mechanism considered as a predictor of non-contact knee injuries such as ACL rupture. Therefore according to current study it seems important to focus on reducing valgus angle in designing injury prevention program.

Key words: ACL injury risk factor – Muscle activation pattern – Medial knee displacement – Single leg drop landing

Introduction

Dynamic knee valgus (DKV) is an abnormal movement pattern visually characterized by excessive medial movement of the lower extremity during weight bearing [12]. DKV has been applied to a multi joint movement impairment syndrome [39]. It refers to an internal excessive movement of lower extremity during weight bearing activities [30]. DKV is widely considered to be one of the main risk factors for anterior cruciate ligament (ACL) injuries in sports involving multiple landing, abrupt stopping and sudden direction change [14, 23, 26, 27, 30 ,40]. Handball is known as one of the 1st level high risks sports in knee injuries [13]. It has been shown that female athletes are at an increased risk for ACL injuries with an injury rate 3 to 5 times higher than men [11, 18, 35]. These studies specified the importance of the preseason assessment. The single leg landing (SLL) test has been used as one of the main tests for assessing DKV in female athletes to consider the risk of knee injuries. Hence minimizing DKV in such activities may prove to be critical in reducing ACL injury incidence.

Since the premier function of the muscle during movement is to stabilize the joints by generating force and prepare the joint for ground contact that also depends on the dynamic lower extremity alignment [10, 17], alternated lower extremity alignment may lead to deficits in dynamic muscle functions. Moreover to limit frontal plane motion, it is important to notice that preparatory muscle activation (PMA) is more vital than reactive muscle firing [3]. In fact as described by previous studies [17, 31], PMA in muscles crossing the joint decreases adverse knee joint angulations during rapid movements and impulsive joint loading. In addition proper lower limb alignment enables the confronted forces to be well transferred to the joints [17].

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The importance of postural control in sports has been stressed from an injury prevention and return-to-play decision perspective [8, 20, 28, 42]. Likewise based on systematic approach in motor control the joint stability is an essential base to have the whole body stability during movements [24]. It has been confirmed that landing kinetics factors (LKF) such as center of pressure (COP), ground reaction force (GRF) and time to stability (TTS) are related to presence of different types of movement impairments and musculoskeletal injuries, e.g. pronation syndrome, ankle instability, ACL injuries etc. [6, 7, 9, 44, 46, 47].

To develop more targeted injury prevention programs to reduce DKV during landing in female handball players, a more detailed description of relation of DKV, LKF and PMA seems beneficent. Some studies have shown that there is significant difference in EMG activity of lower extremity muscles such as gastrocnemius, tibialis anterior, quadriceps, hamstring and gluteal muscle in presence of DKV [2, 31, 36]. In their study, Palmieri-Smith et al. [37] found that for recreationally active females the peak valgus knee angle (VKA) was associated with preparatory vastus medialis, vastus lateralis, and lateral hamstring activation. They specified that a higher peak VKA was associated with increased preparatory vastus lateralis and lateral hamstring activity, while a lower VKA was associated with increased preparatory vastus medialis activity [37].

The activation of muscles surrounding the knee is one of the factors in dynamic knee stability. It is thought that finding the differences between PMA in female handball players with and without DKV can be useful to design training programs for high risk female athletes for ACL injuries. Thus, the aim of the current study was to investigate the differences of the LKF and PMA of lower extremity muscles between female handball players with and without dynamic knee valgus during performing SLL drop landing.

Material and methods

Subjects

In this study 24 female handball players from the 1st league of Poland participated (age: 21.48 ± 0.62, weight: 65.32 ± 1.39 kg, height: 172.12 ± 1.21 cm). They were collected from 35 athletes that responded to the invitation sent by their club including the study details. They all have been professional handball players for more than 2 years and did not have the history of knee or ankle injuries proved by the club medical staff in their dominant leg identified by the stair test. Written informed consent was obtained from all participants before testing. The study has been approved at the research ethics committee in the Faculty of Physical Education and Sports Sciences, University of Tehran[1] and the measurement performed in the central lab of Józef Piłsudski University of Physical Education in Warsaw.

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Participants were divided into 2 groups: 11 with (DKV) and 13 without (Control) dynamic knee valgus. 2D analysing of one leg drop landing test was performed to define the DKV group. Athletes with more than 12 degrees of knee valgus were considered as the DKV group [14].

Instrumentation

The movements of the lower extremity segments were tracked with a three-dimensional motion capture system during a single-leg drop landing from a 40 cm box. EMG data were collected using an 8-channel surface electromyography system (NORAXON, TeleMyo 2400R, G2 8-ch) at 2000 Hz. According to SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) structures for EMG preparation, the skin was shaved and cleaned with isopropyl alcohol before applying the surface electrodes. The electrodes (Skintact, Leonhard Lang GmbH, Innsbruck, Austria) were secured over the muscle bellies of the tibialis anterior (TA), medial gastrocnemius (MGastr), rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), medial hamstring (MH), lateral hamstring (LH), and gluteus medius (GMed) according to the technique described by SENIAM as follows: TA at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus. MGastr on the most prominent bulge of the muscle while it was contracted. RF at 50% on the line from the anterior superior iliac spine to the superior aspect of the patella.VM at 80% on the line between the anterior superior iliac spine and the superior aspect of the patella. VL, at 2/3 on the line from the anterior superior iliac spine to the lateral side of the patella. MH at 50% on the line between the ischia tuberosity and the medial epicondyle of the tibia. LH at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia. Gmed, at 50% on the line from the crista iliac to the trochanter. Two sets of five-second maximum voluntary isometric contractions (MVICs) with 1 min rest between repetitions were accomplished for the purposes of normalization. For TA subjects were asked to stand on both feet in a relaxed position and try to perform Dorsiflexion against resistance (ankle start position was 90 degrees). For Gastr subjects were sat on a chair facing the wall and while the hip joint was strapped and fixed and knee was 60 degrees flexed, they were asked to perform plantar flexion against the wall (ankle start position was 90 degrees). For hamstring MVICs were performed while subjects were in prone position with the knee in 30º of flexion. Quadriceps MVICs were performed while subjects were seated with the knee in 90º of flexion and for GMed subjects performed side lying hip abduction while their foot and shoulder were fixed and knee were flexed.

Three-dimensional trajectory data were acquired using a 10-camera motion-analysis system (Vicon MX T10s-Series) and connected to NORAXON software at a sampling rate of 200 Hz. Twenty eight reflective markers were used to collect kinematic data. These markers were placed on anatomical landmarks according to Helen Hays methods to collect kinematic data. The markers were fixed on the landmarks using double-sided tape (Fig. 1). Static calibration trial was performed with the subject standing in a neutral position on the force plate used to record the kinetic data such as ground reaction force (KISTLER, Multicomponent Force Plate for Biomechanics Type 9287C).

All subjects performed a 5–10 min whole body warm-up before testing. After recording the MVICs and marker placement, the test instruction was explained to athletes and they were permitted sufficient practice (3–5 repetition) trials for familiarization. For the test, the athlete was positioned on top of a 40-cm box adjacent to the force platform and performed 3 sets of landing (Fig. 2) [1].

Data analysis

The NORAXON software from Motion Analysis was used to simultaneously record the EMG and motion data. All EMG data were processed by using MATLAB 2018 (Math Works, Natick, MA, USA). Electromyography

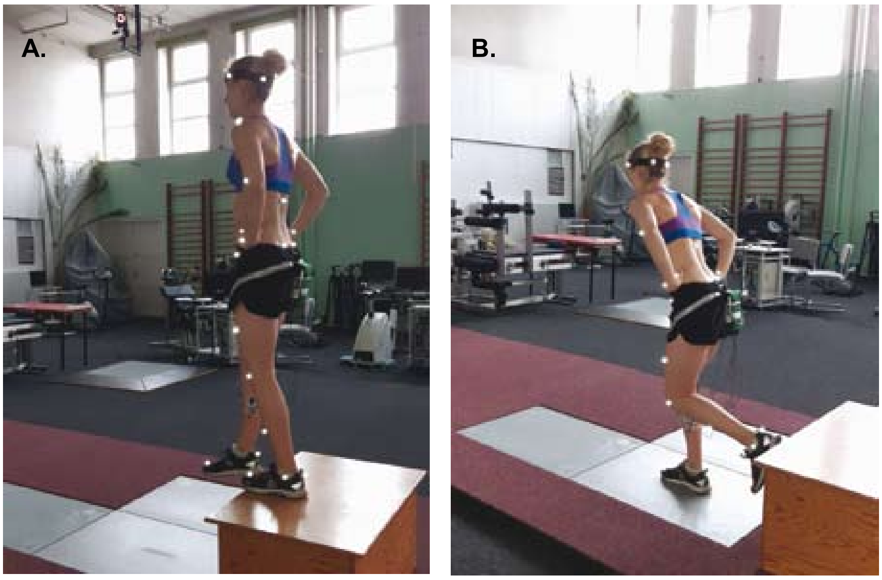

Fig 1. The test position A. Start position B. End position

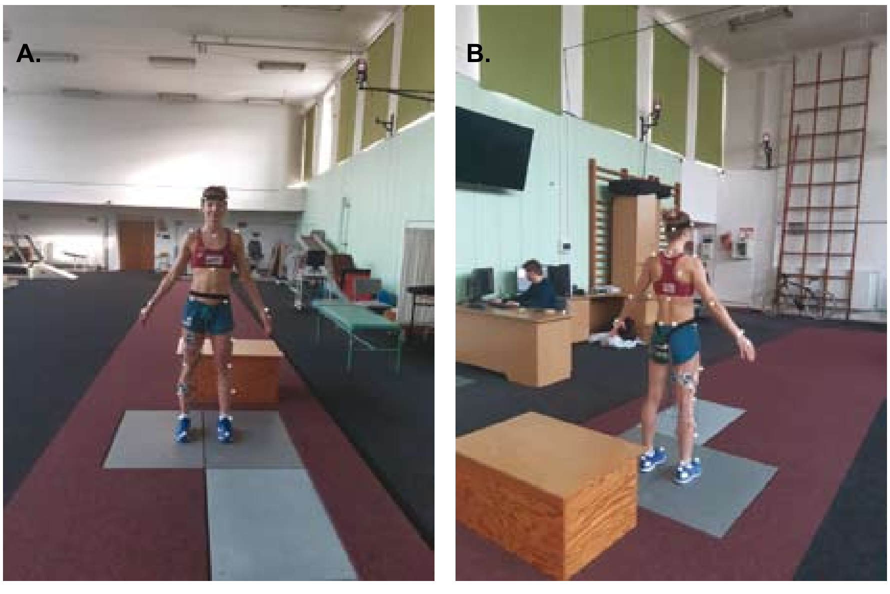

Fig 2. Markers placement A. Anterior B. Posterior view

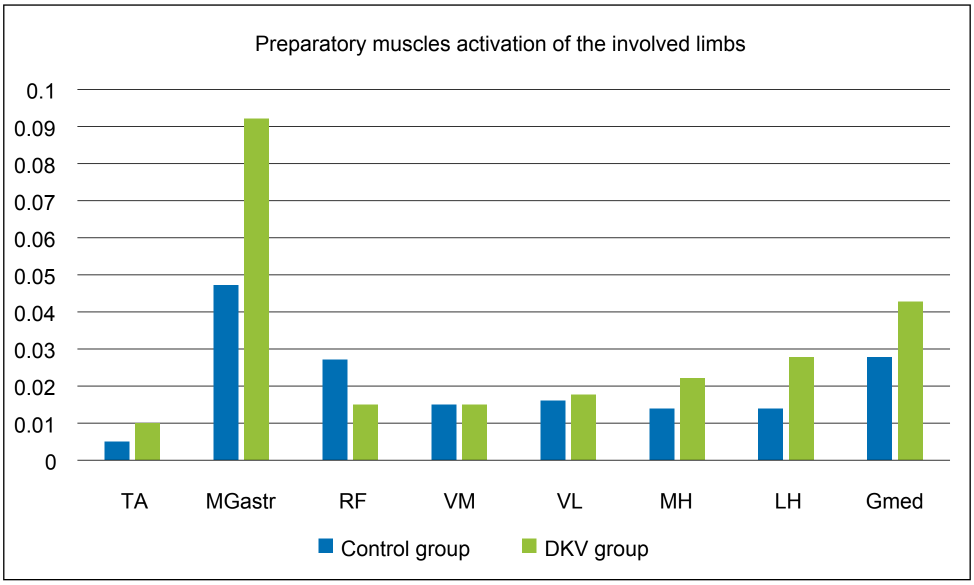

Fig. 3. PMA of the involved limbs

data were first transferred from the time domain to the frequency domain by the Fourier analysis method and then band-pass filtered between 10 and 500 Hz with a zero lag, fourth order Butterworth digital filter. Dynamic EMG data, recorded during the SLL task, were normalized to the average peak muscle activity recorded during the three trials of MVIC tests. Muscle activity was described from 100 ms prior to ground contact to initial ground contact. PMA was extracted as the mean values in this window, calculated for all three trials and averaged for statistical analysis [37].

Raw kinematic data of the knee was post-processed, reconstructed and labeled using NORAXON software. The knee joint center was defined as the midpoint between the medial and lateral femoral epicondyles. Marker trajectories data were low-pass filtered using a 4^{th} order zero-lag Butterworth filter at 12 Hz [32]. The data convention for frontal knee angle was denoted as positive and negative, respectively. Vertical ground reaction force (vGRF) was recorded in order to calculate initial contact. Knee valgus at initial contact was extracted when vGRF exceeded 5 N. Entropy-based method was used For COP analyzing and the 95% confidence ellipse area (CEA) was calculated from the initial contact to 300 ms after [19]. In this study, stability is considered when the vertical force changes on the force plate are in the range [0.95 1.05] × W, where W is the weight of the participant. Stability time is calculated as the time required from initial contact to the moment of stability [9].

Statistical analysis

Descriptive data (means ± SD) were calculated for the age, height and weight for each subject group.

Table 1. Demographic information of subjects

Variable	Mean ± SD
Age [year]	21.33 ± 3.07
Body height [cm]	172.29 ± 5.85
Body nass [kg]	65.46 ± 7.06

Shapiro-Wilk analyses were used to test the normality of all EMG and kinetic data. For analyzing the differences of EMG variables and kinetic factors between two groups, with and without DKV, the multivariate analysis, MANOVA[2] was used. The intraclass correlation coefficient (ICC 1.k) data was calculated according to Weir [35]. Statistical tests were performed with SPSS Statistics Version 25.0 (IBM Corporation, Armonk, NY). A P value of ≤0.05 was considered significant. The results are shown as the mean with 95% confidence intervals (CI) or range, as noted.

Results

The demographic information of all participants is presented in Table 1. Descriptive data of the PMA of the involved limbs and Kinematic results are presented in Figure 3 and Table 2 respectively. Table 3 demonstrates the multivariate analysis of LKF and PMA of selected muscle in two groups. The between subjects test result is shown on Table 4.

[2] Multivariate analysis of variance

Table 2. Descriptive data of landing kinetic factors (LKF)

Variable	Mean ± SD	
	Control group	DKV group
KVA at Initial Contact [deg]	11.18 ± 0.035	21.36 ± 2.57
CEA [cm^2]	70.47 ± 20.67	61.03 ± 7.69
vGRF [N]	4.25 ± 0.22	3.80 ± 0.17
TTS [ms]	666.94 ± 165.30	753.03 ± 324.79

Table 3. The multivariate analysis of landing kinetic factors (LKF) and preparatory muscle activation (PMA) of selected muscle in two groups

	Value*	F	Sig	Partial Eta Squared	Observed power
LKF	2.023	9.61	0.001	0.699	0.997
PMA	0.631	1.184	0.37	0.387	0.361

* We used Hotelling's Trace value for analyzing process.

Discussion

This study examined differences in LKF and PMA of lower extremity muscles between female handball players with and without dynamic knee valgus to clarify the effects of DKV as a major risk factor of ACL injuries in female athletes landing kinetics factors. According to our finding there were significant differences in KVA at Initial Contact and CEA between two groups. Investigating the kinetic factors and landing tasks through biomechanical analysis can provide valuable evidence about the importance of paying attention to reducing DKV in prevention exercises programs. Single-limb landings characterize a rapid deceleration and have been noted to be a mechanism for ACL injury. Decreasing knee valgus during landing may be essential in reducing primary and second ACL injury incidence [15, 38].

There were no statistically significant differences in PMA between two groups. Although previous studies has shown differences in selected muscles, we should consider this that our participant were healthy high level athletes and the literature are mostly focused on injured athletes or non-athletes participants [2, 17, 31, 36]. It is known that the PMA is different in athletes and non-athletes [29, 43]. Correspondingly due to changes in neuromuscular control after sport injuries such as ACL rupture it is believed that

Table 4. The multivariate analysis of landing kinetic factors (LKF) and preparatory muscle activation (PMA) of selected muscle in two groups

Variable	F	Sig.	Partial Eta Squared	Observed power[i]
IC KVA	12.428	0.002*	0.361	0.920
vGRF	2.628	0.119	0.107	0.341
CEA	18.549	0.001*	0.457	0.984
TTS	0.631	0.435	0.028	0.118
TA	2.037	0.168	0.085	0.276
M Gastr	3.121	0.091	0.124	0.394
RF	0.008	0.930	0.000	0.051
VM	0.028	0.868	0.001	0.053
VL	0.468	0.501	0.021	0.100
M Hams	1.252	0.275	0.054	0.188
L Hams	2.568	0.123	0.105	0.335
Gmed	2.479	0.130	0.101	0.325

muscles show alternative activity patterns [31, 34]. However we observed respectively higher PMA in TA 50%, MGastr 49%, VL 11%, MH 36%, LH 50% and Gmed 35% in DKV group. RF was 80% less active in DKV group and there was no differences in VM preparatory activity between two groups.

Previous studies has confirmed that increased co-activation of agonist and antagonist musculature enhanced overall joint stiffness and this may affect distal and proximal joint dynamic stiffness [16, 21]. Our result is similar to Padua et al. in TA and MGastr activation. On study, Neuromuscular Characteristics of Individuals Displaying excessive medial knee displacement (MKD). They reported higher TA and MGastr activation in participant with excessive MKD. They theorized that increased ankle joint stiffness have led to compensatory MKD during the squatting task [36]. However they did not find any differences in Gmed activation in the same way as Padua et al. Their examination was during performing squat that is a simpler task than SLL [36]. As Neamatallah et al. showed the relationship between GMed activation and knee and hip biomechanics depends on the task [33].

Likewise Mohammadpour et al. [31] reported no relations between knee valgus at initial contact and quadriceps preparatory activity in athletes with Anterior Cruciate Ligament Reconstruction. The main knee stabilizer with moment arms maybe the quadriceps and hamstring muscles that support the knee from frontal plane motion and loads [48]. hamstring and quadriceps co-activation has known as one of the most effective knee stabilizing pattern in frontal plane [27]. We believe our findings also indicate that the relative co-activation between the hamstring and quadriceps is more relevant to control the KVA during SLL than the quadriceps alone [25]. However future study seems needed to examine the co-activation of these two muscle in athletes with DKV.

These results are important since our participants were high level athletes with no pathologies or injuries history on their dominant leg while on the most previous study, the relation between knee valgus at initial contact has been investigated on participant with knee injuries such as ACL injuries. The interesting finding of our study maybe the fact that however our results did not show any significant differences in PMA some lower extremity muscles indicated different preparatory activity that may lead to ACL injuries. This suggests that to insure of the importance of DKV in injury prevention programs for female handball players, future studies are required to investigate the effects of DKV on neuromuscular changes and motor control.

We did not observe any significant differences in vGRF and TTS between two groups, however participants with DKV needed more time to stability. This result is similar to Vaz et al. [42]. They also did not observe any differences in TTS between MKD and Control group. Accordingly the need for investigating the correlation of DKV and Landing Stability Index such as TTS in healthy athletes seems necessary. Likewise Claudino et al. [5] did not find any significant relationships between knee valgus displacement (KVD) and vGRF. They found significant correlation between KVD and anterior-posterior component of GRF ($p = 0.025$). Interestingly also Hewett et al. [15] reported significant correlations between knee adduction angle and peak vGRF in ACL injured ($r = 0.67$, $p < 0.001$), but not for uninjured athletes ($p = 0.44$). Previous studies used simpler tasks such as double leg drop landing, for investigating the relationship between KVA and vGRF [5]. Therefore we decided to question the differences in vGRF between two groups with and without DKV while performing SLL, more similar to athletes' performance. In the same way we did not find any significant differences in mean vGRF between two groups. Thus our results suggest that presence of DKV alone cannot be assumed as the factor for changing in vGRF in high level handball players.

The location of center of mass (COM) has been introduced as one of the main factors in non-contact ACL injuries [41]. The COP signal is a bivariate distribution and is jointly defined by AP and ML directions. The output signals are non-linear and non-stationary [19]. There are still some antithesis conclusion about which component of COP displacement is a more important risk factor in ACL injuries [4, 15, 42]. Therefore we used the entropy-based method to avoid the limitations of linear analyzing methods [19]. Our result showed a significant difference in CEA between two groups. It means the mean of smallest ellipses that covered 95% of the points of COP diagram was significantly smaller in DKV group compared to control group. It can be concluded that the variation of COP diagram seems to be more in the control group than DKV group. On the contrary Vaz et al. [42] reported an increase in entropy values in MKD group, indicating greater randomness in CoP fluctuations. They used TTS as the starting point for the CoP oscillations analysis while we started our calculating from the Initial contact. This may be one of the reasons for this contradictory result. Also their participant were recreationally active female and as mentioned before there has been reported that there is differences in neuromuscular functioning of athletes and non-athletes in the drop jump [43]. According to the principle of abundance or task-relative redundancy, apparently redundant degrees-of-freedom are as useful and even vital for many aspects of motor behavior. This enables the central nerves system (CNS) to allow more variation in movement components leading to better control of the task goal [22]. In order to explicate these results we suggest future studies to investigate the impacts of DKV on motor control in healthy athletes.

Conclusion

Our results demonstrated significant difference in LKF between female handball player with and without DKV. Although the PMA differences were not statistically different, they may lead to the observed LKF differences. Altered landing mechanism considered as a predictor of non-contact knee injuries such as ACL Rupture. Therefore according to current study it seems important to focus on reducing valgus angle in designing injury prevention program.

Conflict of interest: Authors state no conflict of interest.

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