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Kinovea®'daki Düşük Kare Hızlı Videonun İnterpolasyonla Derinlik Sıçramasındaki Doğruluğunun Değerlendirilmesi

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Özet

Bu çalışmanın amacı, derinlik sıçramasında 2D Kinovea®'daki düşük kare hızlı videoyu interpole ederek doğruluğunu 3D Qualisys Track Manager (QTM)'e göre değerlendirmektir. Çalışmada 37 sporcudan toplam 74 sıçrama alındı. Sporcuların belirli anatomik noktalarına (akromiyonun sağ/sol üst noktası, anterior superior iliak, femur distal noktası - patella lateral noktası, ön ayak 5. falanks) yansıtıcı işaretleyiciler yerleştirildi. İki farklı kutu yüksekliğinden tek tekrarlı çift bacak derinlik sıçraması gerçekleştirildi. Tüm sıçramalar 500 Hz'de QTM kameralar kullanılarak kaydedildi ve 30 Hz'de video ile senkronize edildi. Tüm yansıtıcı işaretleyiciler izlendi ve pozisyon ve yer değiştirme QTM ve Kinovea®'da analiz edildi. Tüm yansıtıcı işaretleyicilerin atlama anları (ilk temas, kalkış, ikinci temas) için yatay ve düşey konumları hem QTM'de hem de Kinovea®'da elde edildi ve MS Excel'e aktarıldı. Kinovea® verileri Matlab yazılımında doğrusal bir yöntem kullanılarak 500 Hz'e interpole edildi. Tüm işaretleyicilerin yatay ve düşey yer değiştirme parametreleri, sıçramanın iki farklı evresi (temas ve uçuş fazları) için anlar arasındaki konum verilerinin farkları olarak MS Excel'de hesaplandı. Bu değişkenler için JASP 0.17.1'de Bland-Altman yöntemi kullanıldı. Bland-Altman analizi, derinlik sıçraması sırasında ilk temas anında sol ve sağ ayağın yatay konum için QTM ve Kinovea® arasında uyum gösterdi. Temas ve uçuş evreleri sırasında düşey yer değiştirme için uyumsuzluk gözlendi. Sonuç olarak, Kinovea®'da, özellikle bir hareket için düşey yer değiştirmede doğru sonuçlar elde etmek için, videonun kare frekansının 30 Hz'den fazla olması önerilmektedir.

Anahtar Kelimeler: Hareket analizi, Kinovea®, Qualisys Track Manager, Derinlik sıçraması.

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Evaluation of the Accuracy of Low Frame Rate Video in Kinovea® on Drop Jump By Interpolation

Abstract

The aim of this study is to evaluate the accuracy of interpolated low frame frequency video data analyzed in 2D Kinovea® during drop jump movements, in accuracy with 3D measurements obtained from 3D Qualisys Track Manager (QTM version 2020.3). A total of 74 jumps were collected from 37 athletes. Reflective markers were placed on specific anatomical points (right/left upper point of acromion, anterior superior iliac spine, distal point of femur - lateral point of patella, forefoot 5th phalanges, foot) of the athletes. A single trial of a double-legged drop jumps were performed from two different box heights. All jumps were recorded using QTM cameras at 500 Hz and synchronised with video at 30 Hz. All reflective markers were tracked and position and displacement were analysed in QTM and Kinovea®. The horizontal and vertical positions of all reflective markers for jump instants (first contact, take-off, second contact) were obtained both in QTM and the Kinovea®, were exported to MS Excel. Kinovea® data were interpolated to 500 Hz in Matlab software using a linear method. Horizontal and vertical displacement parameters were calculated in MS Excel, as the differences of the position data between the instants for the two different phases of the jumps (contact and flight phases). The Bland-Altman method was used for those parameters in JASP 0.17.1. The Bland-Altman analysis showed agreement between QTM and Kinovea® for the horizontal position of the left and right foot at first contact during the drop jump. Disagreement was observed for the vertical displacement during the contact and flight phases. In conclusion, to obtain accurate results in Kinovea®, especially in the vertical displacement for a movement, it is recommended that the frame frequency of the video should exceed more than 30 Hz.

Keywords: Motion analysis, Kinovea®, Qualisys Track Manager, Drop jump

Introduction

Motion analysis systems are essential to determine sports performance in athletes objectively. For a reliable performance evaluation, it is crucial to have quantitative and accurate data through valid and reliable equipment.

Whether it pertains to a particular sport (kicking, throwing, hitting, etc.) or a fundamental movement analysis (gait, run, etc.), using a camera-based three-dimensional motion analysis system to measure kinematics in the laboratory is considered the gold standard (Eltoukhy et al., 2016). Qualisys Motion Capture SystemTM is one of these widely used laboratory-based systems, that track the reflective markers fixed on the athlete's body via infrared technology (Barris & Button, 2008). Despite providing objective and quantitative data, the system's costly nature, personnel training, and extensive area requirements pose some disadvantages (Fernández-González et al., 2020). These challenges have prompted researchers and practitioners to seek alternative motion analysis systems, which offer high validity and reliability. Collecting positional data through video-based systems has addressed these requirements. Multiple applications and software options exist for mobile and PC use in the field, including Kinovea®, one of the most highly regarded 2D video-based motion analysis systems. The widespread and easy use of these 2D video-based systems encouraged the coaches and practitioners by giving them opportunities to get objective data about their athletes' performance. The reliability and validity of Kinovea® are evidenced in various studies examining half squat (Jimenez-Olmedo et al., 2021), bench press (Sañudo et al., 2016), walking (Amirah et al., 2017; Yusof et al., 2022) and jumping (Balsalobre-Fernández et al., 2014; Nor Adnan et al., 2018; Pueo et al., 2020). Other studies have also employed Kinovea® to evaluate sport-specific performance, such as handball scoring (Al-Jadaan, 2020), soccer penalty kicks (Attaallah et al., 2021), basketball three-point shots (Irawan & Prastiwi, 2022), and tennis spin services (Aprilo et al., 2022). The reliability of Kinovea® is indicated by the intraclass correlation coefficient (ICC), which demonstrates high consistency and absolute agreement (ranging from 0.982-0.997 and 0.975-0.980, respectively). The validity is stated as Pearson's product-moment correlation coefficient (r), which has been found to range between 0.84-0.99 in previous studies (Balsalobre-Fernández et al., 2014; Jimenez-Olmedo et al., 2021; Pueo et al., 2020; Sañudo et al., 2016). Although numerous studies have established Kinovea® as a valid and reliable tool (Nor Adnan et al., 2018; Yusof et al., 2022), only a few studies have compared it to Qualisys Motion Capture SystemTM for sport-specific performances. For example, Marshall suggests that Kinovea® can be an alternative software to Qualisys Motion Capture SystemTM in evaluating vertical and leg stiffness whilst hopping (Marshall, 2018).

In the literature, Kinovea® is widely used by sports scientists for analyzing sport-specific movements across various disciplines. In this context, the present study investigates whether the two-dimensional

(2D) positional and displacement data of anatomical landmarks during a drop jump can validly reflect three-dimensional (3D) data obtained from Qualisys Track Manager (QTM), a gold-standard motion capture system. The aim of this study is to evaluate the accuracy of interpolated low frame frequency (30 fps) video data analyzed in Kinovea® during drop jump movements, in accuracy with 3D measurements obtained from QTM. The hypothesis of the study is that, during the phases of the drop jump, the positions and displacements of anatomical landmarks in the horizontal and vertical planes, as measured in 2D using Kinovea®, will demonstrate significant accuracy and agreement with those measured in 3D using QTM.

Method

Research Group

A total of 37 athletes studying at Halic University, department of Sports Sciences and practicing different sports branches (track and field, body-building, taekwondo, kickboxing, pilates, basketball, soccer, tennis, rowing, swimming, and mountaineering) were participated in the study. Demographic information such as age, height, weight and BMI of the athletes participating in the study were recorded as 22.27±4.00years, 174.62±10.60cm, 64.12±12.79kg, 20.85±2.24kg/m^2, respectively.

The sample size of the subjects was determined by G-Power analysis (G-Power 3.1.9.4) at β = 0.05 α = 0.95. The Halic University Non-Interventional Scientific Research Ethics Committee approved the research for human research by the 2013 Declaration of Helsinki (30.11.2022-227). All measurements were performed in the Sports Biomechanics Laboratory of Halic University Alibeykoy Campus, Faculty of Sport Sciences.

Data Collection

The athletes' personal information and physical characteristics (age, height, body weight), dominant side, sports, and sports age were recorded. Reflective markers were placed on the specific anatomical points (left and the right upper point of the acromion, left and right anterior superior iliac spine, left and right distal point of the femur and lateral point of the patella, left and right forefoot 5th phalanges) of the athletes. The athletes performed a single trial of double-legged drop jumps with hands on hips, on boxes of different heights (26 and 42 cm). Each subject performed the jumps on the same day with one minute rest. Total data collection were finished within ten days. A total of 74 jumps were evaluated as a single dataset to increase the diversity of performances. All drop jumps were recorded by the Qualisys Track Manager (QTM) version 2020.3 (Qualisys Inc., Gothenburg, Sweden), a software for the three-dimensional motion analysis system (Qualisys), using seven Oqus 7+ cameras (dimensions: 18.7×11×12.5cm; weight: 1.9-2.1kg) at 500 Hz. A Sony HDR-CX 330 camera at 30 Hz was connected to the system, working simultaneously with the QTM via the onboard Blackmagic Declink capture card. The Oqus cameras were placed three to six metres apart, surrounding the athletes, who were positioned at the centre of the camera system. The Sony camera was positioned in front of the athlete at a distance of 300 cm without zooming, to record the horizontal (medial-lateral direction) and vertical (inferior-superior direction) axes of movement. Another device connected to the Qualisys system via the QTM was the force plate (Bertec, FP6090-15, USA). An analogue interface (230599, Qualisys, Sweden) was used for the connection. The force plate was placed in front of the boxes and used to accurately determine the contact (first and second) and take-off instants precisely. The platform also limited the area where the athletes would perform their jumps and prevented any possible horizontal deviations. A wired trigger switch was the key element to synchronise the start time of the drop jump among the force platform, Qualysis and Kinovea® via QTM.

Calibration of the QTM system was performed via the dynamic wand calibration method with the T-wand for 45 seconds once a day before the first athlete's drop jump with the L-wand placed on the mid-point of the camera system. The average standard deviation of wand calibration length collected from ten measurement days was 0.32±0.04 mm.

Synchronized video, captured in QTM at AVI format (1920x1080, 30 Hz), was analysed in Kinovea® software version 0.9.5 (Figure 1). The width of the force plate (medial-lateral direction) was used to calibrate the software. It is important to note that no force platform data was utilised in the study.

Apart from the calibration of the systems themselves, markers were placed on top of two different boxes with known height and width and evaluated. For the 26 cm box, the height (inferior-superior direction) of the right front edge was measured as 256.3 mm in QTM, and 253.0 mm in Kinovea®. The height of the left front edge was determined as 262.6 mm in QTM and 261.4 mm in Kinovea®. For the 42 cm box, the height of the right front edge was measured at 404.6 mm in QTM and 406.1 mm in Kinovea®. For the left front edge, the height was determined 407.2 mm in QTM, and 408.9 mm in Kinovea®. The position data of these markers showed agreement on the vertical axis, the right front edge of the box (0.905), and the left front edge of the box (0.255). The width of the 26 cm box was measured as 381.2 mm in QTM and 378.4 mm in Kinovea®, while the width of the 42 cm height box was determined as 371.7 mm in QTM and 372.1 mm in Kinovea®. There was agreement found for the width of the boxes (1.560).

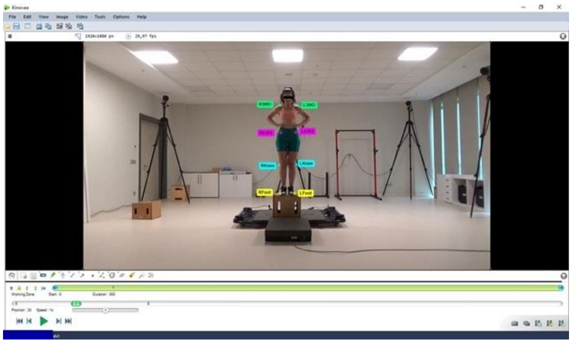

Figure 1. Kinovea® software version 0.9.5

Data Analysis

All reflective markers were labelled manually in the first frame and tracked automatically with model in the QTM. The position data of each marker were gap-filled and smoothed by low-pass fourth-order zero-lag Butterworth with a 6 Hz cut-off frequency in the QTM (Figure 2).

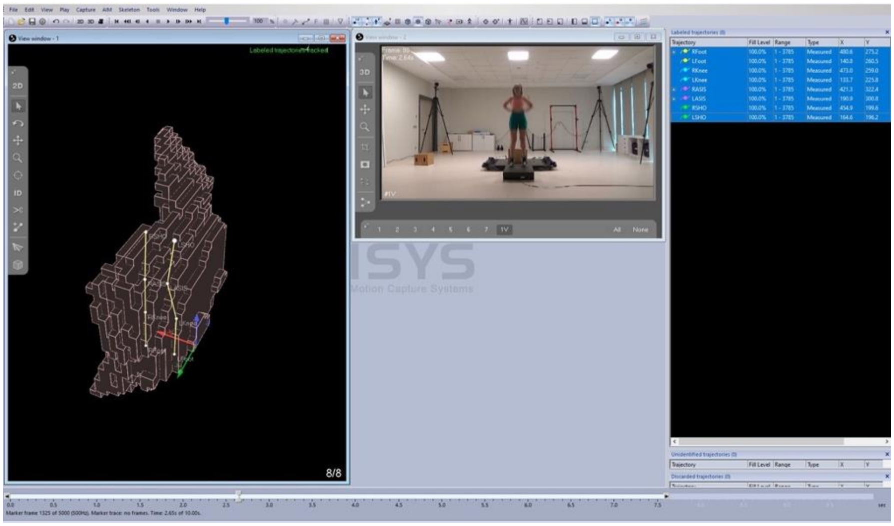

Figure 2. Data collection scheme in QTM

The drop jump was divided into two phases by three instants in the QTM by using the force platform data: a) First contact (FC) b) Take-off (TO) and c) Second contact (SC). Instants were the contact moment from the cameras view. The first frame in which either (the right or left) foot of the subject contacts the force platform after dropping from the box was called FC. The first frame in which either (right or left) foot of the subject left the force platform was called TO. The frames between FC and TO were called the contact phase. The first frame at which either (right or left) foot of the subject touched the force platform after the TO instant was called SC. The frames between TO and SC were called the flight phase. All instants and phases of the drop jump are shown in Figure 3. The horizontal (medial-lateral direction) and vertical (inferior-superior direction) position data of each marker for each instant were exported to MS Excel.

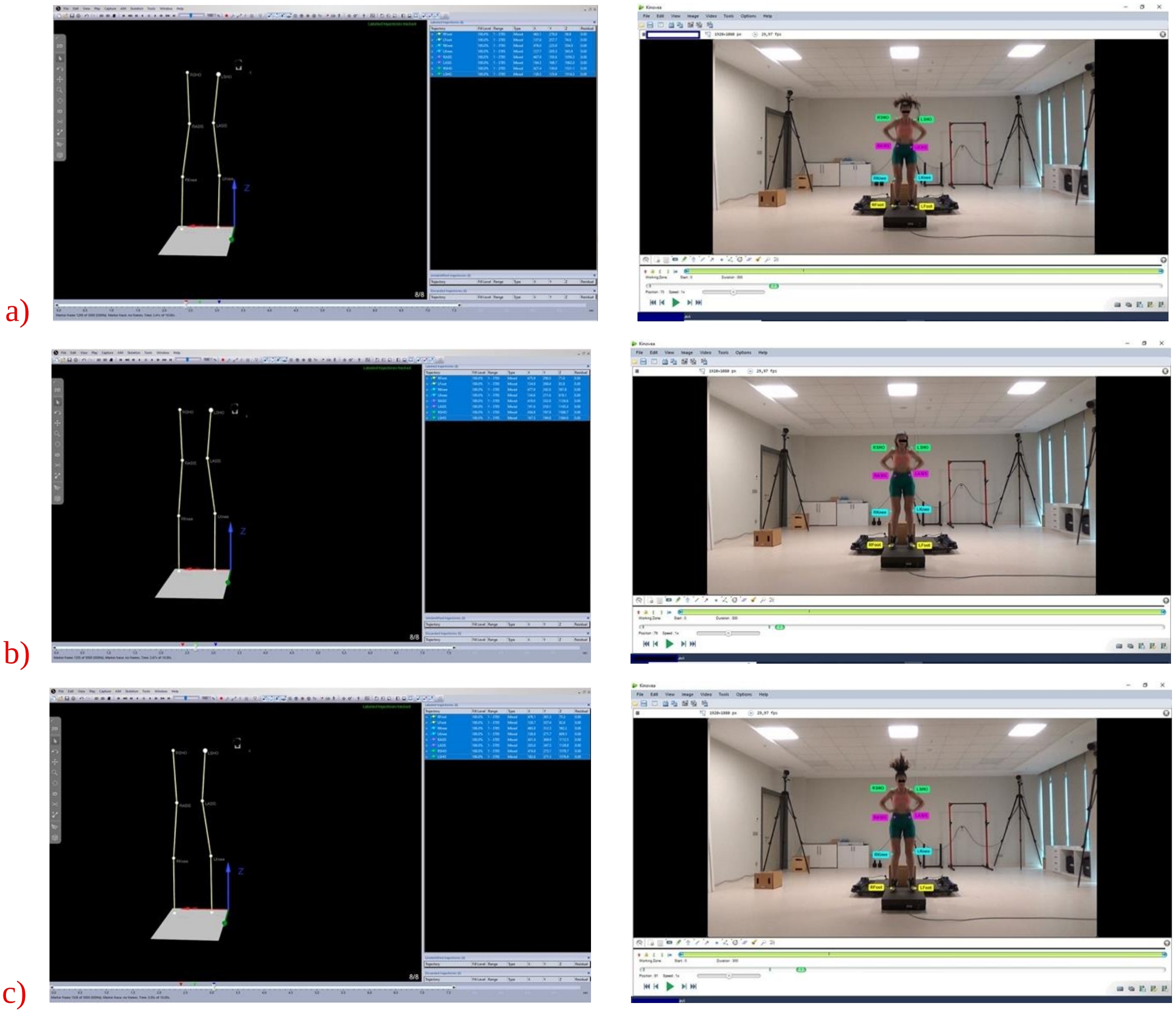

Figure 3. The instants of Drop Jump a) First contact (FC) QTM and Kinovea® b) Take-off (TO) QTM and Kinovea® c) Second contact (SC) QTM and Kinovea®

The reflective markers corresponding to the anatomical points were selected and manually labelled by the analyst in the first frame of the video and then automatically were tracked by the Kinovea® software. After auto-tracking, the analyst manually were checked and corrected the markers in each frame if necessary. In Kinovea®, as in some other studies, manual corrections were ~~are~~ sometimes made when the software cannot detect the correct pixels during auto-tracking (Beulens et al., 2020, Bubanj et al., 2023). The horizontal (medial-lateral direction) and vertical (inferior-superior direction) positions of all the markers were calculated by the Kinovea® software, according to the default settings of the software, were then were exported to MS Excel without any additional filtering. The raw data of the 30 Hz video image analysed in Kinovea® were interpolated by a linear method in Matlab 2012b software, corresponding to 500 Hz, and then were exported to MS Excel. The linear interpolation formula is shown below.

$yn = y0+(tn-t0) \times (t1-t0)/(y1-y0)$

yn: was the new point to be interpolated,

tn: was the new point of timeline,

y0 and y1: previous and next point of yn,

t0 and t1: previous and next point of tn.

The frame numbers corresponding to each instant determined in QTM during the drop jump were also used as the instants in the interpolated Kinovea® data.

The horizontal and vertical positions of the markers for the left upper point of the acromion (LA_h-pos; LA_v-pos), right upper point of the acromion (RA_h-pos; RA_v-pos), left anterior superior iliac spine (LASIS_h-pos; LASIS_v-pos), right anterior superior iliac spine (RASIS_h-pos; RASIS_v-pos), left distal point of femur - lateral point of patella (LKnee_h-pos; LKnee_v-pos), right distal point of femur - lateral point of patella (RKnee_h-pos; RKnee_v-pos), left forefoot 5th phalanges (LFoot_h-pos; LFoot_v-pos), right forefoot 5th phalanges (RFoot_h-pos; RFoot_v-pos) corresponding to first contact, take-off and second contact of all jumps were recorded for statistical analysis.

The horizontal (h-disp) and vertical (v-disp) displacements of the markers were calculated as the differences in the positional data between the FC instant and the lowest vertical positional data of the markers during the contact phase. On the other hand, the h-disp and v-disp of the markers for the flight phase were calculated as the differences in the position data between the TO instant and the highest vertical position data of the markers.

The horizontal and vertical displacements of the markers for the left upper point of the acromion (LA_h-disp; LA_v-disp), right upper point of the acromion (RA_h-disp; RA_v-disp), left anterior superior iliac spine (LASIS_h-disp; LASIS_v-disp), right anterior superior iliac spine (RASIS_h-disp; RASIS_v-disp), left distal point of femur - lateral point of patella (LKnee_h-disp; LKnee_v-disp), right distal point of femur - lateral point of patella (RKnee_h-disp; RKnee_v-disp), left forefoot 5th phalanges (LFoot_h-disp; LFoot_v-disp), right forefoot 5th phalanges (RFoot_h-disp; RFoot_v-disp) were recorded for statistical analysis.

Statistical Analysis

The position and displacement parameters in horizontal and vertical axes were analysed in JASP 0.17.1 (University of Amsterdam-Intel). The conformity of the data to normal distribution was determined by Skewness and Kurtosis values. Skewness and Kurtosis values were found to be between "-2.0" and "+2.0" and in this direction, it was accepted that the data showed normal distribution (George and Mallery, 2010). The descriptive data of the parameters were calculated in this analysis program. One-sample T-test were applied to the position and displacement parameters between the QTM and Kinovea®. Bland-Altman method was used for the parameters which showed no significant differences in One-Samples T-test. In the Bland-Altman method, the differences between the data obtained from the two software were found by subtracting the Kinovea® data from the QTM data. Positive values indicate that QTM data was higher, while negative values mean Kinovea® data was higher. After Bland-Altman, Linear Regression was applied to the data to check if there was any proportional BIAS. Cohen’s d, used as a measure of effect size, is commonly interpreted as 0.20 for a small effect, 0.50 for a medium effect, and 0.80 for a large effect (Cohen, 1988).The confidence interval was accepted as $p<0.05$.

Findings

The descriptive datas and One-Sample t-test results of upper and lower position parameters on the horizontal and vertical axes in three instants (FC, TO, SC) were given in Table 1 and Table 2. Table 1 shows that the LFoot_h-pos at FC, RFoot_h-pos at FC and LASIS_h-pos at SC were not significantly different ($p>0.05$). On the other hand, only RFoot_v-pos at FC data was not significantly different, as indicated in Table 2 ($p>0.05$). Vertical and horizontal displacements of upper and lower body parameters during jumping phases are given in Table 3. Horizontal displacements of RKnee_v-pos and RFoot_v-pos during contact phase and RA_v-pos, LASIS_v-pos, RASIS_v-pos, LKnee_v-pos, LFoot_v-pos during flight phase showed no significant differences ($p>0.05$). Significant differences were found in vertical displacement parameters (Table 3) during two phases ($p<0.05$). The Bland-Altman graphs of non-significant One-Samples T test parameters are given in Figure 4.

Table 1. Descriptive and One-Sample t-test results of upper and lower body position parameters on the horizontal axis

	Mean (mm)	SD	SE	Coefficient of variation	t	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d Lower	Upper
FC										
LA_h-pos	-1.647	1.744	0.203	-1.059	-8.123	<.001	-0.944	0.140	-2.051	1.243
RA_h-pos	-1.321	1.783	0.207	-1.350	-6.373	<.001	-0.741	0.131	-1.734	-0.908
LASIS_h-pos	-1.292	1.826	0.212	-1.413	-6.088	<.001	-0.708	0.130	-1.715	-0.869
RASIS_h-pos	-1.496	1.898	0.221	-1.269	-6.778	<.001	-0.788	0.133	-1.935	-1.056
LKnee_h-pos	-1.539	2.267	0.263	-1.473	-5.841	<.001	-0.679	0.129	-2.064	-1.014
RKnee_h-pos	-0.659	1.583	0.184	-2.404	-3.578	<.001	-0.416	0.121	-1.025	-0.292
LFoot_h-pos	-0.063	1.055	0.123	-16.794	-0.512	0.610	-0.060	0.116	-0.307	0.182
RFoot_h-pos	-0.115	0.890	0.103	-7.731	-1.113	0.269	-0.129	0.117	-0.321	0.091
TO										
LA_h-pos	-31.172	7.870	0.915	-0.252	-34.073	<.001	-3.961	0.346	-32.995	-29.348
RA_h-pos	23.554	7.755	0.902	0.329	26.128	<.001	3.037	0.275	21.757	25.351
LASIS_h-pos	-26.822	5.894	0.685	-0.220	-39.147	<.001	-4.551	0.392	-28.187	-25.456
RASIS_h-pos	19.964	6.084	0.707	0.305	28.225	<.001	3.281	0.294	18.554	21.373
LKnee_h-pos	-32.986	7.747	0.901	-0.235	-36.626	<.001	-4.258	0.369	-34.781	-31.191
RKnee_h-pos	26.810	6.519	0.758	0.243	35.376	<.001	4.112	0.357	25.300	28.321
LFoot_h-pos	-30.028	9.269	1.077	-0.309	-27.870	<.001	-3.240	0.291	-32.176	-27.881
RFoot_h-pos	27.927	7.207	0.838	0.258	33.333	<.001	3.875	0.339	26.258	29.597
SC										
LA_h-pos	-0.902	2.714	0.316	-3.008	-2.860	0.006	-0.332	0.119	-1.531	-0.274
RA_h-pos	-0.889	2.766	0.322	-3.111	-2.765	0.007	-0.321	0.119	-1.530	-0.248
LASIS_h-pos	-0.381	1.822	0.212	-4.787	-1.797	0.076	-0.209	0.118	-0.803	0.041
RASIS_h-pos	-0.517	2.094	0.243	-4.052	-2.123	0.037	-0.247	0.118	-1.002	-0.032
LKnee_h-pos	-0.767	2.706	0.315	-3.526	-2.440	0.017	-0.284	0.119	-1.394	-0.140
RKnee_h-pos	-0.793	2.930	0.341	-3.695	-2.328	0.023	-0.271	0.118	-1.472	-0.114
LFoot_h-pos	-1.703	3.297	0.383	-1.935	-4.445	<.001	-0.517	0.124	-2.467	-0.940
RFoot_h-pos	-0.767	2.989	0.347	-3.898	-2.207	0.030	-0.257	0.118	-1.459	-0.074

R: Right; L: Left; LASIS: Left Anterior Superior Iliac Spine; RASIS: Right Anterior Superior Iliac Spine; LA: Left Acromion; RA: Right Acromion; SD: Standard Deviation; SE: Standard Error; FC: First Contact; TO: Take-off; SC: Second Contact.

Table 2. Descriptive and One-Sample t-test results of upper and lower body position parameters on the vertical axis

	Mean (mm)	SD	SE	Coefficient of variation	t	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d	
									Lower	Upper
FC										
LA_v-pos	-6.229	3.452	0.401	-0.554	-15.523	<.001	-1.805	0.188	-7.028	-5.429
RA_v-pos	-6.027	3.223	0.375	-0.535	-16.088	<.001	-1.870	0.193	-6.774	-5.280
LASIS_v-pos	-5.085	2.152	0.250	-0.423	-20.326	<.001	-2.363	0.226	-5.584	-4.587
RASIS_v-pos	-5.227	2.223	0.258	-0.425	-20.230	<.001	-2.352	0.226	-5.742	-4.712
LKnee_v-pos	-2.237	1.987	0.231	-0.888	-9.687	<.001	-1.126	0.149	-2.698	-1.777
RKnee_v-pos	-2.752	1.564	0.182	-0.568	-15.140	<.001	-1.760	0.186	-3.114	-2.390
LFoot_v-pos	0.769	2.745	0.319	3.572	2.408	0.019	0.280	0.119	0.133	1.404
RFoot_v-pos	-0.117	1.399	0.163	-11.999	-0.717	0.476	-0.083	0.116	-0.441	0.208
TO										
LA_v-pos	-2.067	5.731	0.666	-2.773	-3.102	0.003	-0.361	0.120	-3.395	-0.739
RA_v-pos	-3.200	5.727	0.666	-1.790	-4.807	<.001	-0.559	0.125	-4.527	-1.873
LASIS_v-pos	-8.410	5.404	0.628	-0.643	-13.386	<.001	-1.556	0.173	-9.662	-7.158
RASIS_v-pos	-9.004	5.609	0.652	-0.623	-13.809	<.001	-1.605	0.176	-10.304	-7.705
LKnee_v-pos	-16.117	5.044	0.586	-0.313	-27.489	<.001	-3.196	0.287	-17.285	-14.948
RKnee_v-pos	-15.827	4.950	0.575	-0.313	-27.507	<.001	-3.198	0.287	-16.974	-14.680
LFoot_v-pos	-24.722	6.138	0.714	-0.248	-34.645	<.001	-4.027	0.351	-26.144	-23.300
RFoot_v-pos	-21.734	4.431	0.515	-0.204	-42.192	<.001	-4.905	0.420	-22.761	-20.708
SC										
LA_v-pos	-19.286	6.684	0.777	-0.347	-24.820	<.001	-2.885	0.264	-20.835	-17.738
RA_v-pos	-19.489	6.735	0.783	-0.346	-24.893	<.001	-2.894	0.265	-21.049	-17.928
LASIS_v-pos	-18.406	6.757	0.786	-0.367	-23.432	<.001	-2.724	0.252	-19.972	-16.841
RASIS_v-pos	-18.461	7.051	0.820	-0.382	-22.521	<.001	-2.618	0.245	-20.094	-16.827
LKnee_v-pos	-17.192	5.737	0.667	-0.334	-25.776	<.001	-2.996	0.272	-18.521	-15.862
RKnee_v-pos	-16.467	5.676	0.660	-0.345	-24.957	<.001	-2.901	0.265	-17.782	-15.152
LFoot_v-pos	-8.234	3.388	0.394	-0.412	-20.903	<.001	-2.430	0.231	-9.019	-7.449
RFoot_v-pos	-8.517	3.373	0.392	-0.396	-21.724	<.001	-2.525	0.238	-9.299	-7.736

R: Right; L: Left; LASIS: Left Anterior Superior Iliac Spine; RASIS: Right Anterior Superior Iliac Spine; LA: Left Acromion; RA: Right Acromion; SD: Standard Deviation; SE: Standard Error; FC: First Contact; TO: Take-off; SC: Second Contact.

Table 3. Vertical and horizontal displacements of upper and lower body parameters during contact and flight phases

	Mean (mm)	SD	SE	Coefficient of variation	t	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d Lower	Upper
Horizontal displacements during contact phase										
LA_h-disp	-1.706	1.976	0.230	-1.158	-7.429	<.001	-0.864	0.136	-2.164	-1.249
RA_h-disp	-2.666	2.293	0.266	-0.860	-10.002	<.001	-1.163	0.150	-3.197	-2.134
LASIS_h-disp	-0.930	1.745	0.203	-1.877	-4.584	<.001	-0.533	0.124	-1.334	-0.526
RASIS_h-disp	-1.534	1.819	0.211	-1.186	-7.252	<.001	-0.843	0.135	-1.955	-1.112
LKnee_h-disp	-1.996	2.592	0.301	-1.298	-6.626	<.001	-0.770	0.132	-2.596	-1.396
RKnee_h-disp	-0.310	2.991	0.348	-9.661	-0.890	0.376	-0.104	0.117	-1.003	0.383
LFoot_h-disp	-0.514	1.374	0.160	-2.674	-3.218	0.002	-0.374	0.120	-0.832	-0.196
RFoot_h-disp	-0.070	1.100	0.128	-15.685	-0.548	0.585	-0.064	0.116	-0.325	0.185
Vertical displacements during contact phase										
LA_v-disp	-4.735	3.491	0.406	-0.737	-11.666	<.001	-1.356	0.161	-5.544	-3.926
RA_v-disp	-5.088	3.481	0.405	-0.684	-12.575	<.001	-1.462	0.167	-5.895	-4.282
LASIS_v-disp	-5.126	3.588	0.417	-0.700	-12.290	<.001	-1.429	0.165	-5.957	-4.295
RASIS_v-disp	-6.016	3.514	0.408	-0.584	-14.728	<.001	-1.712	0.183	-6.830	-5.202
LKnee_v-disp	-7.857	3.838	0.446	-0.488	-17.613	<.001	-2.047	0.205	-8.746	-6.968
RKnee_v-disp	-7.441	3.618	0.421	-0.486	-17.691	<.001	-2.057	0.205	-8.280	-6.603
LFoot_v-disp	-10.880	5.143	0.598	-0.473	-18.197	<.001	-2.115	0.209	-12.072	-9.688
RFoot_v-disp	-8.866	3.747	0.436	-0.423	-20.355	<.001	-2.366	0.227	-9.734	-7.998
Horizontal displacements during flight phase										
LA_h-disp	-0.771	2.848	0.331	-3.692	-2.330	0.023	-0.271	0.118	-1.431	-0.111
RA_h-disp	-0.590	2.985	0.347	-5.058	-1.701	0.093	-0.198	0.117	-1.282	0.101
LASIS_h-disp	-0.202	1.943	0.226	-9.623	-0.894	0.374	-0.104	0.117	-0.652	0.248
RASIS_h-disp	-0.461	2.131	0.248	-4.618	-1.863	0.067	-0.217	0.118	-0.955	0.032
LKnee_h-disp	-0.591	2.659	0.309	-4.502	-1.911	0.060	-0.222	0.118	-1.206	0.025
RKnee_h-disp	-0.883	2.902	0.337	-3.287	-2.617	0.011	-0.304	0.119	-1.555	-0.211
LFoot_h-disp	-0.489	3.851	0.448	-7.876	-1.092	0.278	-0.127	0.117	-1.381	0.403
RFoot_h-disp	-1.134	3.763	0.437	-3.320	-2.591	0.012	-0.301	0.119	-2.006	-0.262
Vertical displacements during flight phase										
LA_v-disp	-9.775	3.566	0.414	-0.365	-23.584	<.001	-2.742	0.254	-10.601	-8.949
RA_v-disp	-9.673	3.659	0.425	-0.378	-22.739	<.001	-2.643	0.246	-10.521	-8.825
LASIS_v-disp	-9.310	3.496	0.406	-0.376	-22.907	<.001	-2.663	0.248	-10.120	-8.500
RASIS_v-disp	-9.337	3.871	0.450	-0.415	-20.748	<.001	-2.412	0.230	-10.234	-8.440
LKnee_v-disp	-6.829	2.744	0.319	-0.402	-21.410	<.001	-2.489	0.235	-7.465	-6.194
RKnee_v-disp	-6.538	2.792	0.325	-0.427	-20.144	<.001	-2.342	0.225	-7.185	-5.891
LFoot_v-disp	0.856	1.390	0.162	1.625	5.295	<.001	0.616	0.127	0.534	1.178
RFoot_v-disp	0.794	1.294	0.150	1.631	5.274	<.001	0.613	0.127	0.494	1.093

R: Right; L: Left; LASIS: Left Anterior Superior Iliac Spine; RASIS: Right Anterior Superior Iliac Spine; LA: Left Acromion; RA: Right Acromion; SD: Standard Deviation; SE: Standard Error

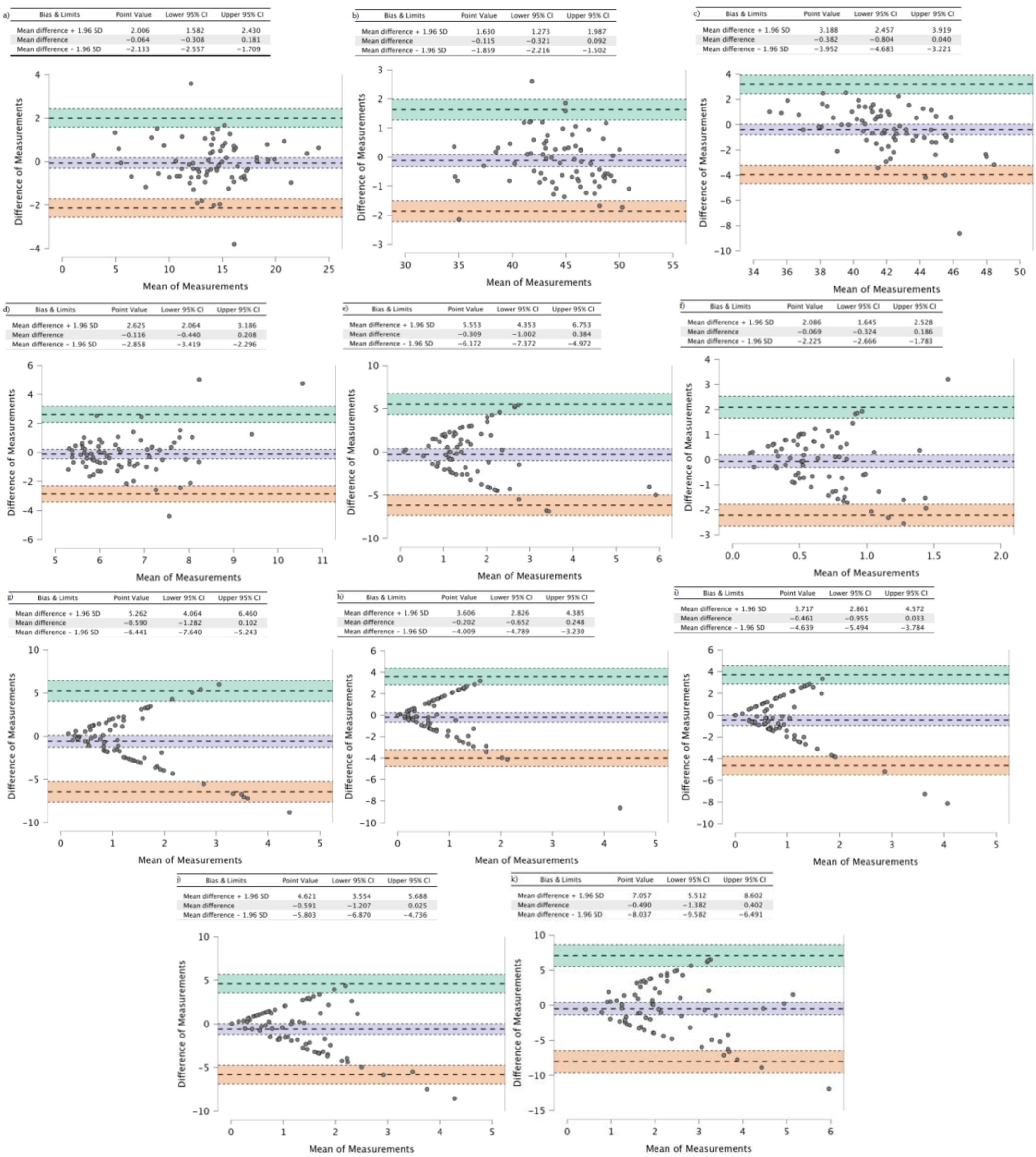

Figure 4. Bland-Altman plots a) LFoot_h-pos at FC (p=0.610) b) RFoot_h-pos at FC (p=0.269) c) LASIS_h-pos at SC (p=0.076) d) RFoot_v-pos at FC (p=0.476) e) RKnee_h-disp during contact phase (p=0.376) f) RFoot_h-disp during contact phase (p=0.585) g) RA_h-disp during flight phase (p=0.093) h) LASIS_h-disp during flight phase (p=0.374) i) RASIS_h-disp during flight phase (p=0.067) j) LKnee_h-disp during flight phase (p=0.060) k) LFoot_h-disp during flight phase (p=0.278)

Bland-Altman plots showed that there was agreement between QTM and Kinovea® on LFoot_h-pos and RFoot_h-pos at FC and LASIS_h-pos at SC, RFoot_v-pos at FC, RKnee_h-disp and RFoot_h-disp during contact phase and RA_h-disp, LASIS_h-disp, RASIS_h-disp, LKnee_h-disp, LFoot_h-disp during flight phase (Figure 4). The results of the linear regression confirmed those obtained using the Bland-Altman method, with p-values of 0.610 and 0.269 for the LFoot_h-pos and RFoot_h-pos, respectively, at the FC, and 0.076 for the LASIS_h-pos at the SC, RFoot_v-disp at FC had a p-value of 0.476, and RKnee_h-disp and RFoot_h-disp during the contact phase were 0.376 and

0.585, respectively. The p-values for the RA_h-disp, LASIS_h-disp, RASIS, LKnee_h-disp, and LFoot_h-disp during the flight phase were 0.093, 0.374, 0.067, 0.060, and 0.278, respectively.

Discussion and Conclusion

The study aimed to assess the accuracy of low frame frequency video in 2D Kinovea® (v. 0.9.5) compared to the 3D QTM (v. 2020.3) on drop jump by interpolation. The results showed that there was a agreement between the QTM and Kinovea® on horizontal position parameters of LFoot and RFoot at first contact, LASIS at second contact and vertical positions of RFoot at first contact. However, in subsequent phases and instants of the drop jump, the results obtained were far from the acceptable range as compared to the QTM. This fact is also supported by the right foot in the vertical position, which showed ~~significant~~ agreement only at first contact.

No research has been conducted on position data in prior literature. The calibration performed in the QTM and Kinovea® might cause a variety of position data. Taking this into account, it is predicted that the agreement limits of parameters will be minimal. Calibration in Kinovea® is allowed to be used only for one axis, vertical or horizontal. This one-axis calibration setting might be a limitation for Kinovea®, while evaluating performance, compared to 3D systems.

In the present study, there was ~~significant~~ agreement between the two methods on horizontal displacement parameters of RKnee and RFoot during the contact phase and RA, LASIS, RASIS, LKnee, and LFoot during the flight phase. In the literature, there was not much research investigating positions and displacement parameters in drop jump performance to support the results of this study. Pueo et al., 2020 stated that Kinovea® and 3D motion capture systems showed a high level of and very low mean systematic bias for jump height, velocity at take-off and impulse, respectively (−0.22 cm; −0.01 m/s; −0.56 Ns) (Pueo et al., 2020). In another study, Caseiro-Filho et al., 2023 compared the maximum vertical jump height, impulse time, and flight time during bipodal and unipodal vertical jumps between Kinovea® and a force platform. They found a significant correlation between impulse time and flight time during the bipodal vertical jump, which was also reflected in the Bland-Altman graphs (Caseiro-Filho et al., 2023). Moreover, Balsalobre-Fernández et al. (2014) reported that flight time and jump height measured from both the infrared platform and Kinovea®-HSC were equally valid and reliable (Balsalobre-Fernández et al., 2014). In another study, Schurr et al., 2017 collected the displacement data of the trunk, hip, knee, and ankle through the Kinovea® and an electromagnetic tracking 3D motion capture system. The data was then compared on the sagittal and frontal planes while performing single-leg squats. Two techniques demonstrated moderate to strong correlations on the sagittal plane for all variables and a marked correlation solely for the knee on the frontal plane (Schurr et al., 2017). Additionally, it was found that Kinovea® was reliable in calculating the knee angle during the seven different phases of drop-jump performance using both the Hawk-Cortex system and Kinovea® software (Nor Adnan et al., 2018). In contrast to prior research, Fernández-González et al. (2020) identified a significant difference between the two systems in their gait analysis study comparing VICON and Kinovea®. The authors utilized Bland-Altman plots to establish the acceptability limits for hip, knee, and ankle angles, with respective ranges of 5.26 to -3.58, 5.01 to -0.98, and 3.70 to -6.09° (Fernández-González et al., 2020).

In this study, disagreement was found in the vertical displacement of all parameters during the contact and flight phases of the drop jump. One reason for the lack of agreement on some displacement parameters might be thought of as the video camera setup. In this study, the camera was placed in front of the subjects at a 90° angle with a 3-meter distance, which was suggested in previous research (Puig-Diví et al., 2019). Therefore, the concern about the possible effect of an inappropriate camera setup was eliminated. 2D Kinovea® (v. 0.9.5) is capable of tracking the reflective markers automatically which were defined in the first frame of the video. This setting of the software may cause tracking errors of the reflective markers during drop jumps. However, to prevent such errors, all reflective markers were corrected manually in each frame for this study. Drop jump movement was performed vertically rather than horizontally and the performance was determined by the vertical displacement. The amount of displacement for all reflective markers, especially in the vertical axis, is affected by the frame frequency of the cameras. In this study, the frame frequency of the video used in Kinovea® was 30 Hz and interpolated to 500 Hz while the QTM frame frequency was 500 Hz. The ratio of the QTM/Kinovea® frame frequency was 16.66. In the literature, Pueo et al., 2020 used 100 Hz for 3D tracking and 60 Hz for video recording Kinovea®, while Schurr et al., 2017 used 144 Hz in the electromagnetic vision system and 60 Hz for Kinovea®. Fernández-González et al., 2020 recorded 100 Hz for Vicon 8 camera and 50 Hz for Kinovea®. The ratio of 3D and Kinovea® was 1.66 in Pueo's study, 2.4 in Schurr et al. (2017) and 2.0 in Fernández-González et al. (2020). It is thought that this ratio is the main reason for the low between both methods.

The 2D analysis has its limitations, compared to the 3D systems. One and the biggest limitation is the lack of position and the displacement data of the subject in the anterior-posterior direction. This could cause some measurement errors if the movement or displacement happens in this axis. For this study, it is believed that this limitation was eliminated because the subject fell directly in front of the box, in terms of the nature of the drop-jump movement.

The main result of the study was the demonstration of agreement between QTM and Kinovea® regarding the horizontal and vertical positions of some lower extremities (LFoot, RFoot, LASIS) at initial contact. A similar result can be obtained for the displacement of some lower extremity anatomical landmarks in two phases (contact phase and flight phase). However, the results obtained during the later stages and moments of the drop jump were far from acceptable range compared to

QTM (11 out of 80 variables were found to be in agreement). Therefore, the frame frequency must be higher than 30 Hz to measure displacement in the vertical and horizontal axes. Therefore, this study demonstrates that the frame frequency is above 30 Hz for drop jumping.

Research Ethic Ethics Committee: Non-Interventional Scientific Research Ethics Committee of Halic University, Türkiye

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