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ORIGINAL RESEARCH

RELIABILITY OF VIDEO-BASED QUANTIFICATION OF THE KNEE- AND HIP ANGLE AT FOOT STRIKE DURING RUNNING

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ABSTRACT

Introduction: In clinical practice, joint kinematics during running are primarily quantified by two-dimensional (2D) video recordings and motion-analysis software. The applicability of this approach depends on the clinicians' ability to quantify kinematics in a reliable manner. The reliability of quantifying knee- and hip angles at foot strike is uninvestigated.

Objective: To investigate the intra- and inter-rater reliability within and between days of clinicians' ability to quantify the knee- and hip angles at foot strike during running.

Methods: Eighteen recreational runners were recorded twice using a clinical 2D video setup during treadmill running. Two blinded raters quantified joint angles on each video twice with freeware motion analysis software (Kinovea 0.8.15)

Results: The range from the lower prediction limit to the upper prediction limit of the 95% prediction interval varied three to eight degrees (within day) and nine to 14 degrees (between day) for the knee angles. Similarly, the hip angles varied three to seven degrees (within day) and nine to 11 degrees (between day).

Conclusion: The intra- and inter rater reliability of within and between day quantifications of the knee- and hip angle based on a clinical 2D video setup is sufficient to encourage clinicians to keep using 2D motion analysis techniques in clinical practice to quantify the knee- and hip angles in healthy runners. However, the interpretation should include critical evaluation of the physical set-up of the 2D motion analysis system prior to the recordings and conclusions should take measurement variations (3-8 degrees and 9-14 degrees for within and between day, respectively) into account.

Level of evidence: 3

Key words: kinematics; knee- and hip angles; motion-analysis software; reliability; running

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INTRODUCTION

The popularity of running has increased remarkably the past 40 years.[1] The major advances of health benefits attributed to physical activity in general and to running particularly, covers reduced risk of certain chronic disorders and lifestyle diseases (e.g., osteoarthritis, osteoporosis, cardiovascular disease, diabetes, cancer, hypertension, obesity and depression)[2-4] and increased quality of life.[5] Thus, physical activity has a positive effect on the general costs in the healthcare system and the main national productivity.[6] Unfortunately, running-related injuries (RRI) have been reported as the main reason to a permanent stop of participation in running[2], with an extraordinary high annual cumulative injury incidence proportion up to 85% in a general running population.[7] The etiology of RRI is, therefore, important to understand in order to establish sufficient prevention strategies and decrease the frequency and the impact of injuries.

Biomechanically, it has been suggested that knee- and hip joint kinematics and kinetics during running are associated with the development of RRI. Furthermore, the risk of sustaining knee and hip injuries might be increased by shod runners utilizing a rear-foot strike compared to using a fore-foot strike [8-11] and since rear-foot striking is the most utilized striking strategy among runners [12,13], the biomechanical impact of the knee- and hip joint during rear-foot striking are of particular interest in relation to RRI.

Milner et al. 2007 suggested that smaller knee flexion at initial contact (IC) among rear-foot strikers contributed to bony injuries because of higher joint stiffness at IC and consequently higher loading rates and impaired shock absorption.[14] Additionally, it has been reported that the peak knee flexion at mid-stance increased among rear-foot strikers resulting in increased knee extensor joint moments during the continued stride with a potential increased risk of RRI.[9,11] Furthermore, rear-foot striking is typically linked with increased stride length as compared to mid and fore-foot striking[8,9] resulting in increased sagittal peak hip flexion during stance and subsequent increased hip joint moments and potential for increased risk of RRI.[9,11] Conversely, fore-foot striking might result in higher risk of injuries in the foot and calf since this running pattern involves increased ankle plantar flexion at initial contact and consequently increases the eccentric foot plantar flexor load.[8,11]

Three-dimensional (3D) motion analysis systems are considered the most accurate and precise methods for analyses of human movements. However, the methodology is time consuming, expensive and consequently, less suitable for field research and clinical use.[15,16] In contrast, 2-dimensional (2D) video-based assessment techniques are cheaper and easy-to-handle and therefore have been emphasized in clinical practice for analyzing joint kinematics during running.[10-12,17,18] Notwithstanding the obvious advantages, caution should be taken when 2D video-based methods are used to quantify dynamic human movements since the validity of the measurements are challenged by reduction of the description of kinematic parameters being limited to two planes.[19]

It is well known that the utility of any assessment tool depends on it's validity and reliability and thus, focus on the validity of 2D video-based motion analyses techniques compared to 3D motion analysis systems in relation to measurements of joint angles has been addressed in previous studies.[20,21] In general, these studies showed promising results for the validity of the 2D assessment technique. This is supported in a recent study by Ugbolue et al[22] that investigated the validity of an augmented-video-based-portable-system (AVPS) based on 2D motion analysis and its potential use as a clinical assessment tool during walking. Using a 3D motion analysis system as a gold standard and a two segment goniometric rig as a reference, the accuracy of joint angles measured by the 2D motion analysis technique was tested on 1) the knee joint angle at IC and at terminal contact (TC) and 2) the tibia inclination angle at IC, foot flat (FF), mid-stance (MS) and at TC. No significant differences were found between AVPS and the 3D motion analysis system ($P = 0.206$), and between the AVPS and the two segment goniometric rig ($P = 0.578$).[22]

These results should be interpreted with caution in relation to running, since the validity of the 2D motion analysis techniques were measured during walking gait. However, to the authors' knowledge the validity of the 2D motion analysis technique in relation to running still remains uninvestigated. Validity implies that measurements are relatively free from error and are highly dependent on the premise that any measurement must be reliable in order to be valid.[23]

Reliability of the 2D motion analysis technique has previously been investigated in relation to different sports[22,24-28] and relative to the foot strike pattern in running[12], but the reliability of the method in relation to quantification of the knee- and hip angles in running has not been reported. Therefore, the aim of the present study was to investigate the intra- and inter-rater reliability of the within- and between day quantification of the knee- and hip angles recorded in the sagittal plane in recreational runners by a clinical 2D video setup and freeware motion-analysis software.

METHODS

Participants

Twenty-five healthy recreational runners (13 women, 12 males, 35 ± 9 years, height 175.8 ± 10.5 cm and body weight 76.6 ± 19 kg), without lower extremity injuries three months preceding baseline, volunteered to participate and they were enrolled in the period July to September 2012. The Local Ethical Committee evaluated the study protocol and waived the request of ethics approval since the study design was observational. The local data protection agency approved the project. All the participants provided informed consent.

Video recordings

A high-speed video camera (Exilim EX-F1, Casio, Tokyo, Japan, resolution 512x384 pixels at 300 frames per second (fps) and shutter-speed at 1/2000 second) was mounted on a self-constructed welded stationary stand to ensure a standardized height of the camera lens, 86 centimeter above the floor. The stationary stand was located at a distance of 1.5 meters to the treadmill with the optical axis perpendicular to the plane of movement and covering the field of the runner on the treadmill in the sagittal plane.

All recordings were obtained while the participants were running on a commercially available treadmill (Run Xt Pro 600, model D390, Technogym, Italy) illuminated by a 500W halogen lamp. (XH, model HY-150S, 500W, Yuyao Xianghua Lighting Co., Ltd., China).

Prior to the recordings, a marker was placed on the runners' tights for identification of the greater trochanter as a reference point to be used in the quantification process of the joint angles. Subsequently, the participants were given time to become familiar with the treadmill until they felt comfortable and were running steadily in their self-selected speed, then a 30-second video was recorded. All participants were recorded twice with a one-week interval between. During the second session, the participants ran at the same pace as during the first session (mean 10.14 ± SD 1.47 km/h) controlled by the display on the treadmill. The participants were running in their own shoes, which were identical during both sessions.

Video processing

In two separate sessions, with a minimum of 14 days in between, two blinded raters (experienced physiotherapists familiar with the use of high-speed video as a tool to quantify joint angles in running) independently quantified the knee- and hip angles at specific video frames on each video (see detailed procedure below), using the freeware motion-analysis software Kinovea (version 0.8.15, available for download at: http://www.kinovea.org).

Prior to or during the quantification process, the raters had the opportunity to comment on the eligibility of each video for inclusion if they needed, based on the video quality by means of illumination, blurriness or other image quality factors that could bias the digitalization of the video and thereby, the raters quantification of joint angles. Seven participants were excluded because of low video quality.

Initially, the video time frame, defined as the duration of one frame (0.03 s^{-1}) for foot strike was identified (see description of Phase one below). Secondly, the knee- and hip angles in the sagittal plane were quantified (see description of Phase two below).

Phase one

Identification of the video time frame for foot strike

A fixed video time frame was selected on the individual video files for every of the five foot strikes, to ensure that the raters quantified the knee- and hip angles at the same video time frame. Identification of the fixed video time frame was conducted through a three step procedure: 1) Each video was forwarded 15 seconds into the total video, and then, the two raters independently identified five consecutive video time frames for initial foot strike of left-legged foot strikes. 2) Step 1 was repeated with a minimum of 14 days apart. 3) Based on the four identification sessions (two sessions from each rater) of the foot strike frames, the fixed video time frame for each of the five foot strikes were defined as the median foot strike frame, rounded up to the forthcoming time frame if the median was between two video time frames.

Phase two

Quantification of the knee- and hip angles

In order to establish consistency in the process of quantifying the knee- and hip angles, a consensus-based standardized protocol was developed by the authors as a part of this investigation (unpublished work).

In brief, the standardized protocol involved the procedure for the raters quantification of knee flexion; the relative angle between tibia and femur and their quantification of hip flexion; the absolute angle between the femur and a vertical line perpendicular to the treadmill, through trochanter major of femur (Figure 1) on five consecutive video time frames for foot strike using the fixed video time frame identified during phase one. The joint angles were quantified by measurement functions in Kinovea by four steps: 1. The raters attached a marker on the lateral femoral condyle and the lateral malleolus on the tibia by the "line " and "cross marker" functions. 2. Using the "angle" function the raters placed a goniometer on the knee centered on the marker denoting the lateral femoral condyle and the spikes were fitted through the greater trochanter and lateral malleolus, respectively. This angle represented the knee flexion angle. 3. A second goniometer was placed on the treadmill vertically below the greater trochanter and the horizontal spike was aligned with the rear edge of the treadmill and the vertical spike was set through the greater trochanter, symbolizing a plumb line. 4. A third goniometer was placed centered on the greater trochanter with one spike fitted through the lateral femoral condyle and one aligned with the plumb line. This angle represented the hip flexion angle. The software associated with Kinovea automatically calculated the angles.

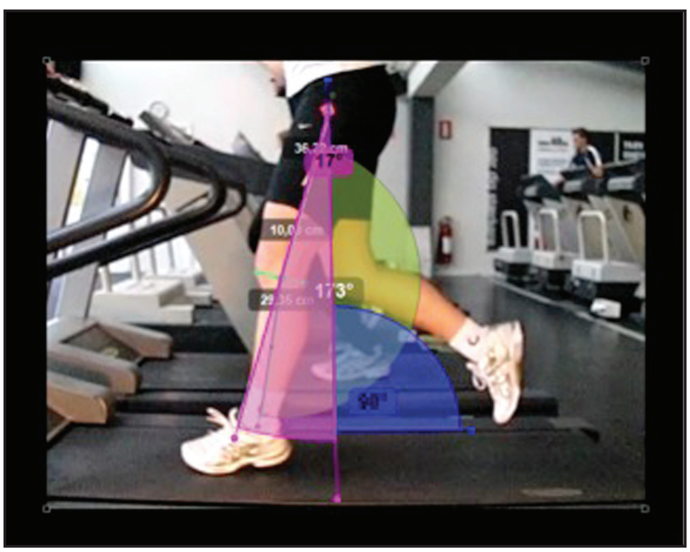

Figure 1. *Print screen picture of the quantified angles. Knee flexion: the relative angle between tibia and femur (the green angle). Hip flexion: the absolute angle between the femur and a vertical line perpendicular to the treadmill (the blue angle), through trochanter major of femur (the pink angle)*

Before the statistical analysis, the dataset was screened for outliers. Five outliers were found between foot strikes; two because the knee- and hip angles were quantified on the opposite leg, one because of typing errors, one because of missing values from a video, displacing the quantification values from the subsequent videos and one because a foot strike was overlooked. The raters were asked to re-quantify these outliers. After this correction, the maximum and the minimum angle values of the five consecutive foot strikes from each video, quantified by each rater were excluded and the remaining 3 angles were averaged.

Statistical analysis

These mean angle values from each rater were compared by using the Bland and Altman's limits of agreements (LOA).[29] This method can be used to calculate the 95% prediction interval (the range from upper prediction limit to lower prediction limit) and thereby, the size of the random error and to visualize the distribution of the data in relation to assessing agreement within and between raters (systematic error). In all analyses the difference and the size of the variation did not depend systematically on the average (Fig. 2), which is fulfilling the assumption that a reliable

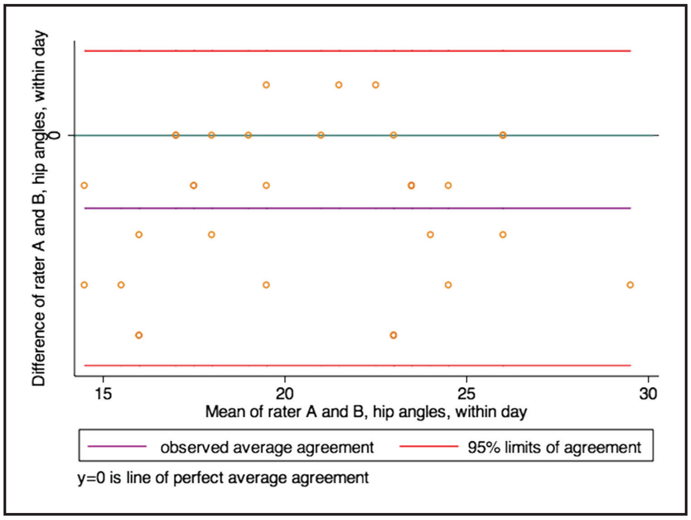

Figure 2. *An example of one of the Bland-Altman plots. This one is for the inter-rater observations for the first quantification of the hip angles, first recording session. The purple horizontal line represents the mean difference, and the red lines the 95% limits of agreement. The y-axis represents the difference in the quantification of hip angles between Rater A and Rater B (labeled "Difference of Rater A, hip angles and Rater B, hip angles). The x-axis represents the mean of the differences in the quantification of hip angles between Rater A and Rater B (labeled " Mean of Rater A, hip angles and Rater B, hip angles)*

method (here the 2D motion analysis technique) must have a reasonably constant variation (standard deviation) throughout the range of measurement.[30]

All statistical analyses were performed in STATA statistical package (Stata Corp., 2011, Stata Statistical Software: Release 12, College Station, Texas, USA) and considered statistically significant at $\alpha < 0.05$.

RESULTS

The analyses were performed within and between raters, both within and between days. This means that the raters' quantification of joint angles was compared within rater on the same video recording of each participant (intra-rater reliability within day) and between rater (inter-rater reliability within day). The between day analyses were performed by comparing two different video recordings of the same participant within raters (intra-rater reliability between day) and between raters (inter-rater reliability between day)

Within day

The 95% prediction interval for the intra-rater reliability varied three to six degrees for both the knee and hip angle. For the inter-rater reliability the range varied from six to eight degrees for the knee angle and three to seven degrees for the hip angle (Table 1).

Between day

The 95% prediction interval for the intra-rater reliability varied nine to 14 degrees for the knee angle and nine to 11 degrees for the hip angle for both the intra-rater and inter-rater reliability (Table 2).

DISCUSSION

The aim of the present study was to investigate the intra- and inter-rater reliability of the within- and between day quantification of the knee- and hip angles recorded in the sagittal plane in recreational runners using a clinical 2D video setup and freeware motion-analysis software.

Table 1. *Within day measurements*

	FIRST RUNNING SESSION		SECOND RUNNING SESSION	
	Knee angle	Hip angle	Knee angle	Hip angle
INTRA:	95% LOA (deg°)	95% LOA (deg°)	95% LOA (deg°)	95% LOA (deg°)
Rater A	-1.95; 0.87 (3)	-2.44; 1.05 (3)	-2.10; 1.40 (3)	-0.94; 1.77 (3)
Rater B	-2.94; 3.05 (6)	-3.04; 3.16 (6)	-1.10; 2.36 (3)	-1.86; 1.69 (3)
INTER:				
A versus B 1st quantification session	-5.59; 2.24 (8)	-5.15; 1.90 (7)	-4.25; 2.31 (7)	-2.52; 2.70 (5)
A versus B 2nd quantification session	-4.50; 2.86 (7)	-3.54; 1.74 (5)	-2.98; 2.92 (6)	-1.92; 1.62 (3)

Table 2. *Between day measurements*

Between day measurements				
	FIRST RUNNING SESSION 1 *versus* SECOND RUNNING SESSION 1		**FIRST RUNNING SESSION 2 *versus* SECOND RUNNING SESSION 2**	
	Knee angle	Hip angle	Knee angle	Hip angle
INTRA:	95% LOA (deg°)	95% LOA (deg°)	95% LOA (deg°)	95% LOA (deg°)
Rater A	-5.12; 4.45 (10)	-5.81; 3.69 (10)	-4.46; 4.82 (9)	-4.48; 4.60 (9)
Rater B	-6.04; 7.66 (14)	-4.50; 6.94 (11)	-4.90; 6.61 (12)	-3.72; 6.06 (10)
INTER:				
A versus B	-7.81; 4.47 (12)	-5.57; 4.38 (10)	-4.95; 4.45 (9)	-5.45; 5.08 (11)
B versus A	-5.56; 8.85 (14)	-4.80; 5.35 (10)	-5.09; 6.62 (12)	-3.49; 5.96 (9)

Quantification of the knee- and hip angle

The 95% prediction intervals varied from three to eight degrees for the within day analyses and nine to 14 degrees for the between day analyses. It remains unknown if these intervals, indicating the size of the differences between the ratings, are clinically relevant and thereby affect the possibility of quantifying joint angles in clinical practice by 2D motion analyses techniques. However, when comparing the current result with the results from the study by Ugbolou et al 2013,[22] similar variations (7.6 to 10.4 degrees) were observed in their measurements of the knee angle at initial contact and larger variations (16.8 to 28 degrees) in their measurements of the knee angle at TC done by the AVPS (a 2D motion analysis technique), although they found no significant differences between the AVPS and the 3D motion analysis system and between the AVPS and the two segment goniometric rig, respectively.

It is worth mentioning that measurement variation of any measurements or measurement tools, in general, is more likely to be detected than no variation, since the nature of reality is such that measurements are rarely perfectly reliable owing to the multifactorial sources to variation that exist within the total measurement system.[23] As such, generating results with no measurement variation and, thereby, showing perfectly reliability would be fairly impossible. The most relevant components causing the measurement variation found in the present study are mainly attributed to human factors (intra- and inter rater factors) and to the time depending variation that inevitable exist when variables are measures over time (between day variation). In relation to the former, there is a tendency towards that the inter rater variation is higher than the intra rater variation simply because the quantifications were made by two differences raters with different personally characteristics. In relation the to latter, the variability in the between day quantifications were likely to vary more than the within day quantification due to the fact that the quantifications were done on two different video files from the same participant.

Despite the range of the 95% prediction intervals found in the present study can be considered as small (especially for the intra ratings within day) it is possible that they may have a clinical relevance in relation to sustaining a RRI, since the differences in the quantification of joint angles may alter the cumulative joint load in the knee- and hip joints when considering the summative effect of increased duration or velocity.

Methodology

2D camera setups and freeware motion-analysis software have easy applicability and are feasible methods reflecting a clinical setup that may be usable instead of advanced motion-capture methods based on 3D kinematics and force plate quantifications. However, 2D approaches are challenged in maintaining control of the instrumental factors essential for high-quality video recordings, like calibration angles, distance to the runner etc. The quality of video recordings are dependent upon sufficient illumination to overcome picture quality deficits when recording high velocity movements as running using high-speed video cameras with high shutter speeds.[15] The pixilation that occurs in standard camera recordings at 300 fps can additionally influence blurriness. In the present study seven videos were rated as ineligible for quantification because of poor video quality and, therefore, these videos were excluded from the analyses. However, this decision must be considered as a limitation of the study, since it might have influenced the results. It is, therefore, important to highlight that prior to using 2D motion analysis techniques in clinical practice it is important to evaluate the clinical surroundings and the overall set-up.

As a reference point in the quantification process of the joint angles a hip marker was used to identify the joint center of motion. This is a practical method, although it's accuracy is sensitive to skin artifacts [31] and movements of the runners' tights. Based on pilot-studies it was obvious, however, that this method would increase the reliability. No standardized guidelines exist in order to increase reliability of the use of 2D video methods and motion-analysis software by clinicians for the purpose of quantifying joint angles. One strength of the present study is, therefore, the development of the standardized protocol based on consensus discussions to enhance the quantifications of joint angles and represents the best available approach to provide consistency in the quantification process.

On the basis of the results from the present study the authors encourage clinicians to keep using 2D motion analysis techniques in clinical practice in order to quantify the knee- and hip angles in healthy runners. However, the interpretation should include critical evaluation of the physical set-up and the 2D video set-up prior to the recordings and conclusions should take measurement variations established in the current study into account.

CONCLUSION

The intra- and inter rater reliability of within and between day quantifications of the knee- and hip angle based on a clinical 2D video setup is sufficient to encourage clinicians to keep using 2D motion analysis techniques in clinical practice to quantify the knee- and hip angles in healthy runners. However, the interpretation should include critical evaluation of the physical set-up of the 2D motion analysis system prior to the recordings and conclusions should take measurement variations (3-8 degrees and 9-14 degrees for within and between day, respectively) into account.

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