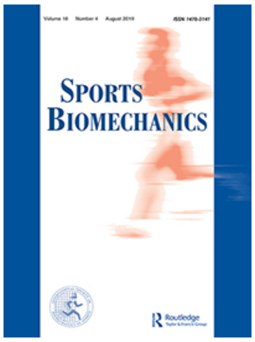

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Concurrent criterion validity of a novel portable motion analysis system for assessing the landing error scoring system (LESS) test

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ABSTRACT

The landing error scoring system (LESS) assesses the quality of a landing after a jump. The quality of the jump is usually evaluated using a three-dimensional (3-D) motion analysis system or a two-dimensional (2-D) video analysis visually rated by a clinician. However, both methods have disadvantages. The aim of this study was to examine the concurrent validity of a novel portable motion analysis system ('PhysiMax System') in assessing the LESS score by comparing it to video analysis. The study population included 48 healthy participants (28.45 ± 5.61 years), each performing the LESS test while two video cameras and the 'PhysiMax' simultaneously recorded the jump. The 'Physimax' system automatically evaluated the LESS. Subsequently, the examiners scored the test by viewing the video recordings, blinded to the 'PhysiMax' results. The mean LESS score, using the video recordings and the 'PhysiMax' was 4.77 (±2.29) and 5.15 (±2.58), respectively, (ICC = 0.80, 95% confidence intervals 0.65–0.87), mean absolute differences 1.13 (95% confidence intervals; 0.79–1.46). The results indicate a high consensus between the methods of measurement. The 'Physimax' system's main advantages are portability, objective evaluation and immediate availability of results. The system can be used by athletic trainers and physiotherapists in the clinic and in the field for jumping assessment.

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Field evaluation; motion analysis; performance; Kinect; jumping

Introduction

Jumping, a major component of different sporting activities, places an increased strain on an athlete's body. Jumping and landing are actions that involve sudden stopping or rapid deceleration. These activities are usually associated with lower limb injuries, especially in sports, which require sudden changes in direction during movements such as basketball and volleyball (Magee, Manske, & Zachazewski, 2011). In most cases, the injuries are associated with the landing technique of the jump more than the jumping technique. Athletes who land with a poor movement pattern are at a higher risk of lower limb injuries (fractures, knee pain, anterior cruciate ligament injury and ankle sprains) (Aerts, Cumps, Verhagen, Verschueren, & Meeusen, 2013; Hewett, Ford, Hoogenboom, & Myer, 2010).

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Functional tests assessing jump-landing performances are important in assisting the physiotherapist, during the rehabilitation processes, to evaluate an athlete after injury and before his/her return to full activity. These tests resemble the real-time sports-specific activity executed by the athlete. One of the most common functional tests evaluating jumping is the bilateral drop jump test using the Landing Error Scoring System (LESS) for evaluation. In this test, the athlete has to jump with both feet from a standard stair (30 cm) to a distance equal to half of his/her height and immediately following the landing, perform another jump to a maximal height (Beese, Joy, Switzler, & Hicks-Little, 2015; Padua, Marshall, & Onate, 2004; Padua et al., 2011). Throughout the test, the examiner monitors the athlete from the front and side positions in order to evaluate the landing quality.

The LESS is a clinical tool developed to identify athletes who are at risk of developing lower limb injuries. This scoring system can ascertain which specific motion components are lacking when landing and the impaired movement components of the lower limb joints and trunk. The impaired movement components were found to be associated with a higher risk of lower limb injuries, particularly anterior cruciate ligament (ACL) injuries in individuals who scored high on the LESS (Padua et al., 2015). The LESS is used as a preseason screening tool to assess quality of movement, identify athletes who are at a high risk of injury and assist athletic trainers and physiotherapists in creating a neuromuscular, stability and strengthening exercise programme jointly with the athlete's regular training (Padua et al., 2015). The LESS is also used following an injury in order to assess the progress achieved during rehabilitation and determine the athlete's competence to return to the field and regular training. It may also assist in focusing on specific errors and impairment, thereby, facilitating appropriate treatment and exercises (Bell, Smith, Pennuto, Stiffler, & Olson, 2014).

Usually, these movement patterns which occur during landing are measured by 3-D motion analysis systems (e.g., Vicon Motion Capture System, Oxford, UK; A Flock of Birds, Ascension Technologies, Inc, Burlington, Vermont); however, these systems are mainly used in research laboratories. These 3-D systems are considered to be the gold standard of motion analysis (Padua et al., 2009); however, there are several disadvantages to this system such as the high cost of equipment, low availability, need for an examiner skilled in operating the system, the lengthy period of time required to prepare the patient and the time-consuming analysis of the results (Ford, Myer, & Hewett, 2007). Another method used in assessing jump-landing performances is the use of 2-D video cameras and a review of the video recording at a later stage (Dingenen, Malfait, Nijs, et al., 2015; Dingenen, Malfait, Vanrenterghem, et al., 2015; Harris-Hayes et al., 2014; Mizner, Chmielewski, Toepke, & Tofte, 2012). By employing this method, the examiner can scroll the video back and forth on the screen to assess landing phases and any movement deviations. Video assessment was found reliable and valid compared to the gold standard 'Flock of birds' method for assessing the LESS (Padua et al., 2009). Another method utilising video movies is the i-LESS, which is a single observation of the video recording from the frontal plane (Cortes & Onate, 2013). A further method of analysis used in rehabilitation and physiotherapy clinics is real-time observation by clinicians using no equipment at all. The examiner assesses landing performances in each plane of movement (sagittal and frontal planes) (Nilstad et al., 2014; Padua et al., 2011). The problem with this method is the difficulty in assessing the changes occurring in all of the joints due to the fast movement. The disadvantage of assessing landing performances with videos or the real-time method is the subjective interpretation of the examiner. The examiner requires a high level of movement assessment skills in order to evaluate the task.

In light of the above, there is a need to develop a simple, portable measurement tool with good validity and reliability, proficient in evaluating landing performances and with the capability to assess ankle, knee, hip and trunk movement in three dimensions. The aim of this device should be to identify faulty movement patterns and quantitative evaluations of the jump, which would thereby, benefit athletic trainers and physiotherapists who will be able to assess jumping and landing in the clinic or outside the laboratory (e.g., in the field or area of training). 'PhysiMax' Technology has developed a portable 3-D motion analysis system ('PhysiMax', Tel-Aviv, Israel) designed to resolve these deficiencies.

The aim of the current study was to examine the concurrent validity of the 'PhysiMax' system in assessing the LESS tool by comparing the system to video analysis, a technique commonly used by athletic trainers and physiotherapists in assessing jump-landing performances. We hypothesised that this new portable motion analysis system could effectively evaluate landing quality assessed by the LESS.

Methods

The study was approved by the University of Haifa's Institutional Review Board (#238/14). All participants signed the review board's approved consent form following verbal instructions describing the procedure. The rights of the participants were protected. The participants were recruited via advertisements placed on the notice boards of Haifa University, Israel and the Wingate Institute, Netanya, Israel.

Sample

The study sample included 49 healthy individuals (32 males and 17 females), aged 20–42 years. Inclusion criteria included healthy adult individuals who had participated in a sports activity at any level at least twice a week and had sustained no injuries or pain during the past year. Individuals with neurological disorders or those who had undergone spinal or surgery of the lower extremities were excluded.

Procedure

The LESS data were simultaneously collected during a jump-landing task via 2 standard video cameras and the 'PhysiMax' system. The LESS score was immediately and automatically generated by the 'PhysiMax' system and at a later stage (up to 2 weeks), the 2-D videos were evaluated by two raters who are trained sport physical therapists. The video movie analysis enabled them to pause, forward or rewind the frames. The assessment by the raters of all videos was conducted independently of each other and then compared. Discrepancies were ascertained after re-examining the video movies and discussing the differences between raters. A decision was then rendered as to the final score. The raters were blinded to the 'PhysiMax' scores.

Assessing the LESS tool by examining video images has been previously described as a valid and reliable method (Padua et al., 2009). As such, this research compared the new 'Physimax' system to this common clinical video analysis used today by athletic trainers and physiotherapists to assess landing performances. The jump-landing task consisted of the participant jumping from a 30 cm high box to a distance of 50% of his/her height away from the box and immediately following landing, to perform a maximal vertical jump. No feedback was given to the participants as to their performance, though it was emphasised that they should try and jump as high as they could without pausing after landing. Participants underwent a familiarisation period which included two practice trial jumps to ensure that they understood and adequately executed the task. An adequate jump was defined as: (1) jumping off the box with both feet, simultaneously; (2) jumping forward off the box; (3) landing on the mark on the floor indicating 50% of the participant's height; (4) jumping smoothly without stopping. Following the trial, a 2 min rest period ensued and then the participant performed three successful jumps. The participants performed the jumps shod and wearing a t-shirt and shorts.

For final analysis, the average score of the three jumps was calculated for each participant and a comparison between methods was conducted. During the video assessment, the camera recording the sagittal plane motion was situated to only one side of the participants (the left side), thus, only this side was rated. Since the 'PhysiMax' rated each leg separately, only the left side was compared during the analysis for the parameters of the sagittal plane. The parameters of the frontal plane were scored for both legs.

For intra-test reliability of the video assessment, one of the authors (AY) re-evaluated the final LESS score of 10 participants, every other day for a total of three times. Inter-tester reliability was performed for the video assessment of the same 10 participants by 2 of the authors (GD and AY) blinded to each other's results.

The LESS score

The LESS score was obtained using the standard LESS protocol (Padua et al., 2009) which evaluates the trunk and lower extremities' positions during initial contact with the ground, at maximum knee flexion, in addition to changes in displacement that had occurred between these two points. It also includes assessment of the frontal (e.g., knee valgus, stance width, foot rotation, lateral trunk movement, foot symmetry) and sagittal planes (e.g., trunk, hip, knee flexion and displacement, ankle plantar flexion).

Our study performed the LESS 17, consisting of 17 criteria assessing the quality of landing. Each item assessed the presence or absence of a faulty movement pattern. Movements in items 1–15 were scored as 0 (no impairment) or 1 (impairment), with 0 indicating a good landing and 1, a partial impairment or less than ideal landing. Items 16 and 17 assessed overall sagittal plane joint displacement and the rater's general perception of landing quality which were scored as: 0 (soft landing and excellent landing for items 16 and 17, respectively), 1 (average joint displacement and average landing pattern, respectively) or 2 (stiff landing and poor landing for items 16 and 17, respectively) (Padua et al., 2004, 2009, 2011). The lower the final score, the better the jumping performance. The maximum possible score was 19 points indicating an inadequate performance in all test components.

Instruments

Video cameras: Two standard 30HZ video cameras (Samsung HMX-H300BT, Samsung Electronics Co. Ltd., South Korea) were placed on the frontal and sagittal planes of the jumping area. The distance between the cameras and the jumping area was fixed at 3.45 m. The camera's height from the floor was 1.22 m. The Kinovea software program (version 8.15) was employed for video analysis.

'PhysiMax system': This system comprises a mobile personal computer (PC), a 3D Microsoft Kinect camera (Kinect-sensor v1, Microsoft Corp. USA) and motion analysis software. The

camera measures depth based on the structured light reflections (30 frames/s). The software contains a technical algorithm assessing the movements of specific joints and then combining the overall test score and individual joint kinematics (e.g., LESS test protocol). The Kinect sensor is located in the frontal plane (e.g., in front of the participant) but as it is a 3-D camera, it also provided data from the sagittal and transverse planes, on the spatial position of the individual's joints. The height of the camera was positioned 85 cm above the floor and the distance from the landing area was 1.5 m. The 'Physimax' and the video cameras did not obstruct each other's view.

The 'PhysiMax' system captured the participants during the jump-landing task and immediately following its completion, automatically furnished the final LESS score in addition to a detailed score for each of the 16 components of the test. For item no. 17, the overall impression was supplied by the assessor. The system also presented the lower extremity joint angles (e.g., trunk, hip and knee flexion, trunk lateral flexion, knee valgus, foot rotation) throughout the landing phases (i.e., initial contact or maximum knee flexion phase) assessing and comparing each leg separately. All data provided by the system are presented both in the graphs and tables. The system identified the initial contact phase which occurred when the foot touched the ground by using an algorithm combining two main components: the tracking of change in velocity of the foot and the distance from the ground of the ankle and foot.

Statistical analysis

Data analysis was performed using the Excel (Microsoft Corporation) and SAS (version 9.4; SAS Institute Inc., Cary, NC, USA) statistical programs. Descriptive statistics were calculated by demographic and participant characteristics.

The intra-class correlation coefficient (ICC) and Bland–Altman plot compared the final LESS score obtained by the two measurement tools for concurrent criterion validity. The mean difference (MD), the mean absolute differences (MAD) and the 95% limits of agreement (LA) were calculated (Atkins, James, Sizer, Jonely, & Brismée, 2014). A percentage agreement was carried out comparing the results of each item of the LESS between the two measurement tools. The percentage agreement was calculated by subtracting one method score from the other, counting the resulting number of zeros and dividing the number of zeros by the number of variables, thus, providing a measure of agreement between the raters. This method is acceptable and appropriate when the values are zero and/or 1 and calculated by two well-trained assessors/raters and minimal guesswork is likely to exist (McHugh, 2012).

Results

A final analysis was conducted on the data of only 48 participants, as there was a technical problem during data collection of one individual (e.g., the system failed to identify him). The demographic characteristics of the studied sample are presented in Table 1. The range of the final LESS score using video assessment and the 'PhysiMax' system was between 0–9 and 0–11, respectively. The final score was divided into 3 categories: excellent landing (<4), moderate (4 to ≤6) and poor (>6). These categories are based on a previous research study (Smith et al., 2012) with a minor modification. We combined the two middle categories in order to generate a larger disparity between them. Seventeen participants (35.4%) performed excellent landings; only one participant scored 0, indicating a flawless performance. Fourteen (29.2%) scored >6. The final LESS score achieved by each assessment technique according to score categories is described in Table 2.

The mean final score of the LESS using video assessment and the ‘PhysiMax’ system was 4.77 (±2.29) and 5.15 (±2.58), respectively (ICC 0.80, confidence intervals 95% 0.65–0.87) (ICC model 2,1), implying good agreement between the two assessment methods (Koo & Li, 2016). In addition, the Bland–Altman plot demonstrated that the final score was in the range of 95% limits of agreement; MD was -0.38 (95% limits of agreement -3.5-2.76) (Figure 1) and the MAD for the final score was 1.13 (95% confidence intervals 0.79–1.46).

Table 1. Demographical characteristic of sample studied.

	Mean (±SD)	Range
Age (years)	28.45 (±5.61)	20–42
Height (cm)	172.16 (±7.75)	154–190
Weight (kg)	72.00 (±10.34)	51–99
BMI (kg/m^2)	24.03 (2.51)	19.37–30.86
No. training session per week	3.55 (±2.18)	2–6

Table 2. The distribution of the final LESS score.

	‘Physimax’ system *N* = 48	Video assessment *N* = 48
Final LESS score	*N* (%)	*N* (%)
Excellent (<4)	15 (31.25%)	17 (35.41%)
Moderate (4 to ≤6)	19 (39.58%)	17 (35.41%)
Poor (>6)	14 (29.16%)	14 (29.16%)

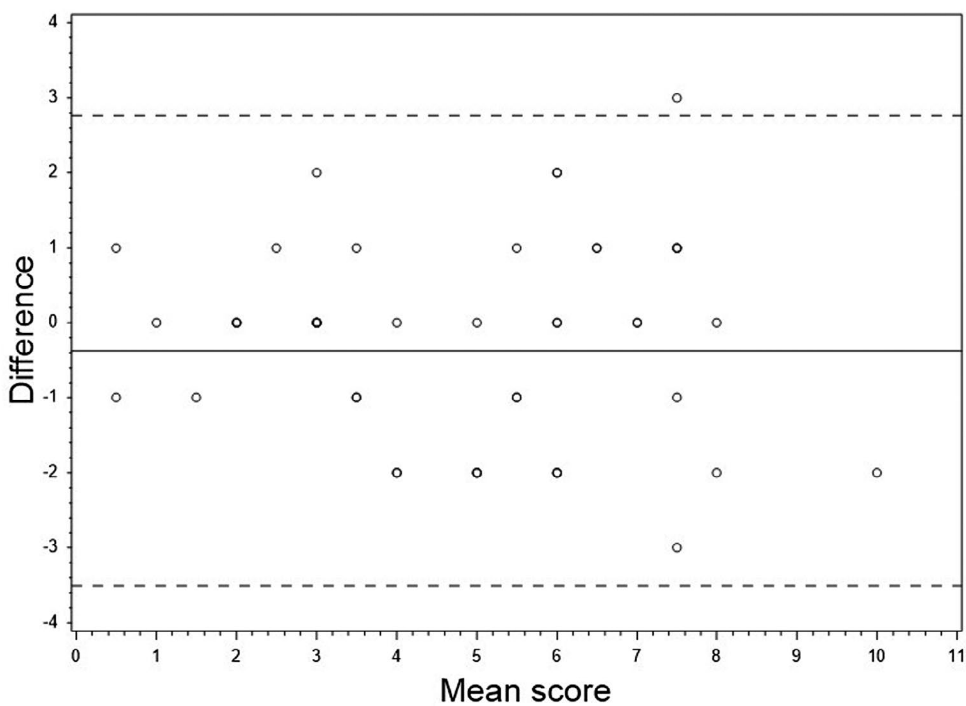

Figure 1. Bland–Altman distribution plot comparing the differences of the final LESS score between the two measurement techniques.

Table 3. The LESS test scores for each test item, by two assessment methods and the percentage agreement between them. (Item no. 17 is provided manually in both methods, no comparison was conducted).

No. item	Name of item	Score 1 (faulty performance) 'Physimax' system (*N*)	Score 1 (faulty performance) Video assessment (*N*)	Score 0 (good performance) 'Physimax' system (*N*)	Score 0 (good performance) Video assessment (*N*)	*Equal grade by methods (*N*)	**%
1	IC knee flexion	18	18	30	30	42	87.5
2	IC hip flexion	1	0	47	48	47	97.9
3	IC trunk flexion	10	12	38	36	40	83.3
4	IC ankle plantar flexion	4	3	44	45	45	93.8
5	IC knee valgus	8	7	40	41	41	85.4
6	IC lateral trunk	14	10	34	38	36	75.0
7	Stance width-wide	2	3	46	45	45	93.7
8	Stance width-narrow	32	30	16	18	38	79.2
9	Toe in	1	0	47	48	47	97.9
10	Toe out	12	12	36	36	44	91.7
11	IC symmetry	10	16	38	32	40	83.3
12	Knee flexion displacement	6	8	42	40	42	87.5
13	Hip flexion at knee MF	3	0	45	48	45	93.8
14	Trunk flexion at knee MF	20	22	26	26	40	83.3
15	Knee valgus displacement	22	19	26	29	39	81.3
16	Joint displacement	Score 2 (significant impairment): Physimax 5, Video 4		Score 1 (faulty performance): Physimax 32, Video 19	Score 0 (good performance): Physimax 11, Video 25	34	68.7

Notes: *Equal grade by methods (*N*)—both methods graded the participant the same (zero or one), **%—per cent agreement between methods, IC—initial contact; MF—maximum flexion.

Results of the scores for all test components by the 'PhysiMax' system and video assessment as well as the percentage agreement between the two evaluation methods are summarised in Table 3. An agreement percentage >80% is considered excellent, 51–79% moderate and <50% is poor (Cortes & Onate, 2013; Onate, Cortes, Welch, & Van Lunen, 2010). Items 1–15 evaluated the quality of landing via two possible scoring options (0 or 1). Among these items, there was an excellent agreement (97%) between assessment methods of item no. 9 which evaluated foot position with toe-in during landing and item no. 2 which evaluated the hip flexion angle during initial contact. In contrast, item no. 3 which evaluated the lateral trunk flexion, demonstrated a moderate agreement (75%) whilst item no. 16, which evaluated the amount of joint movement during landing using three possible scoring options (0, 1 or 2) demonstrated a moderate agreement of 68.75% between methods.

The percentage agreement was very high (>90%) in 6 items, between 80–90% in 7 and between 75–80% in 2. Only in one item (no. 16), as mentioned previously, had <70% agreement between methods. Since item no. 17 evaluated the overall impression by the assessor and was manually scored in both methods, no comparison was conducted. Intra- and inter-observer reliability of the video camera assessment was 0.82 (ICC model 2,1) and 0.83 (ICC model 2,1), respectively ($p < 0.001$). These values present high agreement (Koo & Li, 2016; Landis & Koch, 1977).

Discussion and implications

Functional tests constitute an important component throughout a physical therapy rehabilitation programme in assessing an athlete's post-injury, or simulating a specific movement before his/her return to a full sport activity. As jumping is a major component in many sports activities, the bilateral drop jump test using the LESS scoring is one of the most common functional tests. Using an objective system and accessing the data immediately after jumping might be of clinical importance to physiotherapists, athletic trainers and patients. Our aim was to investigate whether the 'PhysiMax' system, which includes a Microsoft Kinect sensor and computer software is a reliable method in evaluating the LESS score test compared with the conventional video assessment method.

We found that the 'PhysiMax' system furnishes data relating to joint position and movement, similar to the data assessed using video analysis as was hypothesised. We believe that the 'PhysiMax' system is an acceptable method for assessing the LESS score and has the potential to be extensively used during functional assessment and screening in orthopaedic and sports clinics. The 'PhysiMax' system presents an objective score for assessing jump-landing quality following specific parameters defined during the software development. In addition, the system furnishes a final LESS score for each of the 17 test components when comparing the right and left sides of the body (although item 17, being an overall impression, was inputted into the system by the examiner).

A main advantage of this system is that the performance assessment is objective and immediate following the jump-landing performance; thus, the examiner cannot influence the results nor is there a subjective evaluation which could bias the results. Furthermore, the patient needs no special preparation. The only requirement is to wear suitable clothing (shorts and training shoes). Other benefits are its portability, ease of use, relatively inexpensive cost and high reliability as well as no need for markers placed on an individual. However, there are still some shortcomings of this system, i.e., technical malfunctions when the system fails to identify a specific jump. Also, certain clothing items reflected the light, thus interfering with data collection and analysis.

The Microsoft Kinect sensors can create a 3-D map of the area located in front of the sensors, thus, track the 3-D movement through its depth sensor and measure the kinematics of each joint (Eltoukhy et al., 2016; Shani, Shapiro, Oded, Dima, & Melzer, 2017; Xu, McGorry, Chou, Lin, & Chang, 2015) The Microsoft Kinect camera has been previously established as a reliable and valid tool for assessing lower and upper extremity kinematic variables, although there is still controversy in the literature as to its accuracy and consistency (Clark et al., 2012; Eltoukhy et al., 2016; Galna et al., 2014; Stone et al., 2013). Studies have found that the Kinect sensor provides comparable data to the 3-D motion analysis system when assessing drop jump variables (e.g., knee valgus, knee angle), step length, stride time, balance performance, gait cycle and postural control assessment (Auvinet, Multon, Aubin, Meunier, & Raison, 2015; Clark et al., 2012, 2015; Pfister, West, Bronner, & Noah, 2014; Shani et al., 2017; Stone et al., 2013). It also assists in identifying the location of the joint centre, gait parameters and balance performance (Xu & McGorry, 2015; Xu et al., 2015). Worth noting is that the 'PhysiMax' system differs from the Kinect camera described in the literature implying that although the same Kinect camera receives the kinematic data of movement, the 'PhysiMax' system also uses a special newly developed software and algorithm assessing quality of movement, not only angles and movement data.

Although using video analysis in assessing the LESS score has strong validity and reliability (Padua et al., 2009), it is not very easy or simple to operate. The examiner needs two video cameras placed in different locations and requires time to observe the video movies to evaluate the jump-landing performance. Compared to this, the real-time LESS does not require equipment, yet it only consists of 10 items while the full LESS has 17 items. It is also more complicated to perform as the examiner needs to immediately decide on the score without the ability to re-examine his decision. In addition to these methods, the i-LESS developed for screening large groups also utilises video movies. The assessment is performed only from the frontal plane enabling a faster evaluation process. Yet, this method also has a major subjective component and it includes only 5 items of evaluation (Cortes & Onate, 2013).

The ‘PhysiMax’ system is an easy assessment tool consisting of a camera and portable computer with no time period needed for evaluation, as the scores are provided immediately and automatically. We found a moderate to excellent agreement between the examined two methods for the LESS score assessment. The differences between methods might be due to evaluation techniques or problems emerging during assessment, i.e., a knee valgus assessment conducted via video analysis was performed by drawing a vertical line from the centre of the patella and examining if it fell medial to the foot (Padua et al., 2009). Occasionally, false positive results might occur. If the individual lands with an external rotation of the femur or tibia or with a wide stance, this line might fall medial to the foot without true knee valgus. The ‘PhysiMax’ system can calculate the knee valgus with a line connecting the hip, knee and ankle and during the final analysis can calculate the knee valgus in relation to the stance width. Other examples of the differences between the methods are the evaluation of trunk flexion during initial contact. During video assessment, the angle between the trunk and hip is assessed, whereas, the ‘PhysiMax’ system can calculate the flexion angle relative to a vertical line.

Our LESS score results favourably corroborate with Padua et al.’s (2009) research of 2,691 participants. The final LESS score in the current study was 4.77 compared with 4.92 found in Padua et al.’s (2009) study. Following the current research, we suggest that the ‘PhysiMax’ system enables the examiners to correctly assess the LESS.

Conclusions

The ‘PhysiMax’ system which combines Kinect and specific software provides data relating to joint position and movement comparable to the data received by video analysis when assessing the double leg drop jump LESS score. We think that this system can benefit physiotherapists and athletic trainers when evaluating jump-landing performances of athletes or when monitoring a patient’s progress during rehabilitation. The major advantages of this system are its portability, objective, marker-less assessment and generation of immediate results. The ‘PhysiMax’ system fulfils the existing need for an assessment tool that can identify and provide quantitative evaluation of movement pattern quality when performing functional tests.

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Disclosure statement

Maya Cale'-Benzoor is on the scientific advisory board for 'Physimax', however she declares having no financial interest and receiving no financial compensation in this role and for this study.

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