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Research Article / Araştırma Makalesi

Development of a new image processing program for the evaluation of motion analysis system videos

Hareket analizi sistemi videolarının değerlendirilmesinde kullanılabilecek yeni bir görüntü işleme programının geliştirilmesi

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ABSTRACT

Objective: The aim of this study is to develop an application for image processing of motion analysis system videos.

Methods: After recording the descriptive information of the volunteer participants, the International Physical Activity Questionnaire Short Form (IPAQ) was completed in a face-to-face environment. Upon completing the questionnaire, the participants were videotaped in accordance with the Landing Error Scoring System (LESS) protocol. LESS scoring was performed by five researchers using Kinovea v.0.9.5, which has been used in image processing of similar dynamic motion analysis systems in our clinic in the past, and a newly developed program called HAS. The program was developed using .Net Maui .Net 8 on Visual Studio. SPSS v.23 and GraphPad Prism 8 programs were used for data analysis.

Results: Forty healthy young people, of which 47.5% (n=19) male and 52.5% (n=21) female, participated in the study. All of the participants had right dominancy. Those who reported regular exercise habits were 40% (n=16). The age of the participants was 21.7±2.4 years and body mass index was 23.0±3.9 kg/m². The IPAQ-total value was determined as 2006±1801 METs. Considering all of the evaluators, the inter-rater intraclass correlation coefficients were calculated as 0.970 (0.952-0.982) in test-Kinovea, 0.973 (0.957-0.984) in retest-Kinovea, 0.981 (0.969-0.989) in test-New and 0.977 (0.963-0.987) in retest-New, respectively. As visualized in the measurements of the sports medicine specialist, no significant differences were detected in the intra-rater dependent and independent group test results of all evaluators (p>0.05).

Conclusion: Video image processing processes of motion analysis systems, especially LESS, can be realized by using the HAS program.

Keywords: *Motion analysis, image processing, program, LESS*

ÖZ

Amaç: Bu çalışmada, hareket analizi sistemi video görüntülerinin işlenmesi için bir uygulama geliştirmek amaçlandı.

Gereç ve Yöntem: Gönüllü katılımcıların tanımlayıcı bilgileri kaydedildikten sonra Uluslararası Fiziksel Aktivite Anketi Kısa Formu (UFAA) yüz yüze ortamda dolduruldu. Anket tamamlandıktan sonra katılımcıların Sıçramadan Sonra Yere İniş Hata Puanlama Sistemi (SSYİ-HPS) protokolüne uygun videoları çekildi. Kliniğimizce geçmişte benzer dinamik hareket analizi sistemlerinin görüntü işlemelerinde kullanılan Kinovea v.0.9.5 ile birlikte yeni geliştirilen HAS isimli program aracılığında beş araştırmacı tarafından SSYİ-HPS puanlamaları gerçekleştirildi. Program, Visual Studio üzerinde .Net Maui .Net 8 kullanılarak geliştirildi. Verilerin analizinde SPSS v.23 ve GraphPad Prism 8 programları kullanıldı.

Bulgular: Çalışmaya %47.5'i (n=19) erkek, %52.5'i (n=21) kadın 40 sağlıklı genç katıldı. Katılımcıların tamamı sağ ekstremite dominanttı. Düzenli egzersiz alışkanlığı olduğunu bildirenler %40 (n=16) oranındaydı. Katılımcıların yaşı 21.3±2.4 yıl ve vücut kütle indeksi 23.0±3.9 kg/m² idi. UFAA-toplam değeri 2006±1801 MET olarak belirlendi. Tümü dikkate alındığında, değerlendiriciler arası Sınıf içi korelasyon katsayısı sırasıyla test-Kinovea'da 0.970 (0.952-0.982), retest-Kinovea'da 0.973 (0.957-0.984), test-Yeni'de 0.981 (0.969-0.989) ve retest-Yeni'de 0.,977 (0.963-0.987) olarak hesaplandı. Spor hekimliği uzmanının ölçüm sonuçlarında görselleştirildiği üzere tüm değerlendiricilerin değerlendirici içi bağımlı ve bağımsız grup test sonuçlarında anlamlı fark saptanmadı (p>0.05).

Sonuç: SSYİ-HPS başta olmak üzere, hareket analiz sistemlerinin video görüntü işleme süreçleri HAS programı kullanılarak gerçekleştirilebilmektedir.

Anahtar Sözcükler: *Hareket analizi, görüntü işleme, program, SSYİ-HPS*

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INTRODUCTION

Motion analysis systems represent a significant area of inquiry within the field of biomechanics, garnering attention from a diverse array of professionals. In alignment with Newton's third law of motion, these systems facilitate the conversion of biomechanical movements and their corresponding effects on biological tissues into quantifiable data. Utilizing the insights derived from such data, sports scientists investigate various parameters, including the precision of movement techniques and their implications for athletic performance. Concurrently, clinicians employ this information to enhance movement quality by focusing on factors such as injury prevention and the efficacy of therapeutic interventions (1).

Motion analysis systems are basically divided into static and dynamic motion analysis systems. In both types of motion analysis systems, video imaging systems can be used in order to better process and repeatedly evaluate the data (2). Various image processing programs can be used in order to examine the different moments of the video image and the continuous movement in more detail. With the help of these programs, it is easy to quantify the issues that the professional performing the motion analysis focuses on, such as stopping the video at the right moment, speeding up and slowing down the image in order to better understand the continuity of the movement, measuring the angles of different joints during the movement, evaluating changes in the measured angle during the movement, determining the planes of different parts of the body in three-dimensional space (1,2).

The Landing Error Scoring System (LESS) is a dynamic motion analysis system (3). Dynamic motion analysis systems often provide camera-based motion analysis in the current technological state of the art (4). In LESS, which has been the subject of many studies, similar to other dynamic motion analysis systems, video images of subjects are taken for evaluation and quantification, and these video images are analyzed using image processing software. In addition, as the current researchers have worked on LESS in the past, and have experience in various studies, the aforementioned motion analysis system was used as a prototype during the development of the associated program (5-7).

Although an application called Kinovea has been used by the researchers in the past to process video images, due to the limitations such as the lack of national origin of the relevant program, and the addition and removal of desired features to the program, we wanted to develop a unique application with our own resources, in order to evaluate motion analysis systems that we frequently use in clinical practice.

The objective of this study is to develop an application designed for the processing of images derived from motion analysis system videos. Furthermore, this research aims to evaluate whether the results produced by this new application align with those obtained from previous applications utilizing LESS data.

MATERIAL and METHODS

The study was approved by the Clinical Research Ethics Committee of the Faculty of Medicine of the University of Suleyman Demirel by decision dated 18.11.2022. numbered 22/325. The study included healthy individuals aged 18-25 years who did not meet the exclusion criteria for the purpose and rationale of the study. Signed informed consent was obtained from the participants in accordance with the Declaration of Helsinki.

The number of people to be included in the study was determined at baseline using G.Power v 3.1 application with power (1-β err prob)=0.95 and α error score=0.05, and the study was completed with 40 participants (6).

Participants who agreed to participate in the study and signed the consent form were asked demographic information and International Physical Activity Questionnaire-Short Form (IPAQ) questions by a researcher in a face-to-face environment, and were noted down. After the questionnaire was completed, videos were taken in accordance with the LESS protocol.

LESS scoring was performed by five researchers with the newly developed application called 'Hareket Analizi Sistemi (HAS)' (In English: Motion Analysis System) together with Kinovea v.0.9.5, which has been used in the past for image processing of similar dynamic motion analysis systems in our clinic.

International Physical Activity Questionnaire-Short Form: One of the descriptive characteristics of participants was their physical activity levels. The questionnaire in which the physical activity levels of individuals are analysed consists of seven questions. The questionnaire, for which the Turkish validity and reliability was established by Sağlam et al. (8) provides information on the frequency of low, moderate and high levels of physical activity, and time spent sitting and the frequency of physical activity performed in the last week. In addition, the questionnaire provides the metabolic equivalents (METs) spent during low, moderate and high levels of physical activity in the last week. As a result, the METs spent by the participant in the last week can be calculated by an estimation method. According to this calculation, a physical activity level of <600 MET min/wk is classified as 'inactive', 600-3000 MET min/wk as 'moderate' and >3000 MET min/wk as 'vigorous' (8).

Landing Error Scoring System: The LESS uses a checklist of 17 criteria, each scored based on the presence/absence of specific movement errors, such as knee valgus, trunk displacement, or asymmetrical landing. Higher scores indicate a greater number of errors and poorer landing mechanics (3). The evaluation of the image processing program was carried out using LESS, the Turkish validity and reliability of which was established by Ercan et al. (5).

With respect to this movement analysis system, the participants were subjected to a jump test protocol. According to the protocol, a wooden box (with a non-slip floor and a height of 30 cm) was prepared. Half the height of each participant was calculated and the mat was placed at this distance from the box. The researchers first explained and then demonstrated how to make the jump. Participants were given as many trials as they wanted to familiarise themselves with the protocol before the test. When the participant felt ready, the jump was repeated three times in a row according to the protocol. A video cameras was placed in front of the jumping mat and the other one on the dominant limb side of the participant to capture video images during the jump. As clearly stated in the protocol, the video cameras were positioned so that the height from the ground was 122 cm and the distance from the jumping box was 345 cm. The video images were protected by researchers under the 'Personal Data Protection Law'. The relevant images were evaluated by five researchers (one of them was a sports medicine specialist, two were sports medicine speciality students, and the other two were medical faculty students), with the new HAS application developed by one of our researchers and Kinovea v.0.9.5 application and the error scores were noted. The researcher who developed the application did not participate in the error score evaluation.

Development of the HAS Program: The program has been developed using .NET MAUI .NET 8 on Visual Studio. It utilizes XAML for its design, and testing was conducted on the MAUI Windows application. Version control of the project was performed, and MVVM architecture was employed. The program can open video files and allows users to seek forward and backward by one-tenth of a second. Additionally, it offers features such as drawing on the video, measuring angles, and adding frames, all of which can be customized according to user's preferences. There are also features planned for future releases that are not yet active, including web-based video playback, AI-assisted angle measurement, and analysis. The aim is to provide these features to users in subsequent versions.

Statistical analysis

SPSS v.23 and GraphPad Prism 8 programs were used for data analysis. After descriptive characteristics were determined, Intraclass Correlation Coefficient (ICC) analysis was performed to determine the intra-rater, inter-rater and inter-method agreements. For difference analyses, t-test for dependent and independent groups was preferred. Data were presented as mean ± standard deviation, frequency (n), percentage (%) and ICC (95% confidence interval). The ICC was considered excellent between 0.81-1.00, good between 0.61-0.80, and moderate between 0.41-0.60 (9).

RESULTS

Forty healthy young people, 47.5% (n=19) male and 52.5% (n=21) female, participated in the study. All of the participants (n=40) were right extremity dominant. Those who reported regular exercise habits were 40% (n=16). The age of the participants was 21.7±2.4 years and their body mass index was 23.0±3.9 kg/m^2. IPAQ-Total was determined as 2006±1801 MET.

The LESS evaluation of the sample was performed by five different researchers. The evaluators performed the test and re-test measurements separately on both Kinovea and the newly developed program (Table 1, Figure 1).

Table 1. Concordance of LESS results performed by the researchers

Test	E 1	ICC $_{ie}$	E 2	ICC $_{ie}$	E 3	ICC $_{ie}$	E 4	ICC $_{ie}$	E 5	ICC $_{ie}$
Test-Kinovea	6.35±1.70	0.983	6.45±1.84	0.992	6.20±1.65	0.961	6.33±1.70	0.978	6.23±1.64	0.970
Retest-Kinovea	6.35±1.79		6.50±1.77		6.23±1.56		6.43±1.68		6.35±1.67	
Test-HAS	6.35±1.76	0.927	6.45±1.78	1.000	6.35±1.53	0.981	6.45±1.77	0.984	6.35±1.63	0.983
Retest-HAS	6.40±1.71		6.45±1.78		6.43±1.53		6.43±1.65		6.38±1.66	
Test-Kinovea vs HAS ICC	0.960		0.992		0.909		0.968		0.964	
Retest-Kinovea vs HAS ICC	0.943		0.988		0.918		0.976		0.988	

As X±SD (mean±standard deviation), E: evaluator, ICC: intraclass correlation coefficient, ICC $_{ie}$: intra-evaluator ICC.

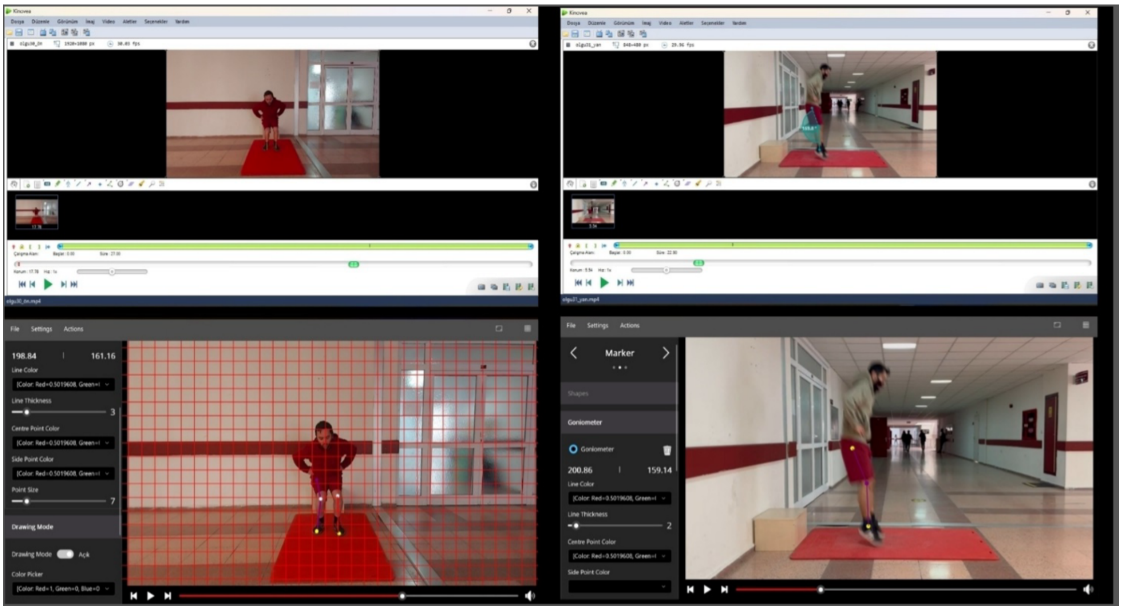

Figure 1. Examples of LESS scoring with image processing programs (Kinovea above, HAS below)

When all of the evaluators were taken into consideration, the inter-rater ICC values were calculated as 0.970 (0.952-0.982) in test-Kinovea, 0.973 (0.957-0.984) in retest-Kinovea, 0.981 (0.969-0.989) in test-HAS and 0.977 (0.963-0.987) in retest-HAS, respectively.

As shown in the sports medicine specialist measurements, no significant differences were detected between the intra-rater dependent and independent group test results of all evaluators ($p>0.05$) (Figure 2).

DISCUSSION

No significant differences were found in the intra-rater dependent and independent group test scores of all raters. In quantitative studies, reliability is defined as the ability of the measurement tool to produce the same result when used multiple times (10). While software algorithms may inherently produce accurate angular results when inputs are correctly defined, the process of manually digitizing data introduces variability due to user-related factors such as hand-eye coordination and sensitivity. This is why inter- and intra-observer reliability are crucial metrics in assessing the usability and performance of measurement tools that involve human input (11).To this end, repeated measurements were made to assess the reliability of the new application, and the results were found to be similar. It was therefore concluded that the developed application is reliable.

Although three-dimensional kinematic systems have been reported as the gold standard in motion analysis, these methods require high hardware costs, expert users, time and specialized laboratory environments. Economical and practical methods are more feasible and preferred by professionals interested in athletes' health (6).

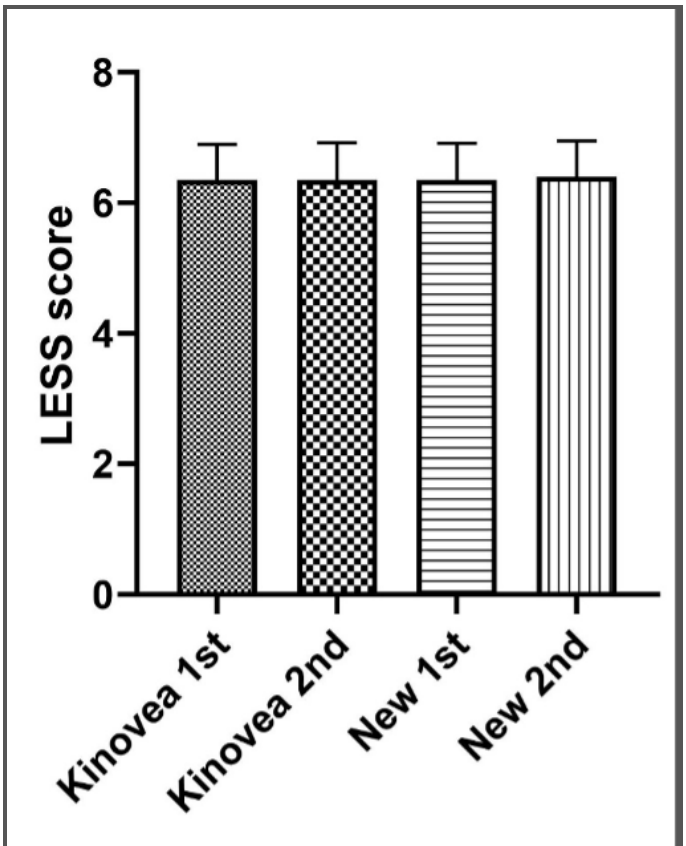

Figure 2. Differences between dependent (Kinovea 1st-2nd/ HAS 1st-2nd) and independent (Kinovea 1st-HAS 1st/Kinovea 2nd-HAS 2nd) groups for the experienced evaluator data

For motion analysis, which is increasingly used in sports and health, it is important to obtain similar results based on precise measurements. As it becomes more accessible in motion analysis, there is growing interest in the use of 2D video analysis applications, and software is needed to analyze these video analyses. One example is Kinovea, a free, open-source motion analysis software developed by sports and health professionals, programmers, researchers and athletes in a worldwide non-profit collaboration (12).

In the literature, it can be seen that the reliability of the Kinovea program has been investigated in various studies. Nor Adnan et al. (13) conducted an analysis using a motion capture software and Kinovea 0.8.25 to examine whether the Kinovea software is reliable for analysing the drop jump performance of athletes, and reported that they found the Kinovea software to be reliable.

A study investigating the validity, reliability and usefulness of a smartphone and Kinovea motion analysis software for measuring vertical jump height showed that Kinovea is a valid, reliable and cost-effective tool for monitoring changes in jump performance in a healthy, active population diverse in gender and physical condition (12).

Elrahim et al. (14) conducted a study to investigate the inter-rater and intra-rater reliability of the Kinovea software for measuring shoulder range of motion in healthy individuals, and reported that the application was reliable for the intended purpose.

In another study conducted to investigate the reliability of the Kinovea computer program in measuring cervical range of motion in the sagittal plane in healthy subjects, it was concluded that the Kinovea software program was both intra- and inter-rater reliable in measuring cervical range of motion in the sagittal plane (15).

As can be seen from the examples in the literature, various movement analyses in the fields of sport and health are being supported by developing technology that allows objective data to be obtained. The Kinovea program, which is widely used, has been found to be reliable as far as it was investigated, and as the researchers have experience in using it, it was used as a reference for the evaluation of our newly developed domestic application. The calculated ICC values of our HAS application with Kinovea were found to be excellent. The advantage of the HAS application we have developed is that it provides the flexibility to add and remove desired features to the program. We find it valuable to offer users a new application that can be used in motion analysis.

In order to produce alternative domestic resources to existing programs, the first version of this application, which we have created and tested the usability, will be developed and new features will be made available in the next versions.

Limitations of this study include the lack of a motion analysis laboratory in the clinic where the study was conducted, and the presence of lighting and background problems in the videos. However, this is not a major problem in the analysis of videos. It is expected that this will be an issue when we move to analysis using artificial intelligence technology.

To conclude; the HAS program can be used to perform video image processing operations on motion analysis systems, in particular LESS.

Note

The pilot study of this research was presented at the 1st Project and Science Days with National Participation held in Isparta on 16 May, 2024.

Ethics Committee Approval / Etik Komite Onayı

The approval for this study was obtained from Clinical Research Ethics Committee of the Faculty of Medicine of the University of Suleyman Demirel, Isparta, Türkiye (Decision no: 22/325, Date: 18/11/2022).

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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Author Contributions / Yazar Katkıları

Concept - GK, SE, TA, EUK, FB, CÇ; Design - GK, BB, ET, CS, ASU, EA, SE; Supervision - GK, ASU, EA, SE, TA, EUK, FB, CÇ; Materials - GK, BB, ET, CS; Data Collection and/or Processing - GK, BB, ET, CS, ASU; Analysis and Interpretation - GK, BB, ET, CS, ASU; Literature Review - GK, BB, ET, CS, EA; Writing manuscript - GK, BB, ET, CS, EA, SE; Critical reviews - GK, SE, TA, EUK, FB, CÇ. All authors contributed to the final version of the manuscript and discussed the results and contributed to the final manuscript.

REFERENCES

1. Dönmez G, Ak E, Ödek U, Özberk N, Korkusuz F. Sporda hareket analizi. *TOTBİD Dergisi.* 2014;13:369-80.
2. Kıyak G, Ercan S. Spor hekimliği bakiş açisiyla hareket analizi sistemleri ve biyomekanik. *Med J SDU.* 2023;30(2):263-75.
3. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett Jr WE, Beutler AI. The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the JUMP-ACL study. *Am J Sports Med.* 2009;37(10):1996-2002.
4. Souza RB. An evidence-based videotaped running biomechanics analysis. *Phys Med Rehabil Clin N Am.* 2016;27(1):217-36.
5. Ercan S, Arslan E, Çetin C, Başkurt F, Başkurt Z, Baser Kolcu M. Sıçramadan Sonra Yere İniş Hata Puanlama Sistemi'nin Türkçe uyarlama çalışması. *Kocaeli Med J.* 2021;10(2):174-8.
6. Ercan S, Arslan E, Çetin C, Başkurt Z, Başkurt F, Kolcu MİB, et al. Sıçrama Sonrası Yere İniş Hatası Puanlama Sistemi-Gerçek Zamanlı'nın Türkçe geçerlik ve güvenilirlik çalışması. *Turk J Sports Med.* 2021;56(1):20-7.
7. Kıyak G, Uyan AS, Arslan E, Acar HT, Ercan S, Çetin C. The effects of knee brace use on landing error, balance, and crossover hop test in healthy athletes. *Turk J Sports Med.* 2024;59(3):105-11.

8. Saglam M, Arikan H, Savci S, Inal-Ince D, Bosnak-Guclu M, Karabulut E, et al. International physical activity questionnaire: reliability and validity of the Turkish version. *Percept Mot Skills.* 2010;111(1):278-84.
9. Mauntel TC, Padua DA, Stanley LE, Frank BS, DiStefano LJ, Peck KY, et al. Automated quantification of the landing error scoring system with a markerless motion-capture system. *J Athl Train*. 2017;52(11):1002-9.
10. Yağar F, Dökme S. Niteliksel araştirmalarin planlanmasi: araştirma sorulari, örneklem seçimi, geçerlik ve güvenirlik. *Gazi Sağlık Bil*. 2018;3(3):1-9.
11. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med.* 1998;26(4):217-38.
12. Pueo B, Penichet-Tomas A, Jimenez-Olmedo JM. Validity, reliability and usefulness of smartphone and kinovea motion analysis software for direct measurement of vertical jump height. *Physiol Behav*. 2020;227:113144.
13. Nor Adnan NM, Ab Patar MNA, Lee H, Yamamoto S-I, Jong-Young L, Mahmud J, editors. Biomechanical analysis using Kinovea for sports application. *IOP Conf Ser Mater Sci Eng.* 2018;342:012097.
14. Abd Elrahim RM, Embaby EA, Ali MF, Kamel RM. Inter-rater and intra-rater reliability of Kinovea software for measurement of shoulder range of motion. *Bull Fac Phys Ther.* 2016;21:80-7.
15. Elwardany SH, El-Sayed WH, Ali MF. Reliability of Kinovea computer program in measuring cervical range of motion in sagittal plane. *OALibJ.* 2015;2(9):e1916