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Reliability of a two-dimensional video analysis protocol to assess forward head posture during walking

Z. Dimitriadis,[1]
S. Argyrou,[1]
A. Diamantis,[1]
K. Kostakis,[1]
A. Kanellopoulos,[1]
N. Strimpakos,[1,2]
I. Poulis,[1]
E. Kapreli[1]

[1]Department of Physiotherapy, School of Sciences, University of Thessaly, Lamia, Greece
[2]Division of Musculoskeletal and Dermatological Sciences, School of Biological Sciences, University of Manchester, Manchester, United Kingdom

OBJECTIVE **To develop a protocol to investigate the dynamic forward head posture during walking, using 2D video analysis, and to examine its reliability.** METHOD **Thirty-six healthy volunteers were recruited (15 men and 21 women; age 23.6±7.65 years). A video camera of a mobile phone was used for recording the forward head posture of the participants during walking in two sessions. Three recordings were obtained at each one of the two sessions. The second session was performed 8 days after the first session. Videos were analyzed by three raters with a different level of experience. Forward head posture was described based on craniovertebral angle.** RESULTS **Intra-rater (intraclass correlation coefficient [ICC]: 0.90–0.92, standard error of measurement [SEM]: 1.44–1.84), inter-rater (ICC: 0.98–0.99, SEM: 0.79–1.08) and test-retest reliability (ICC: 0.95–0.98, SEM: 1.01–1.52) were found to be excellent for the three raters. The test-retest bias (rater A: -0.3±1.97, rater B: -0.74±2.14, rater C: -0.31±1.43) and the inter-rater bias between the two more experienced raters (0.25±1.53) were very low.** CONCLUSIONS **The assessment of dynamic forward head posture by using 2D video-based motion analysis is a feasible and reliable method with small measurement error. A minimal training of raters is sufficient for providing reliable estimates of dynamic forward head posture.**

Αξιοπιστία ενός δισδιάστατου πρωτοκόλλου ανάλυσης video για την αξιολόγηση της πρόσθιας προβολής της κεφαλής κατά τη βάδιση

Περίληψη στο τέλος του άρθρου

Key words

Forward head posture
Gait analysis
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Validity

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Forward head posture (FHP) can be defined as the anterior displacement of head in relation to the body vertical midline.[1] FHP is a postural abnormality that is frequently observed in patients with chronic neck pain.[2] Although the "cause and effect" relationship between FHP and chronic neck pain is not absolutely understood, it seems that they present a bi-directional association.[3]

The adoption of FHP during daily prolonged sitting activities may lead to its permanent establishment due to muscle remodeling changes. The deviation of head from body vertical midline can result in the production of higher torque in cervical muscles in order to maintain static equilibrium. These prolonged contractions may lead to reduced blood flow, fatigue, tissue damage and, finally, pain.[4] FHP is also associated with an increase in anterior tensile forces and posterior compressive forces with consequential stretching of anterior cervical structures and shortening of posterior muscles.[2] Finally, creep phenomena give FHP a continuously aggravating role,[3] whereas the resulting muscle imbalances have been implicated for the observed respiratory dysfunction in patients with chronic neck pain.[5,6]

The importance of assessing FHP has led to the development of a number of measurement tools for its recording. Goniometers,[7] cervical range of motion instruments,[8] plumb lines,[1] electronic motion analysis systems[9] and cameras/videocameras[4,10] are measurement tools that have been occasionally used for its assessment. However, all of these assessment methods examine FHP statically.

Although the examination of static FHP may be of great clinical value, it ignores the dynamic aspects of cervical muscle function. This is further highlighted by the fact that head posture during walking has been recorded to be different from the head posture during standing.[11] In other pain conditions, such as patients with patellofemoral pain, it has been purported that pain mechanisms can be better observed in dynamic, instead of static activities, due to the higher mechanical and muscular demands for their completion.[12] Following a similar rationale, the examination of FHP during more dynamic activities –such as walking– could offer further insight into this postural abnormality due to the more demanding nature of the activity.

The clinical importance of the assessment of head posture necessitates valid and reliable measurement tools for its recording. Although the measurement of static FHP is well-documented, according to our knowledge, the assessment of dynamic FHP has never been appropriately examined. The only existent evidence comes from a previous study[11] which was not designed for this purpose and therefore the methods and results provided are not sufficient for establishing the reliability of the inclinometer-based method used.

Furthermore, the development of protocols based on inexpensive, accessible, and of good quality equipment is nowadays more than demanding. Video-based two-dimensional (2D) motion analysis gains more and more attention as a practical tool for use in clinical setting. The equipment is relatively low-cost and the method offers digital recordings which allow repeated viewing, slow motion and freezing of specific frames.[13] Considering that video-based 2D analysis has been successfully used to identify hip and knee flexion angles during walking or running,[14] it would be important to develop an analogous reliable protocol in order to assess dynamic FHP.

Therefore, the aim of this study was to develop a protocol to investigate the dynamic FHP during walking using video-based 2D analysis that it is feasible even for every day clinical practice and to examine its intra-rater, inter-rater and test-retest reliability.

MATERIAL AND METHOD

Sample

A convenience sample of 36 healthy volunteers between 18 and 26 years old was recruited. Participants with deformities, systematic pain, disability, amputation, skin burns, body mass index (BMI) >25, spinal derangement or dysfunction, spine surgeries or injuries, as well as participants under medical treatment were excluded from the study. Before their participation, the volunteers were informed about the study via an information sheet and they were asked to sign an informed consent. The participants were students that were recruited by different Departments of Technological Education Institute of Central Greece. The study was performed between August 2016 and February 2017. The study was approved by the Ethics Committee of Physiotherapy Department, Technological Educational Institute (TEI) of Central Greece, Lamia, Greece.

Equipment

The assessment of FHP was performed with a video camera of a mobile phone (iPhone, Apple, 720 Pixels HD, 240 frames s^{-1}, speed 300 MB/min). Lens focus was set at 200–250% depending on the participant's height. The iPhone was fixed in a stable tripod. The tripod was calibrated by using an Android clinometer software (Clinometer and bubble level, version 2.4 plaincode, PEGI 3, Germany, available also for iOS) for mobile phones. The height of the tripod was set at 1.30 meters.

The location of the tripod was in the middle of a 2×2 meter wall square frame at a distance of 2.5 m. The vertical midline of the square frame was the point of the lens focus. Vertically to the tripod there was a 5-meter white line. The square frame was at the middle of a 5-meter walking distance (fig. 1a).

Procedure

Before the measurement, a marker was placed at the 7th cervical vertebra and the tragus of the ear of each participant. During the measurements, each participant was wearing sport shoes and short athletic outfit.

Each participant was asked to walk, at their usual speed, a predetermined 5-meter distance looking straight forward in a stable point in the wall at the height of his(her) eyes. The participant was asked to walk so that his(her) left foot would step on a predetermined white line. The 5-meter distance was selected based on the notion that during walking a human needs two meters for acceleration and two meters for deceleration and therefore he(she) could have a steady velocity at the middle one meter of the distance and better achieve the step onto the line.[15] For the same reason, before the video recording, repeated familiarization trials were performed and, when necessary, the initial position of the participant changed until the participant would succeed to step exactly on the white line. More specifically, the video-recording started only after the participant had achieved to step exactly on the white line (middle stance) in front of the square frame at least three times during the familiarization trials. If the participant was successful, then three trials were video-recorded. During the video-recording, if the step of the participant was not exactly on the white line, the trial was not accepted and it was repeated until it was valid.

The instructions were provided to each participant in a standardized manner. The instructions were "Stand on the right side of the room, behind the small white line and look straight ahead at the point opposite to the wall (marking at the participants' height) and walk along the other side of the room, where there is the other white line, passing in front of the video camera. Walk at your usual speed". Three video recordings were obtained for each participant from the same side. The duration of each video was less than 30 sec. Responsible for the measurements was an appropriately trained postgraduate physiotherapist (rater B).

A second session was performed eight days after the first session. Before the second session the participants were asked to complete a questionnaire about potential changes in their lifestyle between the two sessions (e.g. injury). The measurements during the second session were performed exactly as the measurements during the first session.

Data processing

The videos obtained by the videotaping were processed with the software Kinovea, version 0.8.15 (Joan Charmantd & Contrib, France) in order to obtain the participant's caption at midstance. This caption was found when the participant's body was vertical to the midline of the square frame (fig. 1a).

The caption was analyzed with the AutoCad 2013 (Autodesk, United States) in order to record the craniovertebral angle (CVA). CVA is defined as the angle between the horizontal line and the line extending from C7 to the tragus of the ear[10] (fig. 1b). The data processing from the videos was performed by three different raters (rater A, rater B and rater C) with a different level of experience. Rater A was a senior undergraduate physiotherapy student with 10 piloting measurements. Rater B was a senior postgraduate physiotherapy student with 149 piloting measurements. Rater C was an experienced academic physiotherapist with a record of publications regarding the assessment of forward head posture.

Statistical analysis

Reliability was examined by using the first model of intraclass correlation coefficient (ICC), the standard error of measurement (SEM) and the smallest detectable difference (SDD). ICCs >0.75 were accepted as indices of good reliability.[16] SEM was calculated as the root of the mean square of the within subjects' error. SDD was expressed as a percentage of the grand mean and was calculated from the equation $SDD = \frac{1{,}96 \times \sqrt{2} \times SEM}{Grand\ mean} \times 100$. Bland-Altman plots were constructed based on the measurements of the rater B. They were constructed by using the differences of the two set of measurements in the y axis and the mean of the two set of measurements in the × axis. Bias was estimated as the mean difference (MD) of the two sets and its confidence limits were calculated by the equation MD±1.96 SD. The Statistical Package for Social Sciences (SPSS), v. 22.0 was used for all data analysis and plots.

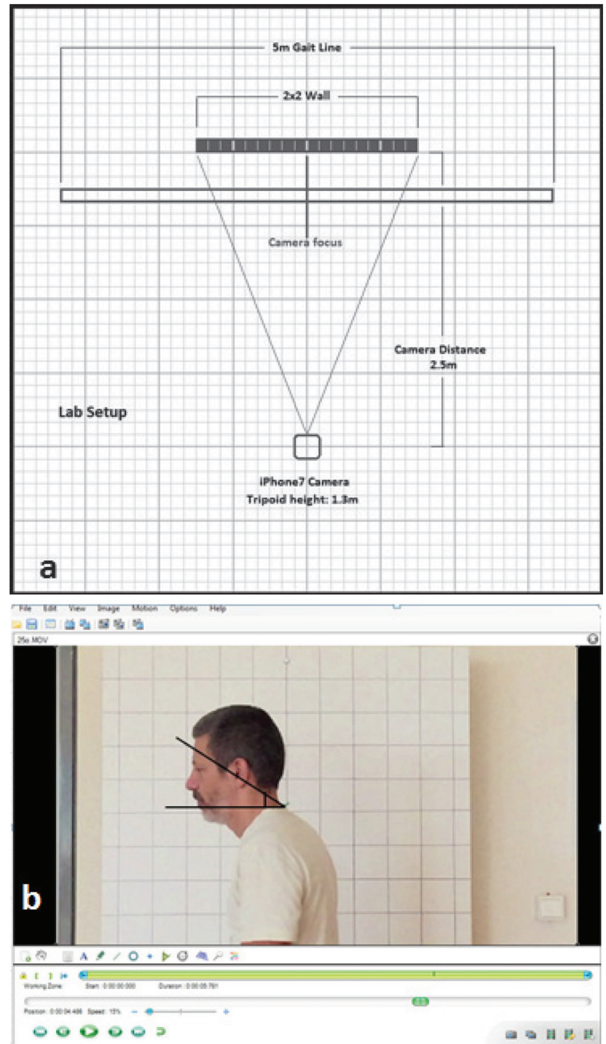

Figure 1. (a) Setting of the study, and **(b)** caption taken by using the Kinovea software (lines have been additionally drawn to show the craniovertebral angle).

RESULTS

The sample was composed mainly of young adults of moderate height and weight (15 male and 21 female, age 23.6 [7.7] years, height 1.70 [0.08], weight 64.8 [9.8] kg).

Intra-rater reliability was found to be high and similar independently of the experience of each rater (ICC: 0.90–0.92, SEM: 1.44–1.84, SDD: 8.20–10.58%). The omission of the first trial from the analysis only slightly improved the reliability indices (for the three trials ICC: 0.90–0.91, SEM: 1.62–1.84, SDD: 9.35–10.58%; for the last two trials ICC: 0.90–0.92, SEM: 1.44–1.58, SDD: 8.80–9.07%).

Test-retest reliability was found to be excellent for the three raters (ICC: 0.95–0.98, SEM: 1.01–1.52, SDD: 5.79–7.90%). The test-retest bias of the procedure was very low, independently of the experience of each rater (rater A: -0.3±1.97, rater B: -0.74±2.14, rater C: -0.31±1.43). Figure 2a presents a Bland-Altman plot for the observed test-retest agreement.

Inter-rater reliability was satisfactory for each pair of the three raters (ICC: 0.98–0.99, SEM: 0.79–1.08, SDD: 4.53–6.23%). Similar were the findings when the measurements of the three raters were examined simultaneously for their reliability (ICC: 0.99, SEM: 0.90, SDD: 4.68%). The inter-rater bias between the two more experienced raters was very low (0.25±1.53). Figure 2b presents a Bland-Altman plot for the observed inter-rater agreement.

The findings regarding intra-rater, test-retest and inter-rater reliability are analytically presented in tables 1 to 3.

DISCUSSION

The results of the study showed that the recording of forward head posture during walking by using 2D video-based analysis is a procedure of high intra-rater, inter-rater and test-retest reliability. The corresponding measurement errors and SDDs were also satisfactory. Bias of the measurement was small with relatively narrow limits of agreement. The findings also revealed that the protocol is highly reliable, independently of the experience of the raters.

According to our knowledge, there is no previous study examining the reliability of recording head posture during walking. A previous study[11] included investigation of the repeatability of measurement of dynamic head posture, but they used an inclinometer rather than 2D video analysis

Table 1. Intra-rater reliability of dynamic forward head posture.

Rater	Trials	Grand mean	ICC	95% CI	SEM	SDD (%)
A	1–3	48.60	0.91	0.84–0.95	1.64	9.35
	2–3	48.68	0.92	0.86–0.96	1.44	8.20
B	1–3	47.96	0.90	0.84–0.95	1.62	9.36
	2–3	48.06	0.90	0.82–0.95	1.57	9.05
C	1–3	48.21	0.90	0.83–0.94	1.84	10.58
	2–3	48.29	0.92	0.84–0.96	1.58	9.07

ICC: Intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: Standard error of measurement, SDD: Smallest detectable difference

Table 2. Test-retest reliability of dynamic forward head posture.

Rater	Grand mean	ICC	95% CI	SEM	SDD (%)
A	48.75	0.96	0.93–0.98	1.39	7.90
B	48.33	0.95	0.91–0.98	1.52	8.72
C	48.36	0.98	0.97–0.99	1.01	5.79

ICC: Intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: Standard error of measurement, SDD: Smallest detectable difference

Table 3. Inter-rater reliability of dynamic forward head posture.

Raters	Grand mean	ICC	95% CI	SEM	SDD (%)
A and B	48.28	0.98	0.97–0.99	0.79	4.53
A and C	48.40	0.99	0.98–0.99	0.82	4.67
B and C	48.08	0.98	0.96–0.99	1.08	6.23
A, B, C	48.25	0.99	0.98–0.99	0.90	4.68

ICC: Intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: Standard error of measurement, SDD: Smallest detectable difference

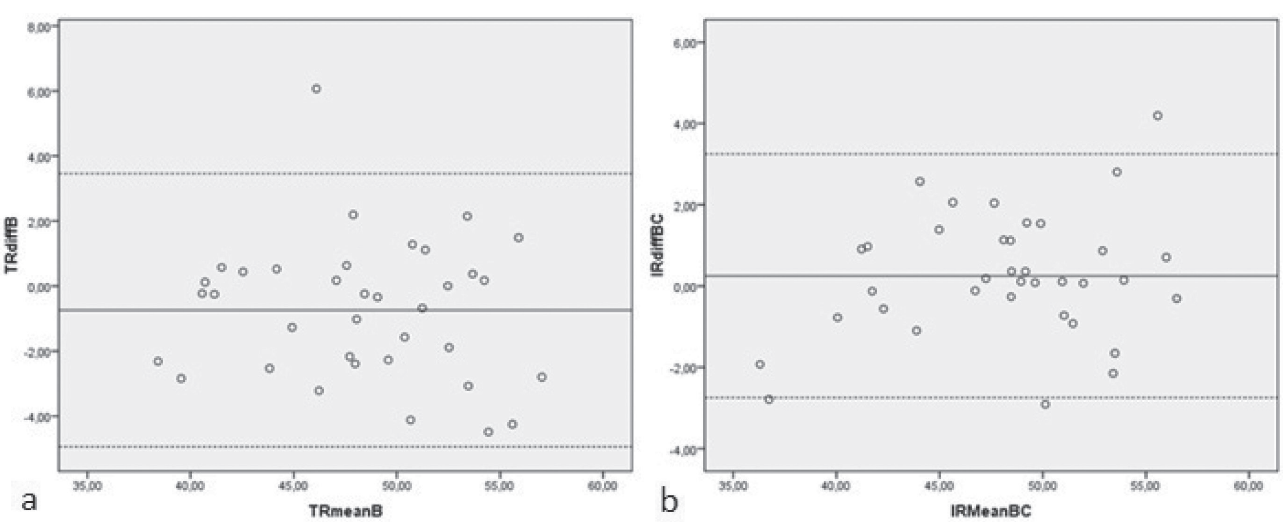

Figure 2. Bland-Altman plot for the **(a)** test-retest and **(b)** inter-rater agreement.

system employed in the present study. Additionally, in contrast to the statistical approach and sample size used in our study, their reliability analysis was performed by examining the differences in mean walking head posture for five consecutive days in three participants. Although their findings led the authors to conclude that the assessment of dynamic forward head posture is reliable, they recognized that their data was insufficient for a full reliability statistical analysis as it was performed mainly for obtaining an insight into the variability of the mean walking head posture measurements.

The findings of this study may have a significant impact on researchers and clinicians, as they are provided with a reliable method for recording dynamic forward head posture during walking. The high reproducibility of the measurements and their low measurement error can render clinicians confident to assess the effectiveness of their interventions on their patients' dynamic head posture. The findings regarding the SDDs of the procedure may be especially useful, as clinicians are provided with the changes that should be observed in dynamic forward head posture in order to conclude that their intervention was effective.[17] Test-retest SDDs were found to range between 5.79% and 8.72%, and therefore it can be concluded that an approximately 9% change in dynamic forward head posture after an intervention represents a real change. Additionally, researchers are provided with a measurement procedure for the examination of their specific hypotheses where accuracy and reliability are of high importance.

According to our knowledge, this study offers a reliable protocol for the assessment of dynamic forward head posture for the first time. The examination of head posture during activities seems to be very important since its static recording ignores the dynamic aspects of cervical muscle function which may be responsible for the differences observed between the standing position and walking.[11] The dynamic recording of FHP may lead to obtain further insight into the pain mechanisms of clinical populations due to the increased muscular and mechanical demands.

Two-dimensional video analysis was proved to be a reliable method for the recording of dynamic FHP. However, the recording of good quality videos is a prerequisite for the appropriate application of the protocol. For example the appropriate lightening, the reduction of parallax and perspective error, the appropriate steadiness/leveling of the camera and the interaction between planes should be always taken into consideration by employing appropriate strategies e.g. using flood light, perpendicular position of the camera, use of camera zoom lens, use markers or visual cues, use a sturdy calibrated tripod.[13] In that way, a clinician or researcher can exploit the advantages of 2D video analysis systems (e.g. relatively inexpensive, digital recordings which allow repeated viewing, slow motion and freezing of specific frames) for the appropriate examination/monitoring of patients or other populations of interest.

Many high-definition cameras are offered at varying prices. Both image resolution and temporal resolution should be taken under consideration when selecting cameras for video-based movement analysis. Many video cameras have excellent image resolution, but are limited to 30 frames per second. FHP during walking is difficult to be analyzed with frame rates <120 Hz as it is not possible to provide clean images in order to be feasible their evaluation. More recently released smartphones and tablets can be adjusted to acquire video at high frame rates and provide adequate video for this purpose with no extra cost.

This study was the necessary first step towards the investigation of the reliability of 2D video analysis systems for the recording of dynamic forward head posture. Future studies should further examine the reliability of the procedure in populations of special clinical interest such as patients with chronic neck pain or other related disorders. The findings of this study can also be compared with the findings of other future studies examining the reliability of alternative methods for recording dynamic head posture. Similar studies could enable the examination of criterion-related validity of the associated methods leading to more informed decisions regarding the management of patients with postural abnormalities of clinical interest.

In conclusion, the assessment of forward head posture during walking by using 2D video-based analysis is a procedure of high intra-rater, inter-rater and test-retest reliability. The protocol provided is reliable independently of the raters' experience. The reliable recording of dynamic forward head posture provides further insight into this postural dysfunction due to the higher mechanical and muscular demands. However, the reliability of the protocol should be additionally examined in populations of clinical interest such as patients with chronic neck pain or other related disorders.

ΠΕΡΙΛΗΨΗ

Αξιοπιστία ενός δισδιάστατου πρωτοκόλλου ανάλυσης video για την αξιολόγηση της πρόσθιας προβολής της κεφαλής κατά τη βάδιση

Ζ. ΔΗΜΗΤΡΙΑΔΗΣ,[1] Σ. ΑΡΓΥΡΟΥ,[1] Α. ΔΙΑΜΑΝΤΗΣ,[1] Κ. ΚΩΣΤΑΚΗΣ,[1] Α. ΚΑΝΕΛΛΟΠΟΥΛΟΣ,[1] Ν. ΣΤΡΙΜΠΑΚΟΣ,[1,2] Ι. ΠΟΥΛΗΣ,[1] Ε. ΚΑΠΡΕΛΗ[1]

[1]Τμήμα Φυσικοθεραπείας, Σχολή Επιστημών Υγείας, Πανεπιστήμιο Θεσσαλίας, Λαμία, [2]Division of Musculoskeletal and Dermatological Sciences, School of Biological Sciences, University of Manchester, Manchester, Ηνωμένο Βασίλειο

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ΣΚΟΠΟΣ Η ανάπτυξη ενός πρωτοκόλλου για τη διερεύνηση της δυναμικής πρόσθιας προβολής της κεφαλής κατά τη διάρκεια της βάδισης, χρησιμοποιώντας δισδιάστατη ανάλυση video και η διερεύνηση της αξιοπιστίας του. **ΥΛΙΚΟ-ΜΕΘΟΔΟΣ** Στη μελέτη συμμετείχαν 36 υγιείς εθελοντές (15 άνδρες και 21 γυναίκες, ηλικίας 23,6±7,65 ετών). Για την καταγραφή της πρόσθιας προβολής της κεφαλής των συμμετεχόντων κατά τη βάδιση χρησιμοποιήθηκε η βιντεοκάμερα ενός κινητού τηλεφώνου σε δύο συνεδρίες. Σε κάθε μία από αυτές τις δύο συνεδρίες πραγματοποιήθηκαν τρεις καταγραφές. Η δεύτερη συνεδρία πραγματοποιήθηκε 8 ημέρες μετά την πρώτη συνεδρία. Τα videos αναλύθηκαν από 3 αξιολογητές με διαφορετικό επίπεδο εμπειρίας. Η πρόσθια προβολή της κεφαλής μετρήθηκε μέσω της κρανιοσπονδυλικής γωνίας. **ΑΠΟΤΕΛΕΣΜΑΤΑ** Η ενδοβαθμολογική αξιοπιστία (ICC: 0,90–0,92, SEM: 1,44–1,84), η διαβαθμολογική αξιοπιστία (ICC: 0,98–0,99, SEM: 0,79–1,08) και η αξιοπιστία ελέγχου-επανελέγχου (ICC: 0,95–0,98, SEM: 1,01–1,52) βρέθηκαν άριστες και από τους 3 αξιολογητές. Το συστηματικό σφάλμα ελέγχου-επανελέγχου (αξιολογητής Α: -0,3±1,97, αξιολογητής Β: -0,74±2,14, αξιολογητής Γ: -0,31±1,43) και μεταξύ των δύο εμπειρότερων αξιολογητών (0,25±1,53) ήταν πολύ μικρό. **ΣΥΜΠΕΡΑΣΜΑΤΑ** Η αξιολόγηση της δυναμικής πρόσθιας προβολής της κεφαλής χρησιμοποιώντας δισδιάστατη κινηματική ανάλυση με χρήση video είναι μια εφικτή και αξιόπιστη μέθοδος, με μικρό σφάλμα μέτρησης. Ελάχιστη εκπαίδευση των αξιολογητών είναι επαρκής για να δώσει αξιόπιστες καταγραφές της δυναμικής πρόσθιας προβολής της κεφαλής.

Λέξεις ευρετηρίου: Ανάλυση βάδισης, Αξιοπιστία, Αυχενικός πόνος, Εγκυρότητα, Πρόσθια προβολή κεφαλής

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Corresponding author:

E. Kapreli, Laboratory of Exercise and Physiology Rehabilitation Research, Department of Physiotherapy, School of Sciences, University of Thessaly, 3rd km Old National Road Athens-Lamia, Lamia, Greece
e-mail: ekapreli@uth.gr