A Complex Semi-automatic Method for Kinetic and Two-dimensional Kinematic Motion Analysis for Posture and Movement Investigation

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Abstract: *Functional reach (FR) – maximal forward reach with both arms while standing, is a well-known dynamic balance test. Different underexplained reaching strategies exist. This study was motivated by the need of an affordable and robust approach for their evaluation. We introduce a complex semi-automatic method for two-dimensional kinematic and kinetic analysis based on video capture with inexpensive camera, free automatic marker tracking software, pedobarographic measurements and problem-oriented algorithms for kinetic and kinematic data evaluation.*
Subjects performed FR with passive markers on their right side while standing on a Tekscan platform. Kinematic and kinetic data were simultaneously collected. Video trimming by sound was applied for synchronization between video and platform recordings. Automatic object tracking by color (Viana.Net) was applied for kinematic measurements. Center-of-pressure excursions were evaluated by Tekscan software. All data were further processed by problem-oriented algorithms (MatLab). Evaluated measures: FR length, horizontal and vertical marker paths, ankle and hip angles and their corresponding linear or angular velocities while moving forward or backward. During these movements the horizontal displacements of the center-of-gravity marker highly correlated with center-of-pressure anterior-posterior sway.
The method allows measuring distances, angles and velocities. It is prospective for concerted kinetic and two-dimensional kinematic analysis of dynamic standing balance.

Keywords: *Functional reach, Posture, Motion analysis, Center-of-pressure.*

Introduction

Standing balance is a complex process that requires the very precise interplay between several sensory systems, the skeletal muscles as effectors and the sensory-motor, postural and motor control functions of the CNS [1, 2]. From biomechanics point of view standing balance is the ability to sustain the projection of the center-of-gravity (COG) within the margins of the support area. Standing balance is often divided into static (quiet stance) and dynamic [9] (the transition from one posture into another during stance). As balance is crucial for the quality of life and sports performance, a variety of clinical, field and laboratory tests have been developed. Tracking the displacements of the center-of-pressure (COP) with a force platform is a sensitive and often used method that provides valuable information about the mechanisms of maintaining balance [9]. A simple, cost-efficient and reliable alternative for testing the limits of stability is the functional reach (FR) test – the maximal reach with hands forward without stepping or toppling [3]. Originally designed for screening elderly people for risks of falling, it has many modifications and new applications up to date [7]. In previous research [5, 7] we used forward and lateral reach as movement supra-postural tasks performed on a force platform and this more sophisticated experimental approach allowed us to study dynamic standing balance in detail. Different strategies in the FR performance (ankle, hip and mixed) have been found [8, 10]. There is little information about their mechanisms or how they relate to the ability to maintain balance. A more complex experimental approach combining the advantages of several methods could provide a valuable insight in the mechanisms of dynamic postural behavior. Motion capture and following kinematic analysis allow evaluating distances traveled by body segments and joint angles, changes in time and space during movement [12] and may indicate strategical shifts in the body schema [1, 2]. However, the high prices of automatic motion tracking devices and sophisticated software are a serious drawback for many labs with limited budget and/or lack of trained and qualified personnel. Two-dimensional motion analysis with a single camera and sports-oriented software has proven to be a reliable and low-cost alternative for evaluating reaching tasks in the sagittal plane [6]. Our study was motivated by the need of an affordable and robust method for complex kinetic and kinematic analysis of movements in one plane, such as FR. The method we introduce is based on two-dimensional video capture and free software for automatic object tracking combined with pedobarographic measurements and problem-oriented algorithms for evaluation of distances, joint angles, linear and angular velocities.

Materials and methods

Subjects

Two healthy volunteers (male – age 35 years, height 184 cm, weight 91 kg; female – age 30 years, height 174 cm, weight 76 kg) participated in this pilot study after signing a written informed consent approved by the local bioethical committee. The subjects had no history of any musculoskeletal or neurological disorders. They performed FR according to a previously established protocol [5] and were familiar with the procedure.

Data acquisition

Motion capture

Camera Canon PowerShot SX 230 HS (Canon Inc., Japan) was used for motion capture. The camera was fixed on a tripod. The optical axis was perpendicular to the working plane and facing its center, from a distance of 300 cm. The video format was WUXGA, frame size 1920×1080 px, aspect ratio 16:9 and frequency of recording 24 fps. These settings were found empirically to be the optimal trade-off between the features of the camera, the size of the working plane and the minimal resolution required by the object tracking software. The camera was tested for lens distortions beforehand (Fig. 1A) in the abovementioned settings. Lens distortions were less than 10%. Passive markers in different colors, shapes (squares, circles and spheres), sizes (12-47 mm in diameter), materials (cardboard, rubber, polystyrene and double density foam) and with different surfaces (reflective or not) were tested. The markers best recognized by the object tracking software were 40 mm polystyrene spheres colored with matt acrylic paint. On the right side of the body they were attached by skin-safe double-sided adhesive tape for body and clothing to specific anatomic landmarks (Fig. 1B), located by palpation. The anatomic landmarks were: greater tubercle of the humerus, base of the proximal 5th finger phalange, superior anterior iliac spine, greater trochanter of the femur, lateral epicondyle of the femur, lateral calcaneus of the fibula, distal end of the fifth metatarsal bone. The distance between the two markers on the femur was measured for planar calibration. The approximate height of subjects' COG was calculated by the most common ratio between the COG height to the adult's height (0.560 for males and 0.543 for females) [4]. A marker was fixed on its estimated projection on the body surface. In this way all markers were in the sagittal plane and in the camera's field of view during the whole trial. When attaching the markers, the colors of subjects' clothes and skin in proximity were considered, so that each marker would contrast sharply. A light grey (30%) cotton sheet proved to be the best background. Unlike other backgrounds we tested, it was not confused with the color of the markers by the object tracking software.

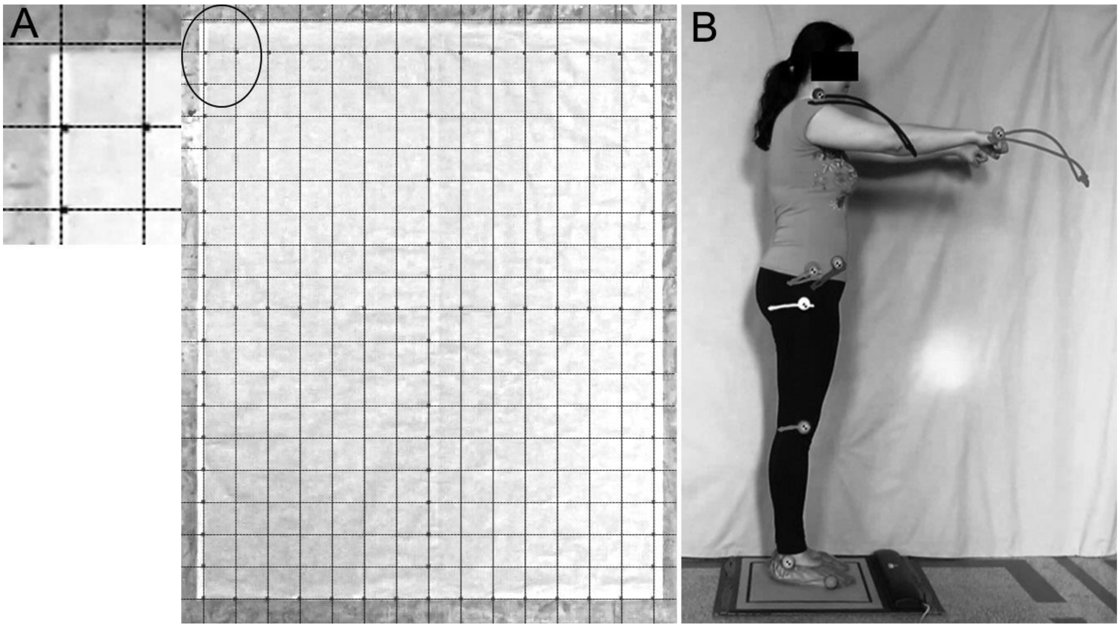

Fig. 1 Preliminary camera test (A) and experimental setup (B): (A) Lens distortions test in the work area. Dots are 10 mm squares (magnified area, top left), distance between each two adjacent black squares: 100 mm. The exact squared grid was superimposed on the picture after the shot; (B) Markers' positioning and trajectories during one trial (Kinovea).

Recording center-of-pressure sway

COP excursions were recorded by a pedobarographic platform Tekscan Evolution, provided with Research Software and Sway Analysis Module (SAM) Matscan (Tekscan Inc., South Boston, MA, USA). The record lasted 30 s, frequency was set at 30 fps. The program signaled for the start of recording with a specific sound which was later used for optimal synchronization with the sound track of the video record.

Evaluated measures

Hand movement and length of functional reach

The horizontal and vertical displacements of the marker on the hand were used for measuring hand movement during trials. Also, the momentary and mean linear velocities of the hand were calculated for two particular movements: when going forward (FR) and backward (returning after the reaching task) which were evaluated with a problem-oriented algorithm in MatLab. The length of FR was measured in two different ways: 1) semi-automatically (from video recording): the maximal forward displacement of the hand marker from its initial position; 2) manually: FR was also measured by ruler, fixed on the wall. In this case the base of the proximal phalange of the 3rd finger was used as marker, as in the original test [3, 5].

Changes in joint angles

The projections of the anatomical hip and ankle angles in the sagittal plane were defined as hip and ankle angle. Hip angle was formed by the markers placed on the superior anterior iliac spine, the greater trochanter of the femur and the lateral epicondyle of the femur. Ankle angle was formed by the markers placed on the lateral epicondyle of the femur, the lateral calcaneus of the fibula and the distal end of the fifth metatarsal bone. These two angles were evaluated during the whole trial, as well as the momentary angular velocities and their mean values when subjects were moving forward and backward (see above).

COG marker horizontal path and COP anterior-posterior displacements
The marker fixed on the projection of COG in the sagittal plane was tracked and its linear horizontal movement was evaluated. COP sway in the sagittal plane (anterior-posterior direction) was evaluated in order to compare it with the COG marker sway in the same plane.

Record and data processing

Video record pre-processing
The Tekscan platform software signaled for the start of recording with a specific sound which was present in the audio track of the video record. For precise video trimming by sound we tested several programs that visualize the audio track. Among them we chose the SolveigMM Video Splitter 3.6.1301.9 [16]. The video trimming by sound allowed better synchronization between the video and platform recordings, so that measurements' dynamics could be analyzed as parts of the same movement events.

Motion tracking and analysis
Two free programs for automatic marker tracking and motion analysis were tested: Kinovea 0.8.15 [13] and Viana.NET 5.5 [17]. Both programs are designed for marker and markerless automatic object tracking, work with a range of video formats, can measure distances and velocities and allow data files export for further analysis. Viana.NET also provides feedback about object tracking performance, displays results in tables and graphs and has some mathematical functions for additional data analysis. Therefore we used Viana.NET for automatic motion tracking and Kinovea only for the visualization of marker trajectories (Fig. 1B). The trimmed video recording was imported in Viana.NET and the general parameters for object tracking were set at the first frame. The origin of the coordinate system was at the bottom left corner. Planar pole calibration was done by the previously measured inter-marker distance and 1 px was 1.87 mm. Markers were chosen manually for automatic tracking by color. Tracking area was confined so that there would be no other object of similar color. Color and size tolerances were set for best marker recognition with the provided feedback.

Data processing
Kinematic and kinetic data were further processed with problem-oriented algorithms (MatLab 7.13) for data pre-processing and analysis based on previous software of ours designed for kinetic data analysis [5, 7]. The new algorithms were modified for semi-automatic evaluation of paths, angles and linear or angular velocities. To reduce noise, kinematic time series were smoothed by a simple moving average filter [14] of order 6 acting as a low-pass filter [11]. Three point angles were calculated as angles between two vectors [15].

Two movements were of interest: forward and backward (returning to initial position after the reaching task) (Fig. 2A, top). The start and end of these two movements were estimated by computer-assisted (graph XY cursor) eyeball method (Figs. 2 and 3). After that the software calculated the momentary (frame to frame) and mean velocities of the corresponding kinematic measure for the selected time periods. FR length was automatically calculated as the difference between two mean horizontal (X) positions of the hand marker: during the first 10 seconds of the trial (quiet stance) and while maintaining the hand in the most forward position maintained for at least 3 seconds (according to FR test protocol [3, 5]). The result was compared with the FR of the same subject, measured manually by ruler. Evaluation of the correlation between the horizontal displacements of the kinematic measure COG marker vs. the anterior-posterior displacements of the kinetic measure COP during forward and backward movements was done by the Pearson correlation method. The time periods of the movements were selected in the same way as for the rest of the measures.

Results and discussion

Hand movement and length of functional reach

Hand horizontal and vertical movement paths are shown in Fig. 2 (A and B, top) as well as the corresponding linear momentary and mean velocities when the hand goes forward (FR) and backward (Fig. 2A and B, bottom). FR lengths of the two subjects calculated semi-automatically were 417 mm (male) and 321 mm (female), while their corresponding maximal reach lengths measured by ruler were 41.5 cm and 32 cm. The two different ways of measuring FR length provided quite similar results.

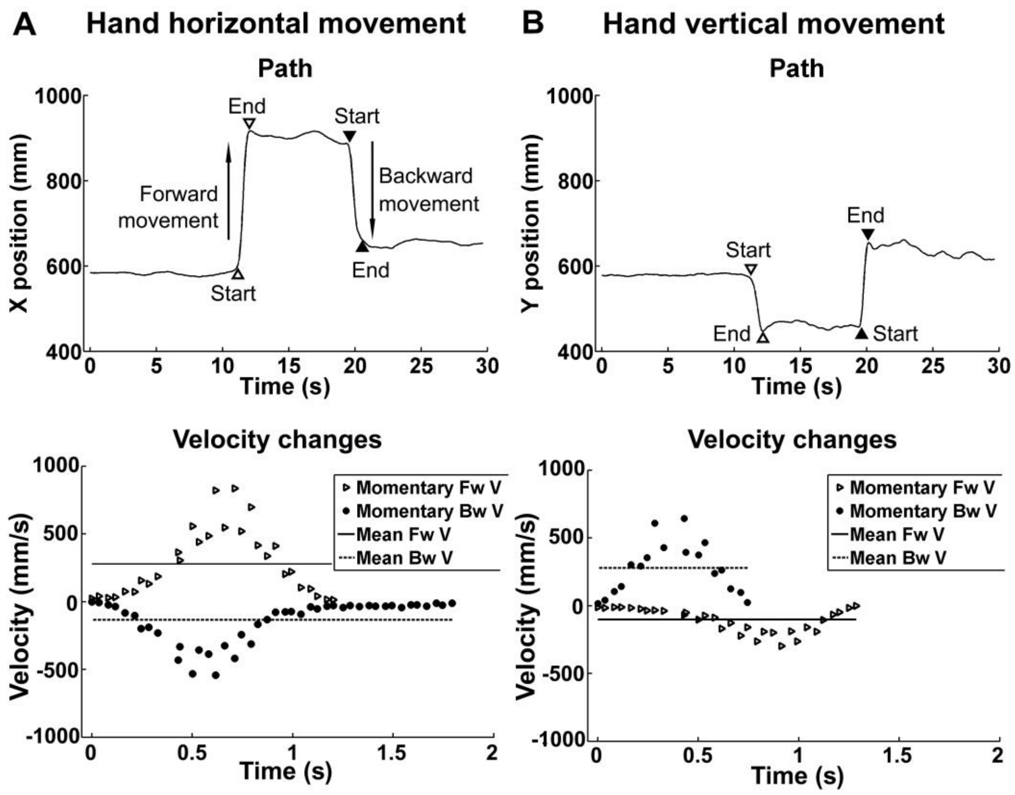

Fig. 2 Hand movement during one trial of FR.
Top: Hand marker horizontal (A) and vertical (B) movement paths. Forward and backward movements are shown with arrows. Labels "Start" and "End" indicate the time periods for which hand linear velocities were calculated (bottom).
Bottom: Momentary forward (Fw V) and backward (Bw V) velocities in the X (A) and Y (B) axes for the two selected time periods (top). Their mean values (Mean Fw V and Mean Bw V) in the X (A) and Y (B) are shown with lines.

Changes in joint angles

The calculated changes of the hip and ankle angles in the sagittal plane are shown in Fig. 3A and B, top, as well as their corresponding angular momentary and mean velocities when subjects went forward (FR) and backward (Fig. 3A and B, bottom).

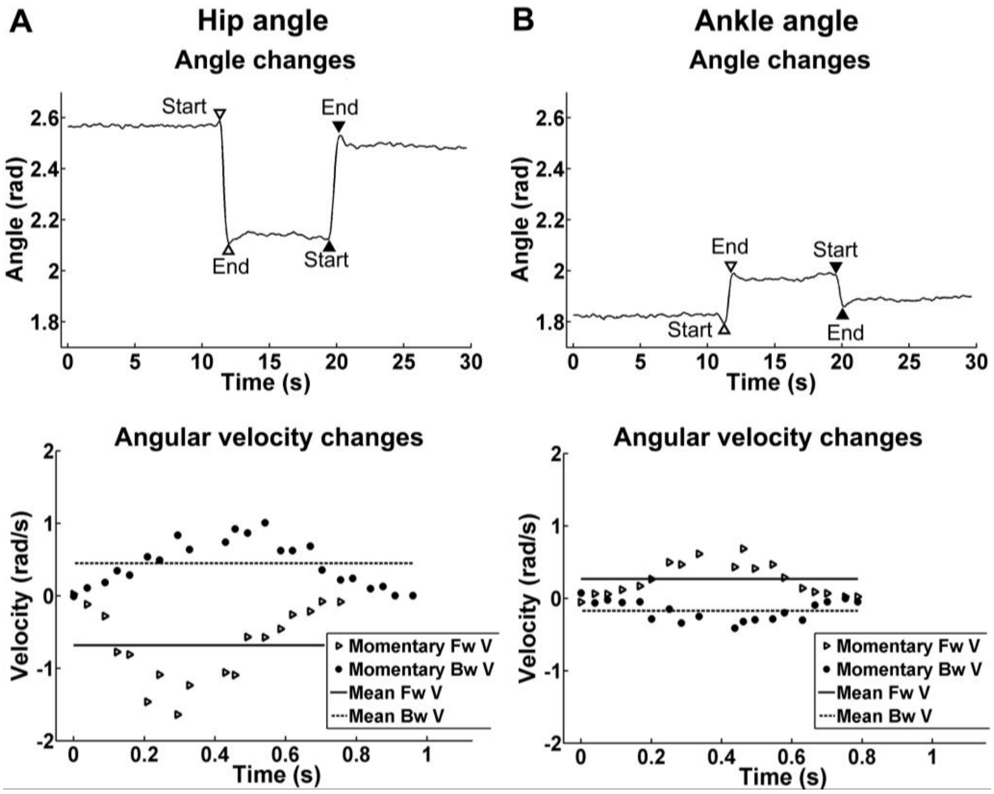

Fig. 3 Hip and ankle angle changes during one trial of FR.
Top: Hip (A) and ankle (B) angle changes. Labels "Start" and "End" indicate the time periods of forward and backward movements for which angular velocities were calculated (bottom).
Bottom: Momentary forward (Fw V) and backward (Bw V) velocities of hip (A) and ankle (B) angles for the two selected time periods (top). Their mean values (Mean Fw V and Mean Bw V) for hip (A) and ankle (B) angular changes are shown with lines.

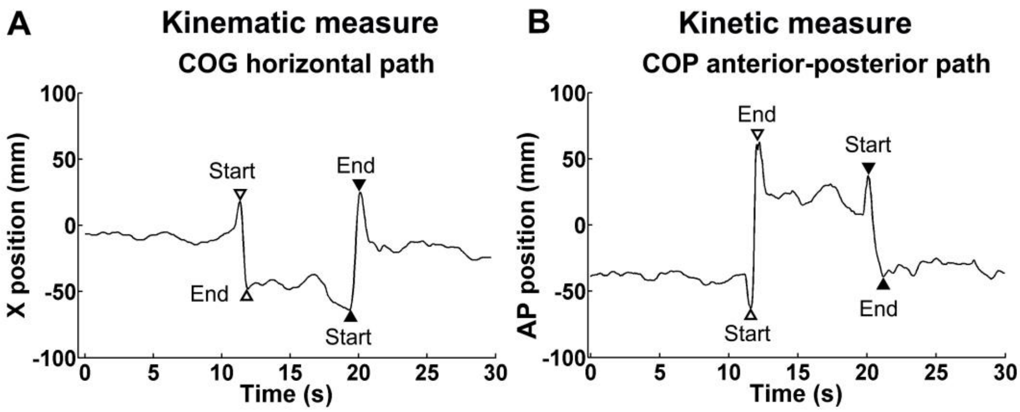

Fig. 4 Anterior-posterior displacements of the kinematic measure COG marker (A) and the kinetic measure COP (B) during one trial of FR. Labels "Start" and "End" indicate the two time periods selected for Pearson correlation analysis.

Kinematic and kinetic measures correlation

The anterior-posterior displacements of the kinematic measure COG marker and the kinetic measure COP are shown in Fig. 4. Pearson correlation analysis showed a strong negative association between the two measures during movement (r = -0.957 for forward moment, $p < 0.001$ and r = -0.856 for backward movement, $p < 0.001$). This correlation may differ with different reaching strategies.

Conclusions

The proposed semi-automatic method for kinetic and two-dimensional kinematic motion analysis is cost-efficient and robust. The capability to evaluate distances, three-point angles, momentary and mean velocities allows analyzing movement strategies of single-plane dynamic standing tasks, such as FR. The complex experimental approach combining kinematic with kinetic measurements makes this method prospective for in-depth studies of the mechanisms of dynamic standing balance.

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References

1. Assaiante C., F. Barlaam, F. Cignetti, M. Vaugoyeau (2014). Body Schema Building during Childhood and Adolescence: A Neurosensory Approach, Neurophysiologie Clinique, 44(1), 3-12.
2. Chiba R., K. Takakusaki, J. Ota, A. Yozu, N. Haga (2016). Human Upright Posture Control Models Based on Multisensory Inputs in Fast and Slow Dynamics, Neuroscience Research, 104, 96-104.
3. Duncan P., D. Weiner, J. Chandler, S. Studenski (1990). Functional Reach: A New Clinical Measure of Balance, Journal of Gerontology, 45(6), M192-M197.
4. Gambino S., M. Mirochnik, S. Schechter (2005). Center of Mass of a Human, In: The Physics Factbook, http://bit.ly/Center-of-Mass-of-a-Human (Access date 24 Sept 2017)
5. Gatev P., K. Kirilova (2015). Sensory Conflict Influences Functional Reach Performance and Dynamic Standing Balance in Posture, Balance, and the Brain, International Workshop Proceedings (Eds., P. Gatev & V. Hatzitaki, Procon Ltd.), Sofia.
6. Gribble P., J. Hertel, C. Denegar, W. Buckley (2005). Reliability and Validity of a 2-D Video Digitizing System during a Static and a Dynamic Task, Journal of Sport Rehabilitation, 14, 137-149.
7. Kirilova K., P. Gatev (2017). Lateral Reach Performance and Dynamic Standing Balance during Sensory Conflict, Comptes Rendus de l'Académie Bulgare des Sciences, 70(4), 511-516.
8. Liao C., S. Lin (2008). Effects of Different Movement Strategies on Forward Reach Distance, Gait & Posture, 28(1), 16-23.
9. Panjan A., N. Sarabon (2012). Review of Methods for the Evaluation of Human Body Balance, Sport Science Review, 19(5-6), 131-163.
10. De Waroquier-Leroy L., S. Bleuse, R. Serafi, E. Watelain, V. Pardessus, A.-V. Tiffreau, A. Thevenon (2014). The Functional Reach Test: Strategies, Performance and the Influence of Age, Annals of Physical and Rehabilitation Medicine, 57(6-7), 452-464.
11. Yedula S., G. Tcheslavski (2015). Design and Analysis of Low Cost Electro-dermal Response System Using Texas Instrument's MSP430 Value Line Launchpad, International Journal Bioautomation, 19(1), 79-94.

12. Zi M. (2017). Motion Analysis of Chinese Bajiquan Based on Three-dimensional Images of Biomechanics, International Journal Bioautomation, 21(2), 189-198.
13. https://www.kinovea.org (Access date September 29, 2017)
14. http://bit.ly/matlab-moving-average (Access date September 28, 2017)
15. http://bit.ly/matlab-angle-between-2-vectors (Access date September 28, 2017)
16. http://www.solveigmm.com (Access date September 30, 2017)
17. http://www.viananet.de (Access date September 29, 2017)

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