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The globe system: An unambiguous description of shoulder positions in daily life movements

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Abstract—Positions of the shoulder joint are commonly described in terms of degrees of humeral elevation in the principal planes. This approach is inadequate for an accurate and unambiguous description of functional arm movements that are not confined to these planes. In this paper, a general unambiguous method for describing shoulder positions is adopted and visualized in globe graphs. This facilitates the use and interpretation of the method in clinical practice. To illustrate this globe system of description, a healthy subject participated in the experiments. The shoulder position is described for several functional and standardized tasks for the upper limb with three angles: (1) the angle of the plane of elevation, (2) the angle of elevation within the plane of elevation, and (3) the angle of axial rotation. With these parameters, the position of the upper arm can be visualized as a position on a "globe" about the shoulder joint. Although not perfect, the globe system provides the most unambiguous description of functional thoraco-humeral positions, which is easy to apply in clinical practice.

Key words: clinical application, daily life activities, movement analysis, shoulder, 3D description.

INTRODUCTION

The shoulder can reach the largest range of movement of the human body. Functionally, the shoulder provides sufficient mobility, in synergy with elbow and wrist, to allow many different positions and orientations of the hand. In clinical practice, an unambiguous description of movements about the shoulder is important to assess the range of movement during physical exam, to evaluate the effect of interventions on arm motion, and/or to enhance communication about the shoulder kinematics during functional movements.

For common clinical examination, the American orthopedic society has provided a standard terminology, which is based on a consensus on three items [1]. First, all positions are referenced to the anatomical posture, defined as the zero-position of the joint. Second, joint positions are measured in one of the three (orthogonal) planes (sagittal, frontal, or transversal) or around the longitudinal axis (rotation). This system is generally referred to as the sagittal, frontal, transverse, rotation (SFTR) system. Finally, the degrees of motion are recorded as the deviation from the reference position in either direction from the anatomical position in a standardized format. For the shoulder, the SFTR system is an adequate way to describe movements of the clinical exam of the patient. However, this method is limited in unambiguously describing shoulder positions that do not occur in the predefined (orthogonal) SFTR planes, as is the case for almost all daily functional movements of the arm.

Abbreviations: ADL = activities of daily living, LED = light-emitting-diode, SFTR = sagittal, frontal, transverse, rotation.

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This problem usually occurs with the use of a sequence of rotations (each related to a principle plane) to define the position. Relating the axis to the SFTR planes, a sequence can be adopted. The clinical well-known method, described by Grood and Suntay [2], is flexion followed by abduction and finally axial rotation, also known as Cardanic decomposition. Note that after the first rotation, the axis of the following rotation has changed. Not following these rules might even result in the use of opposite terms to describe one and the same end position of the arm, dependent on the chosen sequence of the three rotations in the SFTR system. This problem is clearly illustrated by Codman [3], who showed that the position of the hand placed on the head with the hand palm downward could be described with either an external or internal rotation of the upper arm [3]. The occurrence of conflicting terminology for an identical arm position emphasizes the need for a clear and unambiguous system of description.

Additionally, decomposition in three sequential angles results in two (spherical opposite) positions, which remain undetermined the so-called “gimbal-lock” positions. In practice, this means that small movements around these positions will yield enormous angular changes in one of the degrees of freedom. For example, for the knee, the undetermined positions are at 90° adduction and 90° abduction, when using the Cardanic sequence [2]. Fortunately, these positions are anatomically impossible for the knee, so this system works well for this and all other joints, which do not allow such magnitude of ab- and adduction. Nevertheless, for the shoulder, 90° abduction is anatomically possible and is also frequently approached in daily life movements. This means that the choice for the classical sequence about the shoulder will produce erroneous angles at and around this position. Since gimbal lock is related to any decomposition format, an alternative is justified by singular positions that are in the least disturbing positions.

An approach called the “globe system” is currently being used in shoulder literature [4–15], described by Pearl et al. and introduced for unambiguous description of all positions of the humerus relative to the trunk [13]. In this system, three rotations of the upper arm relative to the trunk are described in terms of latitudes and longitudes along a globe in a specified sequence.

The globe system used in this paper is based on a method that describes shoulder positions starting from an anatomical position and with the two gimbal-lock positions at the anatomical position (0°) and at the spherical opposite, i.e., the arm pointing 180° upward. These positions are less relevant for the clinical evaluation of shoulder movement than the classical Cardanic decomposition so that the indeterminacy in those positions is the least disturbing in the performance of functional shoulder movements.

To present kinematic data of arm movements in accordance with the procedures commonly used in clinical practice, one must base the results derived with the globe system on clear observational methods. Although the globe system is currently and frequently used in scientific shoulder studies [4–15], this method is still not well introduced in clinical practice. This paper illustrates the use of the globe system applied on several positions from daily life and from a common physical examination and demonstrates a way of visualization, which agrees well within clinical practice.

METHODS

Description

By means of the three angles that are used in a fixed sequence, each position of the humerus relative to the trunk can be described and subsequently visualized as longitudes and latitudes of a globe projected around the shoulder (**Figure 1**). The globe has its midpoint on an assumed center of rotation about the shoulder [16]. For every parameter, the relationship with respect to the latitudes and longitudes will be described and indicated in the following paragraphs, starting from the anatomical position.

Plane of Elevation

The angle of the plane of elevation is determined first. The plane of elevation is defined as the plane along which the humerus moves from a nonelevated to its elevated position and is actually a half plane. The best way to visualize the planes of elevation at the globe is to look from a top view (the “North Pole”) to the different vertical planes around the shoulder, as shown in **Figure 2**. The plane of elevation is indicated in degrees, relative to the coronal plane (at the lateral side of the body), being 0° and positive for ventral planes. The angle of the elevation plane that coincides with the sagittal plane is +90° during so-called flexion and –90° at so-called extension. In terms of the globe, the plane of elevation corresponds

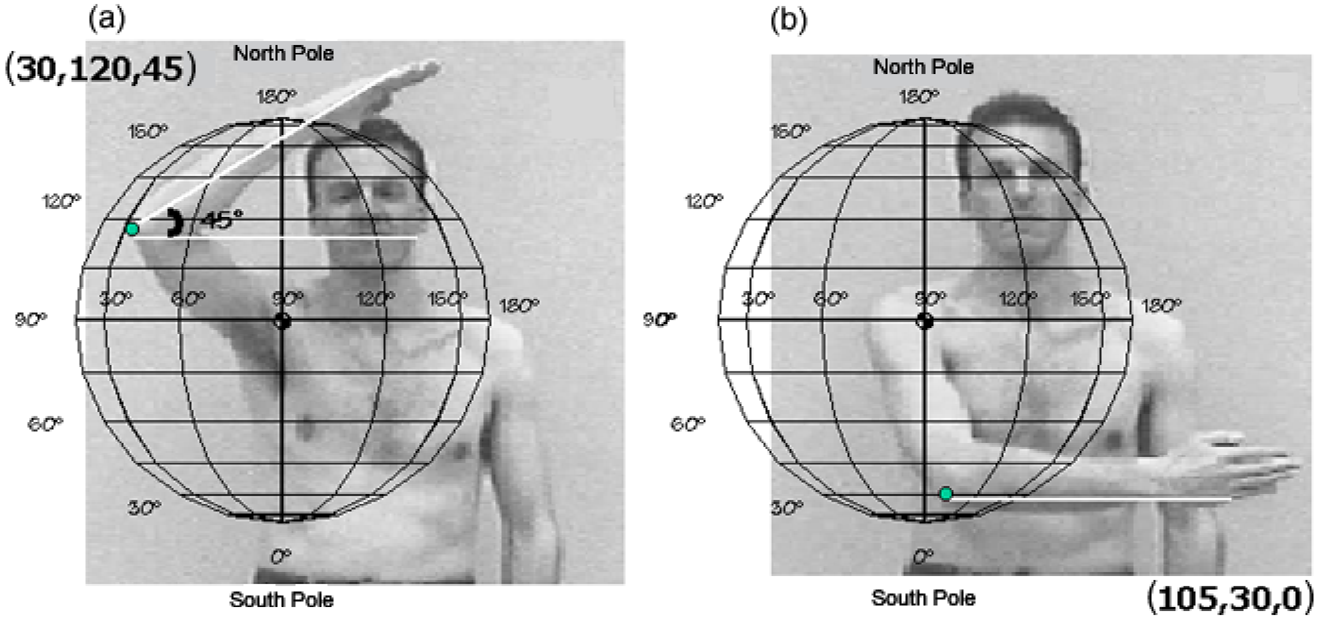

Figure 1.
Illustration of a globe, projected around shoulder. Rotation axis of shoulder is assumed to be midpoint and elbow follows surface of globe. With this illustration, upper-arm position in space around shoulder can be unambiguously determined and described. Longitudes correspond to planes of elevation. On equator, values in degrees are indicated. According to definition, +90° corresponds to sagittal plane in front of body and 0° with coronal plane. Latitudes, with its values given on left side of globe, indicate amount of elevation in a specified plane of elevation. Position of lower arm relative to this latitude is angle of rotation of upper arm. In this way, position of shoulder joint is rather easy to visualize. As an example, positions (elevation plane, elevation angle, and rotation angle) are shown in degrees: **(a)** (30, 120, 45) and **(b)** (105, 30, 0).

with the longitudes as shown in **Figure 2**. With the arm in the anatomical position, i.e., hanging at the side of the trunk and pointing to the "South Pole," the plane of elevation is undetermined. By definition, the plane of elevation is in this position 0°.

Angle of Elevation

The angle of elevation is determined in the previous specified plane of elevation and is defined as the angle between the anatomical position and the elevated arm measured in that half plane. When the upper arm is kept in a horizontal position, the angle of elevation is 90°. Along the globe, elevation angles are indicated by the latitudes, with the anatomical position defined as 0° (**Figure 1**). Maximal elevation is 180°, i.e., the North Pole, which is the second gimbal-lock position.

Angle of Rotation

Finally, the angle of rotation is determined. The rotation angle is defined by the rotation of the upper arm to be assessed from a line through both humeral epicondyles. In practice, one could use the direction of the lower arm in a 90° flexed elbow position. The amount of rotation is thus defined as the angle of the lower arm relative to the horizontal plane, which is defined as 0°. In the globe, this can be considered as a direction of a compass on the surface of the earth (**Figure 1**). In the position of 0° rotation, the right lower arm points to the east. Rotation is defined positive when the hand points at a direction with at least one component in the northern direction.

For an unambiguous description of shoulder positions with the globe system, it is important that all parameters are used in the prescribed sequence [13]:

1. Angle of plane of elevation.
2. Elevation angle.
3. Rotation angle.

The elevation angle is only significant when a corresponding plane of elevation is known. Further, the rotation angle is only meaningful at a specified angle of elevation. As a consequence, the position of the upper arm relative to the trunk is described according to the following notation in degrees (elevation plane, elevation angle, and rotation angle).

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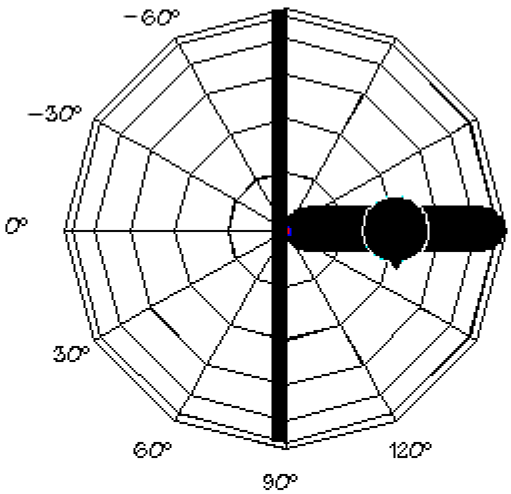

Figure 2.
Illustration of plane of elevation and corresponding values in degrees on globe relative to shoulder. Plane of elevation is indicated by longitudes, viewed from "North Pole." In this plot, plane of +90 to –90° (sagittal plane) is shown as a thick line.

Application

Shoulder Movements

The method of description of shoulder position was applied on the following set of shoulder movements:

- Standard movements (in predefined planes).
  - Extension/flexion.
  - Abduction and adduction.
  - Internal and external rotation.
- Lifting.
  - From floor to shoulder height.
  - From trunk to overhead.
- Throwing.
  - Upper-hand throw (two-handed).
  - Breast throw (two-handed).
  - Underhand pitch (one-handed).
- Small activities of daily living (ADL).
  - Combing hair.
  - Contralateral axilla.
  - Reaching back pocket.
  - Eating.

Subject and Protocol

One healthy male subject (31 yr, 1.72 m, 70 kg) participated in the experiments after signing an informed consent. The subject was instructed about the execution of movement tasks, speed, start, and end position of the hand. After some practice trials, each movement task was recorded with a 3D-movement analysis system, as well as with two video cameras. Lifting and throwing shoulder movements were performed in a standing position. During the standard movements and the small ADL tasks, the subject was seated on a regular chair without back and arm support.

Two nondeformable braces with four light-emitting-diode (LED) markers, noncollinearly mounted on each, were used. They were rigidly fixated to the upper arm and to the thorax, at the height of the first two thoracic vertebrae, to track the subject's arm movements relative to the trunk (**Figure 3**).

Recordings and Analysis

An OptoTrak 3020 optoelectronic tracking system (Northern Digital Inc., Waterloo, Canada) was used to record the 3D-marker positions of each LED marker to within an accuracy of 0.45 mm. Data were sampled at 100 Hz. In addition, the 3D positions of the upper arm and trunk brace were reconstructed for the whole trajectory of each movement [17]. Off-line analysis comprised decomposition of these positions to yield the corresponding angles

Figure 3.
Illustration of experimental setup of subject. Two rigid braces are attached to trunk and upper arm, each having four LEDs on a fixed distance. Positions of each LED during movements were recorded with an optoelectronic 3D system (Optotrak 3020; Northon Digital, Inc., Waterloo, Canada) and used for off-line analysis.

of the globe system: plane of elevation, angle of elevation, and rotation angle. Video recordings (25 Hz) were made of each movement task in different planes of view. From each task, the video frames of the start and end positions were selected and used within the visualization method.

RESULTS

Figure 4 shows the angles of the elevation planes reached at the start (**Figure 4(a)**) and end (**Figure 4(b)**) positions during the conventionally called extension and flexion movement. For extension, the elbow is positioned in the –81° plane and for the flexion in the +98° plane. Not surprisingly, extension and flexion did not occur in a pure sagittal plane. The photographs shown as **Figure 4(c)** and **(d)** are an example of the visualization of the end positions in the globe notation for these positions. It is important to realize that the angles for the amount of elevation are always positive in a determined plane of elevation.

As an example of a functional movement, the lifting maneuver from trunk to overhead (**Figure 5**) is chosen to describe the shoulder position with the three parameters. In

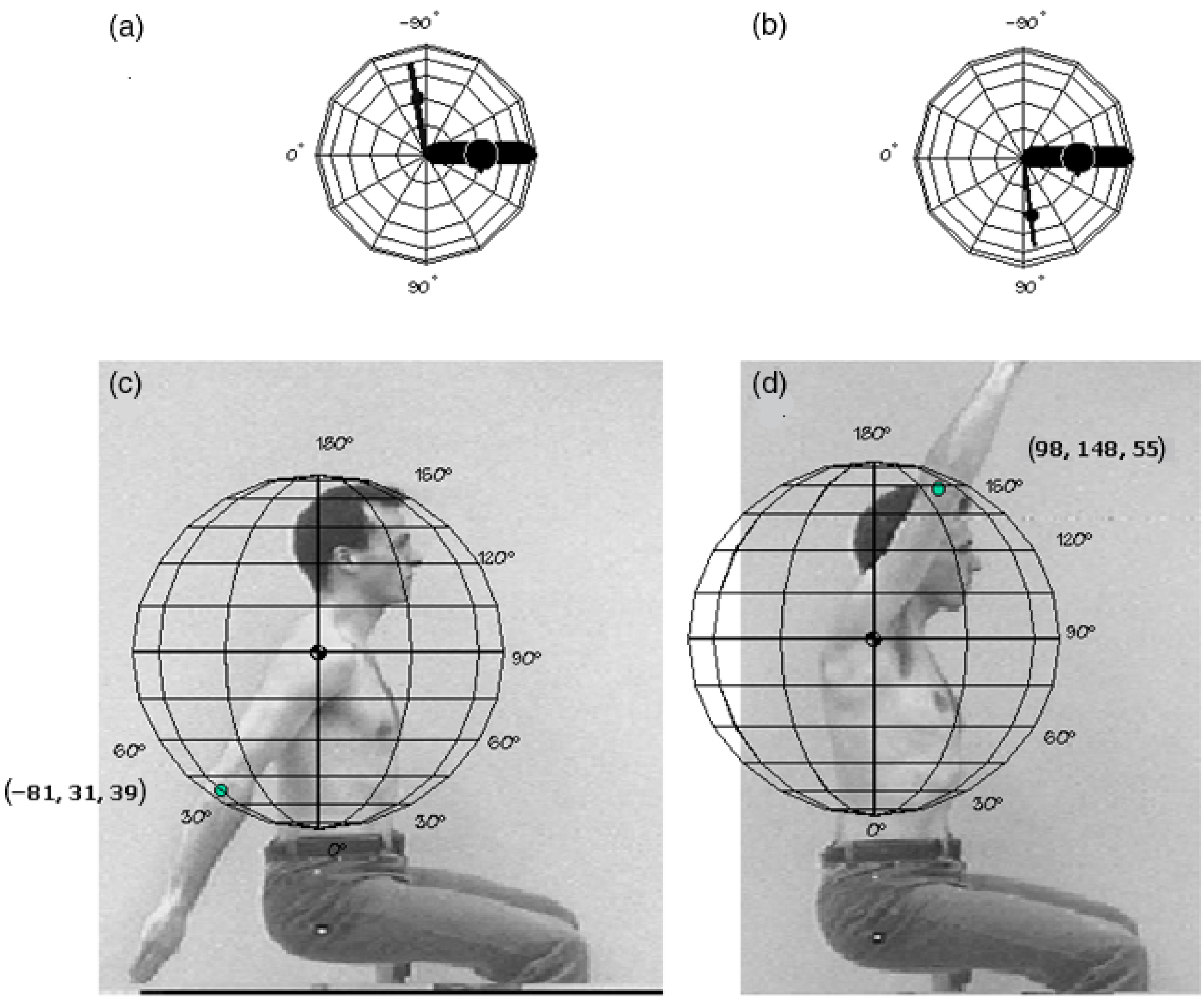

Figure 4.
Illustrations of **(a)** position of elbow (dot) and plane of elevation at STARTING position of extension and flexion movement, **(b)** position of elbow (dot) and plane of elevation at END position of extension and flexion movement, and **(c)** and **(d)** execution of extension and flexion movement, showing start and end positions, respectively. Projection of globe to visualize position of humerus also is shown.

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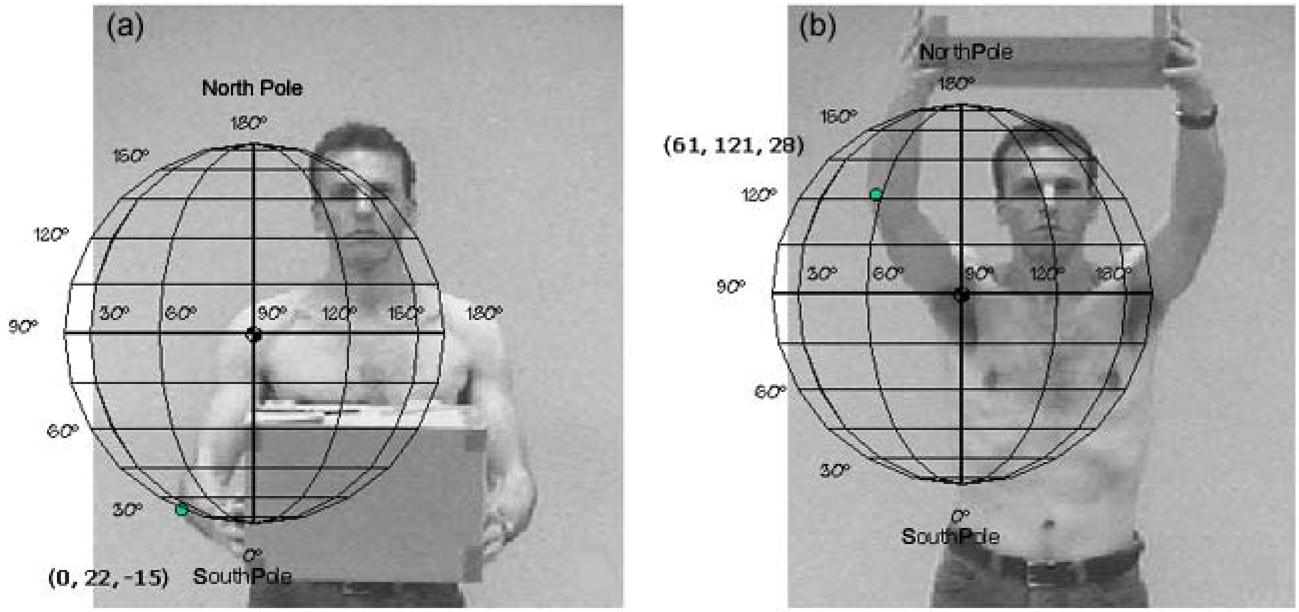

Figure 5.
Person executing a lifting movement (trunk to overhead). Projection of globe to visualize position of humerus is added. **(a)** shows start and **(b)** shows end position.

Figure 5, the three parameters of the start and end positions for this movement are indicated and visualized in globe coordinates.

An overview of all movements as measured during the experiment is shown in **Figure 6**. In this figure, the corresponding planes of elevation are also indicated. The position of the shoulder in the start and end positions of each movement is described with the corresponding angles of each parameter. One can observe that for the execution of these activities, the range of planes of elevation is about 180° around the shoulder and from 101° for the contralateral axilla to –68° for reaching the back pocket (**Figure 6**). Maximal elevation angle for the measured functional movements is about 138° (upper-hand throw).

DISCUSSION

Although every shoulder movement is the result of complex coordinated movements of different joints and bones [18], it is often conceptualized as a functional ball-and-socket joint relative to the thorax. In clinical practice, the assessment of shoulder range of motion is interpreted with the observation of the angular changes between humerus and trunk, along with the inspection and palpation of the scapula position and movement [19–20]. Also, the globe system is based on the assumption that range of motion of the shoulder complex can be sufficiently described by the angular changes in the functional thoracohumeral joint, which agrees well with the clinical convention. Recent studies showed that for a large range of arm movements, a valid prediction of the shoulder rhythm is possible, based on the orientations of thorax and humerus alone, with negligible effects of load and velocity [21–25]. This finding implies that the description of the positions of the upper arm relative to the trunk about the (anatomical nonexistent) thoracohumeral joint can adequately represent the movements of the shoulder complex, at least for healthy subjects.

With the support of a valid assessment of the shoulder complex function describing the movement of the arm relative to the trunk, the globe system will be valuable for many different purposes. It can be applied in clinical practice for any shoulder position with the use of a goniometer, as well as in research settings to evaluate functional movements, which often use more advanced movement analysis systems [5–15]. Speaking the same language will also enhance the interaction between fundamental research findings and their implementation in clinical disciplines [26].

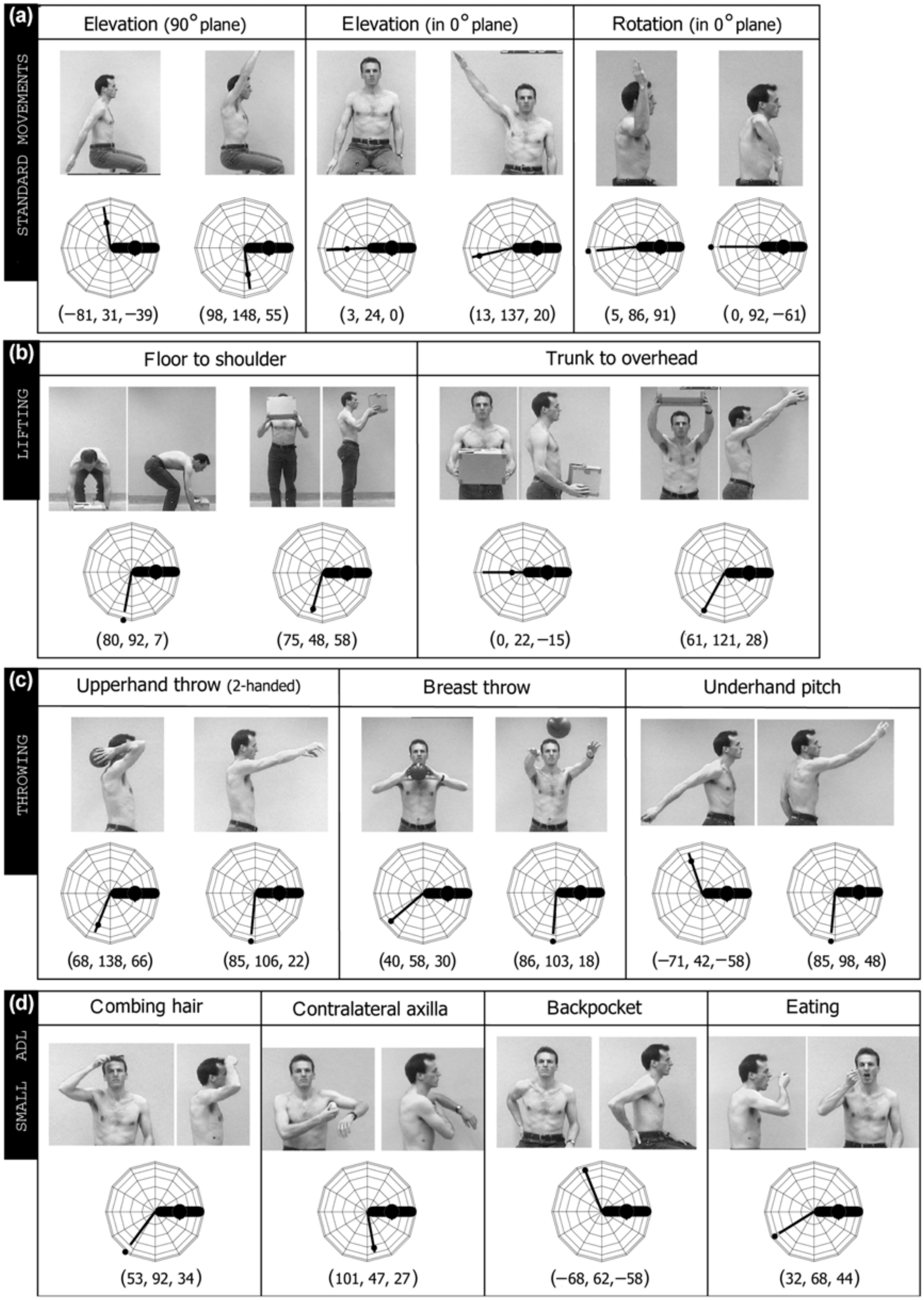

Figure 6.
Shown are maximum positions reached for **(a)** standard movements, **(b)** lifting, **(c)** throwing, and **(d)** small ADL. For each position, a top view of a cross-sectioned globe is shown to visualize corresponding plane of elevation (indicated by thick line). Black dot in that line is position of elbow. At bottom of each plot, three angles of parameters are shown parenthetically as plane elevation, elevation angle, and rotation angle.

Although the undetermined (i.e., gimbal lock) positions at 0° and 180° of elevation are not eliminated, one of the advantages of the globe system is that for most ADL tasks, the gimbal-lock positions are situated outside the movement range and do not disturb a clear quantitative kinematic description. Moreover, the system of description with the three parameters (elevation plane, elevation angle, and rotation angle), combined with the visualization of the shoulder positions on a globe, facilitates the evaluation of shoulder mobility during functional movements.

The presented data and method in this paper that describe the kinematics of shoulder position provide a structure to collect reference values from a larger population about the minimally required mobility of the shoulder joint to perform daily activities. Such a set of trajectories of normative data will be important in (for example) clinical applications where the understanding of arm positions is crucial, e.g., for decisions about shoulder arthrodesis positioning or evaluation of shoulder endoprostheses. With the development and implementation of such an observational tool in clinical practice, the impairments of specific pathological groups that are related to a minimally required range of motion for specific tasks could be outlined. Therefore, this globe system should be used in current clinical practice as well as in educational and research topics about shoulder movements.

CONCLUSION

In this paper, a method to use a specific sequence of rotation angles around the shoulder to describe the position of the humerus with respect to the thorax is evaluated. The globe system used is less ambivalent and a more convenient, applicable method in clinical practice to describe shoulder motion and positions of daily life (ADL) movements compared to the classical decomposition. The introduction of this system provides a language for clinical standardization of these types of movements in the practice of physical therapy, rehabilitation, orthopedics, and education on human movement science. Additionally, the way the parameters of the globe system are visualized facilitates an unambiguous interpretation of the movement and positions of the shoulder complex in relation to functional activities.

REFERENCES

1. American Academy of Orthopaedic Surgeons Joint Motion. Methods of measuring and recording. Edinburgh: Churchill Livingstone; 1965.
2. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng 1983;105:136–44.
3. Codman EA. The shoulder. New York: G. Miller & Company; 1934.
4. An KN, Browne AO, Korinek S, Tanaka S, Morrey BF. Three-dimensional kinematics of glenohumeral elevation. J Orthop Res 1991;9:143–49.
5. Anglin C, Wyss UP. Arm motion and load analysis of sit-to-stand, stand-to-sit, cane walking and lifting. Clin Biomech 2000;15:441–48.
6. Anglin C, Wyss UP. Review of arm motion analyses. Proc Inst Mech Eng 2000;214:541–55.
7. Browne AO, Hoffmeyer P, Tanaka S, An KN, Morrey BF. Glenohumeral elevation studied in three dimensions. J Bone Joint Surg Br 1990;72:843–45.
8. Cheng PL. A spherical rotation coordinate system for the description of three-dimensional joint rotations. Ann Biomed Eng 2000;28:1381–92.
9. van der Helm FCT, Pronk GM. Three-dimensional recording and description of motions of the shoulder mechanism. J Biomech Eng 1997;117:27–40.
10. McQuade KJ, Smidt GL. Dynamic scapulohumeral rhythm: the effects of external resistance during elevation of the arm in the scapular plane. J Orthop Sports Phys Ther 1998;27:125–33.
11. McQuade KJ, Smidt GL. Effects of local fatigue on three-dimensional scapulohumeral rhythm. Clin Biomech 1995; 10:144–48.
12. Newsam CJ, Rao SS, Mulroy SJ, Gronley JK, Bontrager EL, Perry J. Three dimensional upper extremity motion during manual wheelchair propulsion in men with different levels of spinal cord injury. Gait Posture 1999;223–32.
13. Pearl ML, Harris SL, Lippitt SB, Sidles JA, Harryman DT, Matsen FA. A system for describing positions of the humerus relative to the thorax and its use in the presentation of several functionally important arm positions. J Shoulder Elbow Surg 1992;1:113–18.
14. Romilly DP, Anglin C, Gosine RG, Herschler C, Rashke SU. A functional task analysis and motion simulation for the development of a powered upper-limb orthosis. IEEE Trans Rehabil Eng 1994;2:119–29.
15. Wang X, Maurin M, Mazet F, De Castro Maia N, Voinot K, Verriest JP, Fayet MR. Three-dimensional modelling of the motion range of axial rotation of the upper arm. J Biomech 1998;31:899–908.

16. Doorenbosch CAM, Mourits JJM, Veeger HEJ, Harlaar J, van der Helm FCT. Determination of the axes of rotation about the shoulder during elevation. J Orthop Sports Phys Ther 2001;31:133–37.
17. Söderkvist I, Wedin P-A. Determining the movements of the skeleton using well-configured markers. J Biomech 1993;26:1473–77.
18. Inman VT, Saunders FRC, Abbott LC. Observations on the function of the shoulder joint. J Bone Joint Surg Am 1944;26-A:1–30.
19. Hoppenfeld S. Physical examination of the spine and extremities. New York: Appleton-Century-Crofts; 1976.
20. Polley HF, Hunder GG. Physical examination of the joints. Philadelphia: WB Saunders Company; 1978.
21. de Groot JH, van Woensel W, van der Helm FCT. Effect of different arm loads on the position of the scapula in abduction postures. Clin Biomech 1999;14:309–14.
22. de Groot JH, Valstar ER, Arwert HJ. Velocity effects on the scapulo-humeral rhythm. Clin Biomech 1998;13:593–602.
23. de Groot JH, Brand R. A three dimensional regression model of the shoulder rhythm. Clin Biomech 2001:735–43.
24. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. J Biomech Eng 2001; 123: 184–90.
25. Pascoal AG, van der Helm FCT, Correia PP, Carita I. Effects of different arm external loads on the scapulo-humeral rhythm. Clin Biomech 2000;15:S21–S24.
26. Vermeulen HM, Stokdijk M, Eilers PHC, Meskers CGM, Rozing PM, Vliet Vlieland TPM. Measurement of three dimensional shoulder movement patterns with an electro-magnetic tracking device in patients with a frozen shoulder. Ann Rheum Dis 2002;61:115–20.

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