



Kinematic characteristics of the scapula and clavicle during military press exercise and shoulder flexion

Noriaki Ichihashi, PT, PhD^{a,*}, Satoko Ibuki, PT^a, Naoki Otsuka, PT, MS^b, Shingo Takashima, PT, MS^b, Aoi Matsumura, PT, MS^c

^aHuman Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan

^bASICS Corporation, Institution of Sport Science, Kobe, Japan

^cKyoto University Hospital, Kyoto, Japan

Background: The military press is an exercise frequently prescribed for scapular and shoulder rehabilitation. Although this exercise has previously been analyzed by electromyography, its kinematic features remain poorly understood. In this study, we aimed to clarify these features of the military press and suggest relevant clinical applications.

Methods: Sixteen healthy men participated in this study. The participants performed the military press while holding 2 kg weights, as well as shoulder flexion with and without 2 kg weights, and an electromagnetic motion capture system was used to analyze the kinematic features of the scapula, clavicle, and humerus during these exercises. The motions of the scapula and clavicle were analyzed at 10° increments of shoulder flexion from 30° to 120°.

Results: The military press involved less scapular internal rotation, greater upward rotation, and greater posterior tilt than shoulder flexion with or without weights, especially in the starting to middle range of shoulder flexion. Greater clavicular retraction and elevation were also seen during the military press.

Discussion: The movements of the scapula and clavicle during the military press differ significantly from those during shoulder flexion with and without weights. The kinematic features of the military press, which involved less scapular internal rotation, greater upward rotation, and greater posterior tilt than did shoulder flexion, may make it a useful re-education exercise (if pain allows) for patients with decreased scapular external rotation, upward rotation, and posterior tilting. The results of this study might provide a kinematic basis for the use of this widely performed shoulder exercise.

Level of evidence: Basic Science, Kinesiology Study.

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Keywords: Scapular motion; biomechanics; rehabilitation; military press; shoulder flexion; multi-joint movement

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*Reprint requests: Noriaki Ichihashi, PT, PhD, Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Kawara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan.

E-mail address: ichihashi.noriaki.5z@kyoto-u.ac.jp (N. Ichihashi).

The military press is an exercise frequently used in scapular and shoulder rehabilitation.^{2,3,7,10,21,26,29} It is a variation of an overhead press, which elevates the humerus overhead from an initial position with the elbow flexed and positioned anterior to the shoulder. Most of the previous studies on this exercise have involved electromyographic

analysis. Townsend et al²⁹ analyzed the activities of the rotator cuff, deltoid, pectoralis major, and latissimus dorsi muscles of the shoulder during shoulder exercises, including the military press. They suggested that the supraspinatus, subscapularis, and anterior and middle deltoid muscles are highly active during the military press. Moseley et al²¹ studied the activities of the scapular muscles during the military press and other rehabilitation exercises and suggested that the military press is a useful exercise for the upper trapezius, middle serratus anterior, and lower serratus anterior muscles.

On the other hand, the kinematic features of this exercise are not well understood. Crenshaw et al⁴ indicated that the overhead pressing motion involved in the military press can decrease the amount of space in the subacromial area and thereby increase the stress on the subacromial space in throwing athletes who have pre-existing chronic changes in this space. However, it is also true that in clinical situations, there are many patients with shoulder complications (eg, impingement, labral injury, and frozen shoulder) who can elevate their arms (or weights) more easily during the military press than during shoulder flexion. Although many kinematic analyses have been performed on humeral elevation in various planes such as abduction,¹⁶ scap-
tion,^{1,19,28} and flexion,¹⁶ all of these analyses were performed with the arms fully extended. To our knowledge, there is no kinematic study of the military press, that is, humeral elevation accompanied by active elbow movement.

In this study, using an electromagnetic sensor, we aimed to investigate the 3-dimensional kinetic features of the military press in comparison with those of shoulder flexion, performed with and without weights, to clarify the clinically relevant characteristics of this exercise. We hypothesize that the military press has kinematic features such as greater scapular upward rotation, posterior tilt, and external rotation that could make it a better humeral elevation exercise than normal shoulder flexion with the elbow extended.

Materials and methods

Participants

Sixteen healthy men (age, 21.8 ± 1.1 years [mean \pm SD]; height, 173.3 ± 5.3 cm; weight, 62.9 ± 7.3 kg) participated in this study. Subjects with a previous history of upper limb surgery, present neuromuscular disease or a history of neuromuscular disease, or any complaint in the upper limb in the past year were excluded from the study. The participants' dominant limbs were analyzed.

Instrumentation

Three-dimensional kinematic data for the scapula, clavicle, and humerus were recorded with a 6-*df* electromagnetic motion tracker system (Liberty; Polhemus, Colchester, VT, USA). The Liberty motion tracker system consists of a transmitter and sensors. Its System Electronics Unit generates and senses the magnetic fields and computes the position and orientation of each

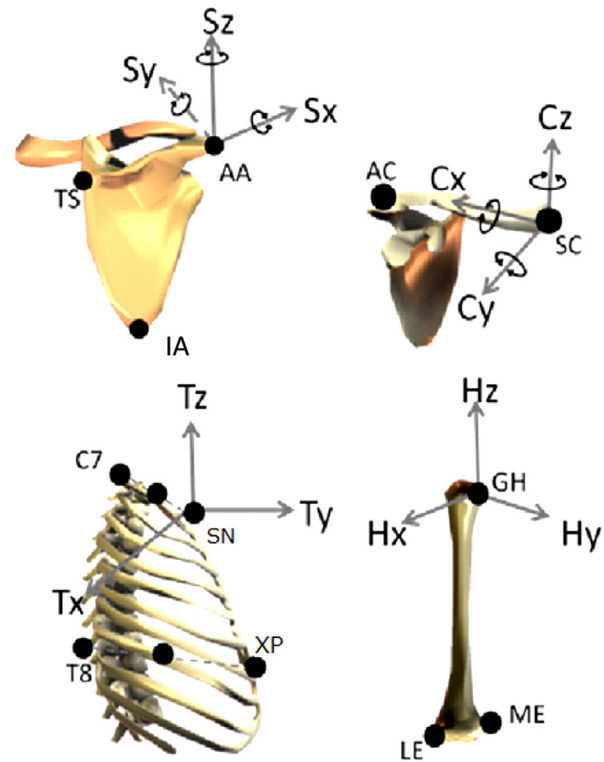


Figure 1 Locations of anatomic landmarks used for digitization and establishment of coordinate axes.

sensor. Previous studies have shown the accuracy of this device for the measurement of upper limb motion. For angles of shoulder flexion less than 120° , the error of measurement of the scapula and clavicle (relative to measurements made using bone pins) is less than 5° .^{12,13,16,18} Therefore, only the data corresponding to shoulder flexion angles up to 120° were analyzed in this study.

The transmitter was fixed on a rigid wooden board, and the global coordinate system was established. The sensors were fixed to the skin overlying the flat surface of the superior acromion process, the sternum, and the humerus (via a molded thermoplastic cuff at the midpoint of the humerus). Next, the bony landmarks of the scapula, clavicle, and humerus were palpated and then digitized with the Liberty sensor stylus to establish the anatomically based local coordinate systems (LCSs). These measurements were performed with the subjects standing still with their arms hanging beside their bodies. Each LCS was defined according to the International Society of Biomechanics standardization proposal for the upper extremity³² (Fig. 1). The acromial angle (AA), trigonum spinae (TS), and inferior angle (IA) were used to define the LCS of the scapula. The scapular x-axis (Sx-axis) was directed from the TS to the AA. The scapular y-axis (Sy-axis) was perpendicular to the plane defined by the TS, AA, and IA, and the scapular z-axis (Sz-axis) was defined as the cross product of the Sx-axis and Sy-axis.

The xiphoid process (XP), suprasternal notch (SN), spinous process of the seventh cervical vertebra (C7), and spinous process of the eighth thoracic vertebra (T8) were used to define the LCS of the thorax. The thoracic vertical axis (Tz-axis) was directed from the midpoint of the T8 and XP to the midpoint of the SN and C7; the transverse axis (Tx-axis) was perpendicular to the plane defined by the SN, C7, T8, and XP; and the sagittal axis (Ty-axis)

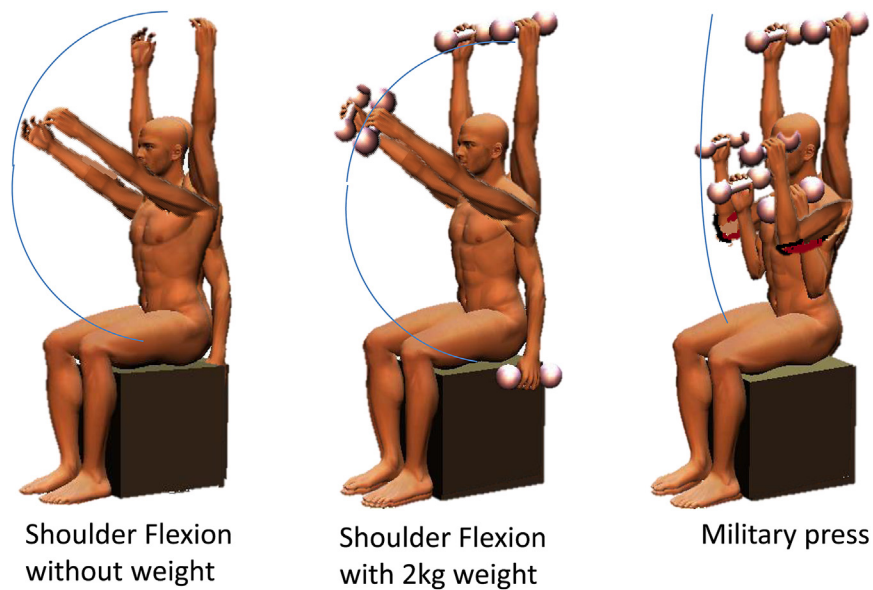


Figure 2 Shoulder flexion with and without weights and military press.

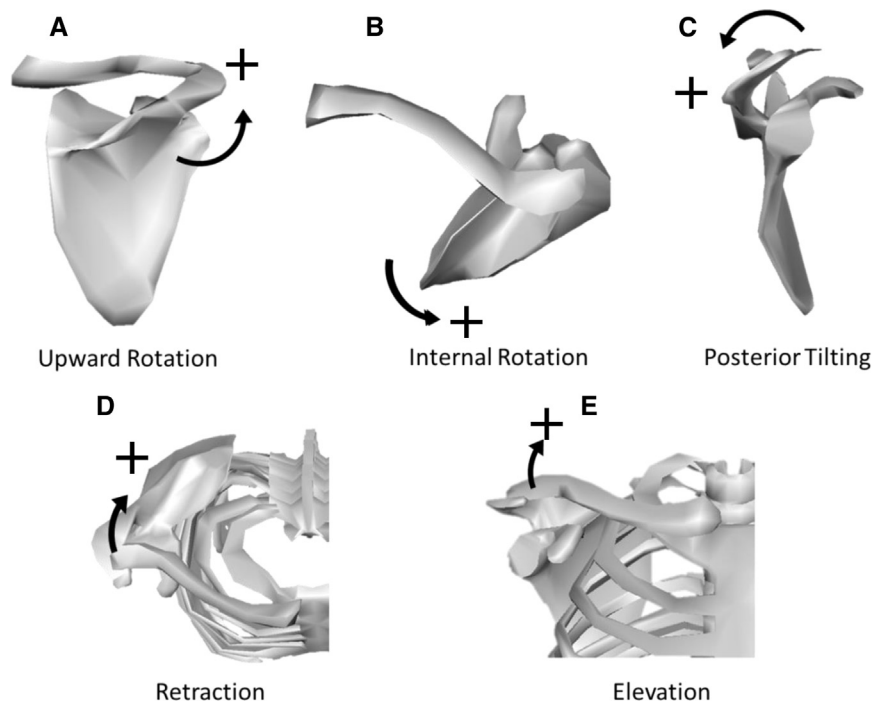


Figure 3 Definitions of motions of scapula and clavicle: upward-downward scapular rotation shown on posterior view of a right shoulder (A), internal-external scapular rotation shown on superior view of a right shoulder (B), anterior-posterior scapular tilting shown on lateral view of a right shoulder (C), clavicular retraction-protraction shown on superior view of a right shoulder (D), and clavicular elevation-depression shown on anterior view of a right shoulder (E).

was defined as the cross product of the Tz-axis and Tx-axis. The medial epicondyle (ME), lateral epicondyle (LE), and glenohumeral joint center (GH) were digitized to define the humeral coordinate system. The humeral longitudinal axis (Hz-axis) was directed from the midpoint of the ME and LE to the GH; the anterior-directed axis (Hy-axis) was perpendicular to the plane

defined by the GH, ME, and LE; and the laterally directed axis (Hx-axis) was defined as the cross product of the Hy-axis and Hz-axis. The acromioclavicular joint (AC) and sternoclavicular joint (SC) were used to define the LCS of the clavicle. The clavicular x-axis (Cx-axis) was directed from the AC to the SC. The thoracic Tz-axis was also used as the clavicular z-axis (Cz-axis), and the

Table I Changes in scapular position at each humeral elevation angle

	Change in scapular position (mean \pm SD) ($^{\circ}$)									
	30 $^{\circ}$	40 $^{\circ}$	50 $^{\circ}$	60 $^{\circ}$	70 $^{\circ}$	80 $^{\circ}$	90 $^{\circ}$	100 $^{\circ}$	110 $^{\circ}$	120 $^{\circ}$
Internal rotation										
Flexion without weight	28.2 \pm 10.2	29.7 \pm 10.4	31.1 \pm 10.8	32.4 \pm 11.2	33.5 \pm 11.6	34.3 \pm 12.1	34.8 \pm 12.5	34.6 \pm 13.0	33.0 \pm 13.3	29.6 \pm 14.2
Flexion with 2 kg weight	29.2 \pm 10.1	30.8 \pm 10.3	32.4 \pm 10.6	33.8 \pm 11.0	34.7 \pm 11.4	35.2 \pm 11.9	34.9 \pm 12.6	33.7 \pm 13.2	31.2 \pm 14.0	28.0 \pm 15.1
Military press	21.6 \pm 11.1	23.5 \pm 11.1	25.2 \pm 11.4	26.7 \pm 12.0	27.9 \pm 12.5	28.4 \pm 12.9	28.5 \pm 12.9	28.6 \pm 12.8	28.3 \pm 12.6	28.3 \pm 13.6
Upward rotation										
Flexion without weight	8.4 \pm 7.0	11.6 \pm 7.0	15.5 \pm 7.2	19.8 \pm 7.4	24.5 \pm 7.6	29.1 \pm 7.7	33.4 \pm 7.7	37.1 \pm 7.5	39.8 \pm 7.2	41.4 \pm 7.1
Flexion with 2 kg weight	6.7 \pm 7.0	10.5 \pm 6.9	14.8 \pm 7.2	19.5 \pm 7.5	24.8 \pm 7.8	29.9 \pm 8.1	34.6 \pm 8.2	38.4 \pm 8.1	41.1 \pm 7.9	42.7 \pm 7.5
Military press	10.8 \pm 8.2	14.1 \pm 8.0	17.7 \pm 8.3	22.0 \pm 8.7	26.9 \pm 8.9	32.1 \pm 9.1	37.1 \pm 9.2	41.2 \pm 8.8	43.8 \pm 8.3	45.7 \pm 7.7
Posterior tilt										
Flexion without weight	-4.6 \pm 6.0	-3.3 \pm 6.5	-2.4 \pm 6.9	-1.9 \pm 7.5	-1.7 \pm 8.3	-1.4 \pm 9.3	-1.0 \pm 10.3	-0.1 \pm 11.2	1.6 \pm 12.2	4.8 \pm 13.6
Flexion with 2 kg weight	-6.5 \pm 6.3	-5.2 \pm 6.4	-4.2 \pm 6.7	-3.9 \pm 7.3	-3.9 \pm 8.2	-4.1 \pm 9.3	-4.1 \pm 10.1	-3.2 \pm 11.1	-0.8 \pm 12.5	2.9 \pm 14.0
Military press	-4.1 \pm 7.7	-1.6 \pm 7.6	0.1 \pm 7.9	1.2 \pm 8.3	2.1 \pm 9.0	2.9 \pm 9.6	3.5 \pm 10.5	3.8 \pm 12.0	4.7 \pm 13.2	6.0 \pm 14.5

clavicular y-axis (Cy-axis) was defined as the cross product of the Cx-axis and Cz-axis.

Procedures

The kinematic features of the shoulder were analyzed during the following 3 exercises: shoulder flexion without weights, shoulder flexion while holding 2 kg weights in both hands, and the military press while holding 2 kg weights in both hands (Fig. 2). All 3 exercises were performed with the subject sitting on a platform without any backrest or armrest. In all 3 motions, humeral elevation was performed in the sagittal plane. In the starting position, the arms were allowed to hang at the sides with the elbow extended for shoulder flexion and with the elbow fully flexed for the military press. The subjects raised their arms to full elevation over the course of 4 seconds, using a metronome for speed control. Each exercise was performed 5 times consecutively, and the mean of the middle 3 elevations was analyzed. The patients underwent sufficient rest before performing the next exercise, and the order in which the exercises were performed was randomized for each participant to avoid any effect of the testing order. For the military press, the subjects were instructed to keep the elbow in the plane of flexion. In our previous study, the repeat-trial intraclass correlation coefficient values for the kinematic data for the scapula and clavicle ranged from 0.94 to 0.99, indicating almost-perfect reliability.²²

Data reduction

The raw kinematic data were filtered by use of a low-pass 4-Hz Butterworth filter. The rotations of the distal coordinate system were described with respect to the proximal coordinate system using Euler angles in accordance with the recommendations of the International Shoulder Group of the International Society of Biomechanics³² (Fig. 3). The rotational motion of the scapula relative to the thorax was defined as follows: The motion of the scapula around the Sz-axis was defined as external rotation (negative)/internal rotation (positive), the motion around the Sy-axis was defined as upward rotation (negative)/downward rotation (positive), and the motion around the Sx-axis was defined as anterior tilt (negative)/posterior tilt (positive). The rotation of the clavicle relative to the thorax was defined as follows: The motion of the clavicle around the Cz-axis was defined as protraction (negative) or retraction (positive). The motion of the clavicle around the Cy-axis was defined as elevation (negative) or depression (positive). The motion of the humerus relative to the thorax was defined as the elevation angle, wherein a positive value represented elevation. The scapular angle (upward/downward rotation, external/internal rotation, and posterior/anterior tilting) and clavicular angle (protraction/retraction and elevation/depression) were measured at selected humeral elevation angles during the ascending phase of each task using custom MATLAB code (The MathWorks, Natick, MA, USA). For the descriptive portion of the study, humeral angles relative to the thorax were selected at 10 $^{\circ}$ intervals and ranged from 30 $^{\circ}$ to 120 $^{\circ}$ of humeral elevation.

Data analysis

The means of the middle 3 trials were analyzed. Two-way (exercise type [flexion without weights/flexion with weights/military

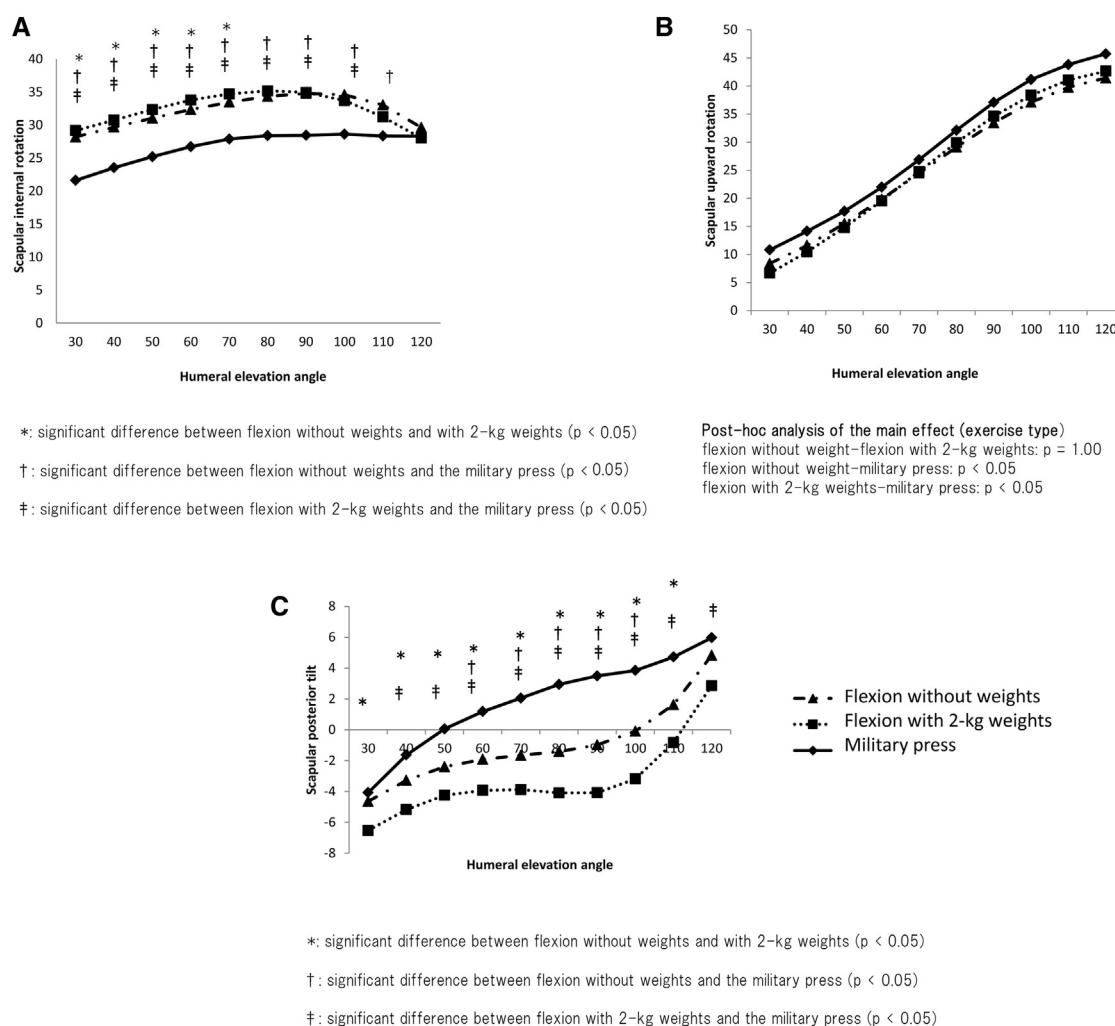


Figure 4 Motions of scapula relative to thorax during humeral elevation: scapular internal/external rotation (A), scapular upward/downward rotation (B), and scapular posterior/anterior tilting (C). *Diamonds* indicate the military press, *squares* indicate flexion with 2 kg weights, and *triangles* indicate flexion without weights. In A and C, the *asterisks* indicate significant differences between flexion without weights and flexion with 2 kg weights ($P < .05$); the *daggers* indicate significant differences between flexion without weights and the military press ($P < .05$); and the *double daggers* indicate significant differences between flexion with 2 kg weights and the military press ($P < .05$). In B, post hoc analysis of the main effect (exercise type) showed the following: $P > .99$ for flexion without weights versus flexion with 2 kg weights, $P < .05$ for flexion without weights versus military press, and $P < .05$ for flexion with 2 kg weights versus military press.

press] \times humeral elevation angle) repeated-measures analysis of variance was used to analyze differences in the scapular and clavicular angles. Differences were considered statistically significant at $P < .05$. When a significant main effect or any interaction of the exercise type was found, post hoc analysis with Holm adjustment was used to assess the significance of differences between the individual types of exercise.

Results

Scapular internal/external rotation

The exercise type had a significant main effect on the scapular internal/external rotation angle ($P < .01$), with a

significant interaction noted between the exercise type and the humeral elevation angle ($P < .01$) (Table I; Fig. 4, A). Post hoc analysis with Holm adjustment showed significantly less scapular internal rotation during the military press than during shoulder flexion with or without weights at humeral elevation angles of 30° to 100° ($P < .05$).

Scapular upward/downward rotation

Both exercise type and humeral elevation angle ($P < .01$) had significant main effects on scapular upward rotation (Table I; Fig. 4, B). No significant interaction between exercise type and humeral elevation angle was seen for

Table II Changes in clavicular position at each humeral elevation angle

Change in clavicular position (mean \pm SD) ($^{\circ}$)		30 $^{\circ}$	40 $^{\circ}$	50 $^{\circ}$	60 $^{\circ}$	70 $^{\circ}$	80 $^{\circ}$	90 $^{\circ}$	100 $^{\circ}$	110 $^{\circ}$	120 $^{\circ}$
Clavicular retraction											
Flexion without weight	28.3 \pm 7.4	28.1 \pm 7.6	28.1 \pm 7.9	28.3 \pm 8.1	28.9 \pm 8.3	29.9 \pm 8.4	31.3 \pm 8.4	33.2 \pm 8.2	36.2 \pm 7.8	39.8 \pm 7.6	
Flexion with 2 kg weight	28.2 \pm 7.5	28.0 \pm 7.8	28.1 \pm 8.1	28.4 \pm 8.3	29.5 \pm 8.3	31.1 \pm 8.3	33.3 \pm 8.3	36.0 \pm 8.2	39.0 \pm 8.1	42.0 \pm 8.0	
Military press	33.0 \pm 8.2	33.0 \pm 8.5	33.0 \pm 8.8	33.3 \pm 9.0	33.8 \pm 9.1	35.0 \pm 9.0	36.7 \pm 8.8	38.5 \pm 8.6	40.5 \pm 8.3	42.8 \pm 8.2	
Clavicular elevation											
Flexion without weight	11.5 \pm 5.1	12.0 \pm 5.1	12.7 \pm 5.2	13.6 \pm 5.3	14.8 \pm 5.4	16.2 \pm 5.5	17.9 \pm 5.6	19.6 \pm 5.7	20.8 \pm 5.8	21.5 \pm 6.1	
Flexion with 2 kg weight	11.0 \pm 5.1	11.5 \pm 5.2	12.3 \pm 5.4	13.5 \pm 5.8	15.2 \pm 6.1	17.1 \pm 6.4	19.1 \pm 6.7	20.8 \pm 7.0	21.8 \pm 7.2	22.2 \pm 7.5	
Military press	12.6 \pm 6.1	13.2 \pm 6.2	14.1 \pm 6.3	15.3 \pm 6.6	16.8 \pm 6.9	18.4 \pm 7.1	20.0 \pm 7.5	21.8 \pm 7.7	22.9 \pm 7.8	24.3 \pm 7.8	

scapular upward rotation. The scapular upward rotation was significantly greater during the military press than during shoulder flexion with or without weights throughout the entire range of humeral elevation angles ($P < .05$).

Scapular anterior/posterior tilt

The type of exercise had a significant main effect ($P < .01$) on the scapular anterior/posterior tilt, with a significant interaction noted between the type of exercise and the humeral elevation angle ($P < .01$) (Table I; Fig. 4, C). Post hoc analysis with Holm adjustment showed that the scapular posterior tilt was significantly greater during the military press than during shoulder flexion at angles of 40 $^{\circ}$ to 120 $^{\circ}$ and angles of 60 $^{\circ}$ to 100 $^{\circ}$ for shoulder flexion with and without 2 kg weights, respectively.

Clavicular retraction/protraction

The type of exercise significantly affected clavicular retraction ($P < .01$), with a significant interaction noted between the type of exercise and the humeral elevation angle ($P < .01$) (Table II; Fig. 5, A). Clavicular retraction was significantly greater during the military press than during shoulder flexion with weights at humeral elevation angles of 30 $^{\circ}$ to 100 $^{\circ}$ and was significantly greater than during shoulder flexion without weights at humeral elevation angles of 30 $^{\circ}$ to 120 $^{\circ}$ ($P < .05$).

Clavicular elevation/depression

The type of exercise significantly affected the clavicular elevation angle ($P < .01$), with a significant interaction noted between the type of exercise and the humeral elevation angle ($P < .01$) (Table II; Fig. 5, B). Clavicular elevation was significantly greater during the military press than during shoulder flexion at humeral elevation angles of 30 $^{\circ}$ to 80 $^{\circ}$ and 120 $^{\circ}$ for shoulder flexion without weights ($P < .05$) but only at humeral elevation angles of 40 $^{\circ}$ to 70 $^{\circ}$ and 120 $^{\circ}$ for shoulder flexion with weights ($P < .05$).

Discussion

The 3-dimensional kinematic features of the military press were compared with those of shoulder flexion performed with and without weights to clarify the characteristics of this exercise. The military press involved greater scapular upward rotation, posterior tilt, and external rotation relative to normal shoulder flexion in at least part of the examined range, which supported our hypothesis.

Several previous studies have evaluated the kinematics of the scapula and clavicle during humeral elevation.^{8,16,18,28} The results of our study agree with those of the

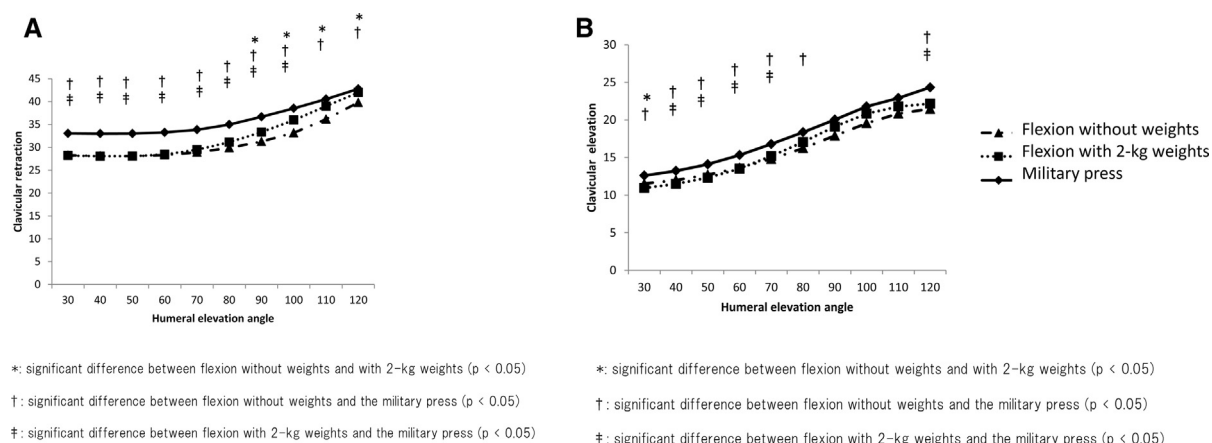


Figure 5 Motions of clavicle relative to thorax during humeral elevation: clavicular retraction/protraction (**A**) and clavicular elevation/depression (**B**). *Diamonds* indicate the military press, *squares* indicate flexion with 2 kg weights, and *triangles* indicate flexion without weights. The *asterisks* indicate significant differences between flexion without weights and flexion with 2 kg weights ($P < .05$); the *daggers* indicate significant differences between flexion without weights and the military press ($P < .05$); and the *double daggers* indicate significant differences between flexion with 2 kg weights and the military press ($P < .05$).

previous studies. However, detailed examination showed that the scapular motions during the military press differed from those during shoulder flexion either with or without weights and involved less scapular internal rotation, greater posterior tilt, and greater upward rotation, which were noted mainly in the initial and middle range of shoulder elevation. The military press also produced greater clavicular elevation and retraction. The differences between the military press and shoulder flexion became smaller as the angle of elevation increased, and no significant difference except in scapular upward rotation was noted for scapular and clavicular motion at angles greater than 110° .

Previous studies using electromyography have shown that the trapezius, especially the upper trapezius, and serratus anterior muscles are highly activated during the military press.^{21,22} The serratus anterior muscle is known to be responsible for posterior tilt, external rotation, and upward rotation of the scapula,^{5,15} and these actions are consistent with the scapular motions seen during the military press in our study. The upper trapezius is known to elevate the clavicle,²⁷ and this action is also consistent with the greater clavicular elevation during the military press shown in this study.

Clavicular motion is known to relate directly to scapular translation with respect to the thorax. Given the lack of significant motion at the acromioclavicular joint, clavicular elevation and retraction will translate the scapula superiorly and posteriorly (ie, elevation and retraction).¹² Together with the 3 motions of the scapula, these 2 scapular translations account for the 5 *df* of scapular motion.²⁰

Another kinematic difference between shoulder flexion and the military press was the inclusion of elbow extension and flexion during shoulder motion. The combined shoulder and elbow motion used for the military press is probably more similar to motions used in daily activities, such

as reaching up or putting something on a shelf, and may therefore be more “functional.”

In this study, the maximum angular differences in scapular position observed between the military press and flexion with 2 kg weights were 7.5° less internal rotation, 4.1° greater upward rotation, and 7.6° greater posterior tilt in the military press. Ludwig and Cook¹⁴ have reported on the kinematic differences between subjects with impingement and control subjects. They observed significant differences in all 3 rotations of the scapula, with greater medial rotation, greater anterior tilt, and less upward rotation in the impingement group. The maximum mean differences were 5.2° for medial rotation, 5.8° for anterior tilt, and 4.1° for upward rotation. They concluded that a modest angular difference of 4° to 6° was sufficient to produce clinically relevant changes in the subacromial space and impingement. Because the maximum differences observed in our study were above this threshold, we consider the differences in scapular position shown herein to be clinically meaningful.

Use of military press as coordination exercise

The characteristics of scapular and clavicular motion observed during the military press might be useful as a shoulder coordination exercise as part of a rehabilitation program. Many previous studies have reported decreased scapular external rotation, scapular upward rotation, and posterior scapular tilting in patients with shoulder impingement syndrome,^{6,9,14,17} and a similar pattern has also been seen in subjects with glenohumeral instability.^{11,23,25,30,31} A study by Oyama et al²⁴ measured the 3-dimensional motion of the scapula and the clavicle while subjects performed various exercises, in the prone position, that retract (externally rotate) the scapula; the results

suggested that these exercises could be effective for restoring normal scapular and clavicular kinematics and might be indicated for patients with shoulder pathologies. The military press also involves external rotation accompanied by upward rotation and posterior tilting of the scapula. Moreover, because the military press uses the desired motion of the scapula as part of a more practical motion—that is, humeral elevation involving the movement of multiple joints—it may be a useful re-education exercise for patients with pathologic conditions characterized by decreased scapular external rotation, decreased scapular upward rotation, and decreased posterior scapular tilting.

Limitations

Some limitations of this study should be considered. First, because of the requirements for accurate measurement using the electromagnetic sensor, the data corresponding to shoulder flexion angles of greater than 120° were not analyzed. Second, the subjects in this study were healthy young men. Therefore, the results may not be directly applicable to patients with shoulder problems. Third, the military press in this study was performed in the sagittal plane. It cannot be assumed that the results of this study will be applicable to other forms of the military press. Finally, the efficiency of the exercise in improving scapular kinematics has not been determined. Further study is needed in patients with shoulder pathology and to determine the effectiveness of the exercise.

Conclusions

The 3-dimensional kinematic characteristics of the scapular and clavicular movements during the military press were investigated and compared with those during shoulder flexion. The military press produced greater upward rotation, external rotation, and posterior tilting of the scapula and more protraction and elevation of the clavicle. These kinematic features of the military press may make it a useful re-education exercise for patients with decreased scapular external rotation, upward rotation, and posterior tilting. This study may serve as a kinematic basis for prescribing this well-known exercise in clinical practice.

Disclaimer

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