Trunk kinematics and the muscle activities during arm elevation

Kazuhiro Takahashi[1)2)], Takehiko Yamaji[1)], Naoki Wada[2)], Kenji Shirakura[2)], Hideomi Watanabe[1)]

1) Department of Rehabilitation Sciences, Gunma University Graduate School of Health Sciences, 3-39-22 Showa, Maebashi, Gunma 371-8514 Japan

2) Division of Rehabilitation Medicine, Gunma University Hospital, 3-39-15 Showa, Maebashi, Gunma 371-8511 Japan

ABSTRACT

Background While trunk movement accompanies arm elevation, trunk muscle activities during arm elevation at different speeds are unclear. The purpose of this study was to examine the trunk muscle activities at various speeds of arm elevation and then to evaluate their roles in trunk kinematics.

Methods Twenty-two healthy subjects participated. The participants performed shoulder flexion at three different speeds. Surface electromyography was used to measure the activities of bilateral external oblique muscles (EO), internal oblique muscles (IO), rectus abdominis muscles (RA) and lumber erector spinae muscles (ES). A three-dimensional motion analyzer was used to measure arm and trunk movements.

Results In natural and slow movements, the muscle activities of left ES, right EO and left IO were significantly augmented compared with those of the contralateral muscles, in the relatively late phase. In fast movement, the muscle activities of the both ES during the early phase were significantly augmented more than during other phase. The muscle activities of the left ES and the right EO were significantly augmented compared with those of the contralateral muscles. There was a consistent pattern of trunk extension, lateral flexion and rotation during arm elevation, irrespective of the speed.

Conclusions Bilateral ES activity may be required for back-extension torques, especially for the early phase of rapid elevating motion. The anterior muscles' activity may contribute to the production of anterior force against the backward movement of the center of mass of the upper limb in the late phase. Trunk rotation, controlled by the trunk muscles in harmony, may assist the scapular movement to align the scapular plane in the arm elevating plane.

1. Introduction

Shoulder impingement syndrome (SIS) is believed to be the most common conditions. Repetitive arm elevation required for work, sports and daily living activities [1, 2], especially for elevation with high velocity [3], has been identified as risk factors for the development of shoulder impingement syndrome. Individuals with SIS have shown to present lower activity of serratus anterior, higher activity of upper and lower trapezius, and lower activity of infraspinatus, subscapularis and middle deltoid during arm elevation [4-6]. As for kinematics, contrasting results have been reported in studies on scapular movement during arm elevation following SIS showing either an increase or decrease of scapular posterior tilting and lateral rotation [4, 7, 8]. Increased clavicular elevation and retraction have also been observed [7]. These alterations may be due to impingement of subacrominal structures and subsequent pain during arm elevation. To overcome this controversial issue and then to elucidate the SIS pathogenesis from biomechanical point of view kinematic approach to dynamic change during arm elevation in health subjects is required.

There have been several studies on the kinematics and electromyography (EMG) activities around shoulder during arm elevation. At the glenohumeral joint, the deltoid muscle is the prime mover of the arm into humeral elevation, assisted by the supraspinatus as an accessory elevator [9-11]. At scapulothoracic joint, the scapula rotates upwardly and tilts posteriorly on the thorax during arm elevation [7]. The trapezius and the serratus anterior muscles are the prime movers for this scapula motion [9, 12].

Trunk kinematics and the muscle activities, on the other hand, play an important role in arm elevation from viewpoints of kinetic chain. Trunk extension, contralateral side flexion and rotation have suggested to be caused by unilateral humeral flexion in trunk [13]. Furthermore rapid movement of the limb is preceded by contraction of the erector spinae, the transversus abdominis, and the internal oblique muscle [14-16]. However, little has been reported on the relationship between trunk muscle activity and kinematics of the trunk with different arm-elevating speed. A few studies evaluated trunk movement during arm elevation but results were discordant [13, 17, 18]. Fayad et al suggested that differences might be explained by variations in study design, age group and placement of the transmitter and the electromagnetic sensor [18].

The present study examined the trunk kinematics and the muscle activities during right arm elevation by using motion capture system and EMG synchronously, and revealed a constant left rotation of the thorax against pelvis regardless of the speeds. The role of the trunk muscles in the trunk motion will be discussed by using the results from EMG analyses. The present results should be useful for the development of therapeutic plan in physical therapy for patients with shoulder conditions such as SIS by providing standard data in the examination of trunk kinematics of the patients.

2. Methods

2.1. Subjects

This study involved 22 males aged 26.4 ± 3.4 years with height and weight of 1.69 ± 0.05 m and 63.2 ± 7.0 kg, respectively. Participants were excluded if they had a history of shoulder pain, low-back pain, neurological or orthopedic conditions. This study was approved by of Gunma University Faculty of Medicine.

The local Clinical Research Ethics Committee approved the study (Gunma University, Maebashi, Gunma, Japan), and each individual participant in the study gave informed consent.

2. 2. Instrumentation

Surface EMG was acquired using a multitelemeter system (WEB-5000, Nihon Kohden, Japan) with a common mode rejection ratio of 54 dB. All recordings were acquired using solid-gel, disposable silver / silver chloride electrodes (Vitrode J, Nihon Kohden, Japan), with a 40mm diameter, in a bipolar configuration. Electrodes were positioned with a centre-to-centre distance of 25mm, parallel to the muscle fibers, and following careful preparation of the skin overlaying the muscle sites of interest (cleaned, shaved and lightly abraded). The EMG raw data were collected with a computer (BIMTUS2, Kissei Co. Japan) at a sampling rate of 1080 Hz through a 12-bit A/D board. All EMG signals were filtered with a band-pass of 30-500 Hz. Muscle activity was recorded over the right lower serratus anterior muscle and 4 trunk muscles bilaterally: the external oblique muscles (EO), the internal oblique muscles (IO), the rectus abdominis muscles (RA), and the lumber erector spinae muscles (ES). The skin was prepped, and electrodes were aligned parallel to muscle fibers and placed in accordance with previous studies [19, 20]. Briefly, the serratus anterior muscle electrodes were placed over the muscle fibers anterior to the latissimus dorsi muscle when the arm was flexed 90 degree in the sagittal plane. The EO electrodes were placed lower edge of eight ribs next to costal cartilage. The IO electrodes were placed 2cm below the line between anterior superior iliac spines (ASISs), medial to the inguinal ligament, but lateral to the lateral border of the rectus sheath. The RA electrodes were placed the level of ASIS and 2cm lateral to the midline. The ES electrodes were placed at the level of the L1 spinous process and 3cm lateral to midline. A reference electrode was placed on the left anterior superior iliac spine.

In addition, kinematics data were collected using a motion capture system (VICON Motion System, Oxford Metrics, Oxford, UK), and synchronized through the same 12-bit A/D board. To obtain trunk and arm kinematic data using motion capture system eight infra-red markers were placed over surface landmarks of the right arm and the trunk in Fig. 1: right acromion, right olecranon, spinous process of the seventh cervical vertebrae (C7), spinous process of the first sacral (S1), both ASISs and both ninth ribs 10 cm from the midline (R9), as described previously [16].

2.3. Procedure

As a normalization reference, EMG data were sampled for two 3-second trials during manually resisted maximal voluntary contractions (MVCs) for each muscle [21]. The highest value (averaged over 1 second) was used as the normalization reference.

Subjects stood with their arms relaxed at their side. Kinematic and EMG data were collected for 10 seconds in this resting standing posture. Then shoulder flexion was performed at each of three different speeds to maximum elevation. The speed conditions involved in the previous study were as follows [22] : (1) Natural, movement performed at a speed natural to the participant; (2) Slow, movement performed at a speed approximately 2-seconds to complete the 60° of movement (i.e. 30 °/s); and (3) Fast, movement performed as fast as possible. The data from three trials for each speed were collected. Prior to measurement, each subject was instructed verbally and visually about how to perform, and given 5 minutes practice time for each condition for familiarization of exertion.

2. 4 Data reduction

For kinematic data, shoulder flexion angle was calculated as the parasagittal angle between the vertical axis and the line connecting the markers placed at elbow and acromion. The angle between vertical line and the line connecting the markers placed at C7 and S1 was calculated in the sagittal and frontal planes as trunk angles. Pelvic and thorax rotation angles in transverse plane were calculated as angle change using lines connecting both ASISs and R9s, respectively. Trunk rotation was calculated the difference in transverse plane rotation between the pelvis and thorax rotation. The starting angles were set at 0°.

For EMG data, Root Mean Square (RMS) values were calculated. To provide a basis for EMG signal amplitude normalization for the elevation tasks, the MVCs were used. A relative value as the percentage of the MVC was calculated by dividing the average RMS of the elevation tasks by the average RMS of MVC with resting standing posture, the whole elevation task (0-150°) and 30 degrees-divided phase of movement (0-30°, 30-60°, 60-90°, 90-120°, 120-150°). To emphasize the relationship between resting standing posture and the whole elevation task, the relative activity was expressed as ratios of trunk muscle during arm elevation to resting standing posture.

2.5. Data analysis

SPSS software package version 19.0 was used to generate all statistics. Whether the data are normally distributed those was analyzed by Shapiro-Wilk test. Then a one-way analysis of variance with repeated measures was used with the alpha level set at .05. When the significant difference was found among the percentage of the MVCs and ratios, we then used the Bonferroni adjustment with the alpha level set at .01 (.05/5). Comparisons of the percentage of MVC between in resting standing posture and during arm elevation in various speeds were analyzed with a Wilcoxon signed rank test. Comparisons of ratios between right and left were analyzed with a Wilcoxon signed rank test.

3. Results

Results from the analyses of the serratus anterior muscle activity are showed in Fig. 2. The serratus anterior muscle activity in resting standing posture was negligible. The muscle activity continued to increase throughout the range in natural and slow movements. In contrast, the serratus anterior activity showed constant high activity in fast movement throughout all range of movement.

As shown in Table 1, the percentage of the MVC in the trunk muscle activities were more than 5 % in resting standing posture. There was no significant difference between right and left muscle activities in all trunk muscles in the resting standing posture. The percentage of the MVC in the IO activity in the resting standing posture was higher than in the other muscles, corresponding well to the previous finding [23]. In both slow and natural movements, only ES muscle activity was significantly enhanced in approximately 1.5-fold as compared with in resting standing posture. In contrast, all trunk muscle activities in fast movement were enhanced as compared with in resting standing posture in approximately 2- to 4-fold. It is interesting that the right EO but not left EO muscle activity was enhanced in natural movement.

To examine the dynamic change of the muscle activity in arm elevation in detail relative muscle activity (elevation / resting standing posture) in each 30 degree was analyzed in natural (Fig. 3), slow (Fig. 4) and fast movement (Fig. 5). In natural movement both right and left ES muscle activities were significantly augmented in all phases as compared with those in resting standing posture. The right EO muscle activity significantly augmented in all range of the elevation and the activity during 90 to 150 degree significantly augmented more than that during initial phase. Interestingly, the relative muscle activity of the left ES was significantly augmented more than that of the contralateral side during 0 to 30 degree. The relative muscle activities of the right EO and left IO were significantly augmented more than those of the contralateral side, respectively, in the relatively late phase. There were few changes in the relative muscle activity in RA in natural movement. As shown in Fig. 4, the dynamic changes in the relative muscle activity in slow movement were essentially same as those in natural movement.

The responses of trunk muscles to fast movement were different from those to natural and slow movements. In fast movement the relative muscle activities of the both ES during 0 to 30 degree phase were 8 times as much as those in resting standing posture and significantly augmented more than those during other phases. In both initial, i.e., during 0 to 30 degree, and late, i.e., during 90 to 150 degree, the left ES activity was significantly higher than that of the contralateral side. In both EO the muscle activities were significantly augmented more than those in resting standing posture, and around 90 degree right activities were significantly higher than left ones. The relative muscle activities of the both RA and IO in fast movement significantly augmented in the relatively late phase.

During arm elevation in all speeds, there was a consistent pattern of trunk extension and lateral flexion to the left side (approximately 2.2 degree and 1.9 degree, respectively, data not shown), corresponding to the previous reports [13, 17, 18]. On the other hand, pelvic and thorax rotation in all speeds showed different patterns (Fig. 6). In natural movement thorax rotated simply to the left, while pelvis rotated slightly to the right and then to the left. In slow movement both thorax and pelvis rotated simply to left. In fast movement both thorax and pelvis rotated to right in initial phase and then to left side finally. Interestingly, however, the trunk rotation to the left was constantly increased without any difference among movement speeds except for 150 degree (Fig. 6).

4. Discussion

In the present study we firstly observed the serratus anterior muscle activity as a positive control. As common features of trunk muscles among different speeds, both right and left ES muscles activated in all range of the movement, and the activity was higher in left side than in right side in the initial movement. Right EO muscle was activated and the activity was higher than the left EO. In IO muscle left side was activated and the higher activity as compared with right side was evident in both natural and slow movements. In addition to these findings, the unique features in fast movement included initial high ES activity in both sides and the left high ES activity in the late phase of the arm elevation. In terms of the trunk kinetics, the trunk rotation to left was constantly increased without any difference among movement speeds, while thorax and pelvis rotated temporally to right as the motion speed increased, indicating possible mechanism(s) regulating the close relation of left trunk rotation to arm elevation regardless of the movement speeds.

The serratus anterior muscle activity in natural and slow movement was augmented progressively throughout the range. The serratus anterior muscle rotates the scapula upward [24] and the activity predominantly associates with rotation of scapula [19]. The present observations corresponded well to the findings that the amplitude of the serratus anterior muscles was augmented in liner form in flexion [9, 12]. On the other hand, serratus anterior muscle activity in fast movement was constant high. Kinematics are bound by Newton’s second law that the moment is proportional to angular acceleration [25]. Thus high muscular activity of serratus anterior may contribute to the high angular acceleration of the scapular upward rotation, which may assist the high angular acceleration of arm elevation even in the initial phase.

The ES muscle on both sides was significantly activated compared with that in a resting standing posture. It has been shown that trunk extension is associated with arm elevation [13, 17, 18]. Back-extension torques were created by ES activity [26]. These findings suggest that both ES activities may play an important role in the production of trunk extension during arm elevation. This may be confirmed by the present result of the high activation of the muscle on both sides in the early phase of the fast movement. Rapid movement of the upper limb produced a complex interplay of dynamic forces acting on the trunk and body [15]. As kinematics is bound by Newton’s second law in that the moment is proportional to angular acceleration [25], the ES activity may thus be required for much larger back-extension torques in the early phase of the fast elevating motion.

The relative muscle activities of the anterior potion of the trunk, namely, RA, EO, and IO, were significantly augmented in the relatively late phase of the fast elevation. This was unique to the fast movement and not observed in the natural and slow motion. The center of mass of the upper limb moves rapidly backward in more than 90 degree. It is thus suggested that the anterior muscles’ activity may contribute to production of anterior force against the backward movement of the center of mass of the upper limb.

The trunk rotation to left was constantly increased without any difference among movement speeds, implying for possible mechanism(s) regulating the close relation of left trunk rotation to arm elevation regardless of the movement speeds. In the present study with natural and slow movements, the right EO activity and the left IO activity were increased as compared with the muscle activities of their contralateral sides. Urquhart suggested that the oblique muscles were active with trunk rotation, with ipsilateral IO active and with contraleral EO active [27]. On the other hand, in both initial and late phase of the fast arm elevation, the left ES activity was significantly higher than that of the contralateral side. Lee et al suggested that the ES was active during ipsilateral rotation [28]. These findings suggest that the muscle activities of left ES, right EO, and left IO may harmonize to control trunk left rotation in arm elevation.

It is uncertain why the trunk left rotation between the pelvis and thorax was regulated rigorously constant using the left ES, right EO, and left IO muscles' activity regardless of the movement speed. The scapula begins the movement with internal rotation and then starts the movement with external rotation beyond 90 degree in arm elevation [7, 29, 30]. Careful examination has revealed that the scapula relative to the thorax is significantly more internally rotated in flexion and externally rotation in abduction as compared with scapular plane abduction [30]. Thus the scapula may move so that the scapular aligned the glenoid in the appropriate plane to maintain congruency with the humeral head and to achieve the correct placement of the elevating arm in space, namely, the scapular plane [30]. Therefore the trunk rotation may assist the scapular movement to align the scapular plane in arm elevating plane.

There are a few limitations to this study. Firstly, we recorded EMG activity and kinematics in flexion. Since scapular movement depends on the elevation plane [30], the trunk kinematics and muscle activity may also depend on the elevation plane. Thus, examination of trunk muscle activities and kinematics in other arm elevation planes will be necessary. Secondly, it is unclear whether our results from healthy young adults can be applied to patients with shoulder problems. Further study will be needed to design effective rehabilitation exercises.

5. Conclusion

The bilateral ES activity may be required for back-extension torques, especially for the early phase of the fast elevating motion. The anterior muscles' activity may contribute to production of anterior force against the backward movement of the center of mass of the upper limb in the late phase. The trunk rotation, which is controlled in harmony with each other among trunk muscles, may assist the scapular movement to align the scapular plane in arm elevating plane.

Acknowledgments

This work was supported in part by Grant-in-Aid for Scientific Research (C) 23592156 (H.W.) from Ministry of Education, Culture, Sports, Science and Technology of the Japanese Government.

Conflict of interest

The authors report no declarations of interest.

References

1. van der Heijden GJ. Shoulder disorders: a state-of-the-art-review. Baillieres Best Pract Res Clin Rheumatol. 1999 Jun; 13(2): 287-309.
2. Andersen JH, Haahr JP, Frost P. Risk factors for more severe regional musculoskeletal symptoms: a two-year prospective study of a general working population. Arthritis Rheum. 2007 Apr; 56(4): 1355-64.
3. Roy JS, Moffet H, McFadyen BJ. Upper limb motor strategies in persons with and without shoulder impingement syndrome across different speeds of movement. Clin Biomech. 2008 Dec; 23(10): 1227-36.
4. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with

symptoms of shoulder impingement. Phys Ther. 2000 Mar; 80(3): 276-91.

5. Lin JJ, Hanten WP, Olson SL, Roddey TS, Soto-quijano DA, Lim HK, Sherwood AM. Functional activity characteristics of individuals with shoulder dysfunctions. J Electromyogr Kinesiol. 2005 Dec; 15(6): 576-86.
6. Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg. 2000 Nov-Dec; 9(6): 519-23.
7. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elbow Surg. 2001 May-Jun; 10(3): 269-77.
8. Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. J Orthop Sports Phys Ther. 1999 Oct; 29(10): 574-86.
9. Inman VT, Saunders JB, Abbott LC. Observations on the function of the shoulder joint. J Bone Joint Surg. 1944 Jun; 26(1): 1-30.
10. Sharkey NA, Marder RA, Hanson PB. The entire rotator cuff contributes to elevation of the arm. J Orthop Res. 1994 Sep; 12(5): 699-708.
11. Saha AK. Dynamic stability of the glenohumeral joint. Acta Orthop Scand. 1971; 42(6): 491-505.
12. Bagg SD, Forrest WJ. Electromyographic study of the scapular rotators during arm abduction in the scapular plane. Am J Phys Med. 1986 Jun; 65(3): 111-24.
13. Crosbie J, Kilbreath SL, Hollmann L, York S. Scapulohumeral rhythm and associated spinal motion. Clin Biomech. 2008 Feb; 23(2): 184-92.
14. Hodges PW, Richardson CA. Feedforward contraction of transversus abdominis in not influenced by the direction of arm movement. Exp Brain Res. 1997 Apr; 114(2): 362-70.
15. Aruin AS, Latash ML. Directional specificity of postural muscles in feed-forward postural reactions during fast voluntary arm movements. Exp Brain Res. 1995; 103(2): 323-32.
16. Hodges PW, Cresswell AG, Daggfeldt K, Thorstensson A. Three dimensional preparatory trunk motion precedes asymmetrical upper limb movement. Gait Posture. 2000 Apr; 11(2): 92-101.
17. Theodoridis D, Ruston S. The effect of shoulder movements on thoracic spine 3D motion. Clin Biomech. 2002 Jun; 17(5): 418-21.
18. Fayad F, Hanneton S, Lefevre-Colau MM, Poiraudeau S, Revel M, Roby-Brami A. The trunk as part of the kinematic chain for arm elevation in healthy subjects and in patients with frozen shoulder. Brain Res. 2008 Jan; 29: 107-15.
19. Ng JK, Kippers V, Richardson CA. Muscle fibre orientation of abdominal muscles and suggested surface EMG electrode positions. Electromyogr Clin Neurophysiol. 1998 Jan-Feb; 38(1): 51-58.
20. van der Helm FC. A finite element musculoskeletal model of the shoulder mechanism. J Biomech. 1994 May; 27(5): 551-69.
21. Kendall FP, McCreary EK. Trunk. Muscle Testing and Function . 5th ed. Baltimore: Williams & Wilkins, 2005
22. Hodges PW, Richardson CA. Relationship between limb movement speed and associated contraction of the

trunk muscles. Ergonomics. 1997 Nov; 40(11): 1220-30.

23. Snijders CJ, Bakker MP, Vleeming A, Stoeckart R. Stam HJ. Oblique abdominal muscle activity in standing and in sitting on hard and soft seats. Clin Biomech. 1995 Mar; 10(2): 73-78.

34. Huang CK, Siu KC, Lien HY, Lee YJ, Lin YH. Scapular kinematics and muscle activities during pushing tasks. J Occup Health. 2013; 55(4): 259-66.

25. Carol AO. Kinesiology: The mechanics and pathomechanics of human movement. Philadelphia: Lippincott Williams & Wilkins, 2004

26. Daggfeldt K, Thorstensson A. The mechanics of back-extensor torque production about the lumbar spine. J Biomech. 2003 Jun; 36(6): 815-25.

27. Urquhart DM, Hodges PW. Differential activity of regions of transversus abdominis during trunk rotaion. Eur Spine J. 2005 May; 14(4): 393-400.

28. Lee LJ, Coppieters MW, Hodges PW. Differential activation of the thoracic multifidus and longissimus thoracis during trunk rotation. Spine. 2005 Apr; 30(8): 870-6.

29. Fayad F, Hoffmann G, Hanneton S, Yazbeck C, Lefevre-Colau MM, Poiraudeau S, Revel M, Roby-Brami A. 3-D scapular kinematics during arm elevation: effect of motion velocity. Clin Biomech. 2006 Nov; 21(9): 932-41.

30. Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RE. Motion of the shoulder complex during multiplanar humeral elevation. J Bone Joint Surg Am. 2009 Feb; 91(2): 378-89.

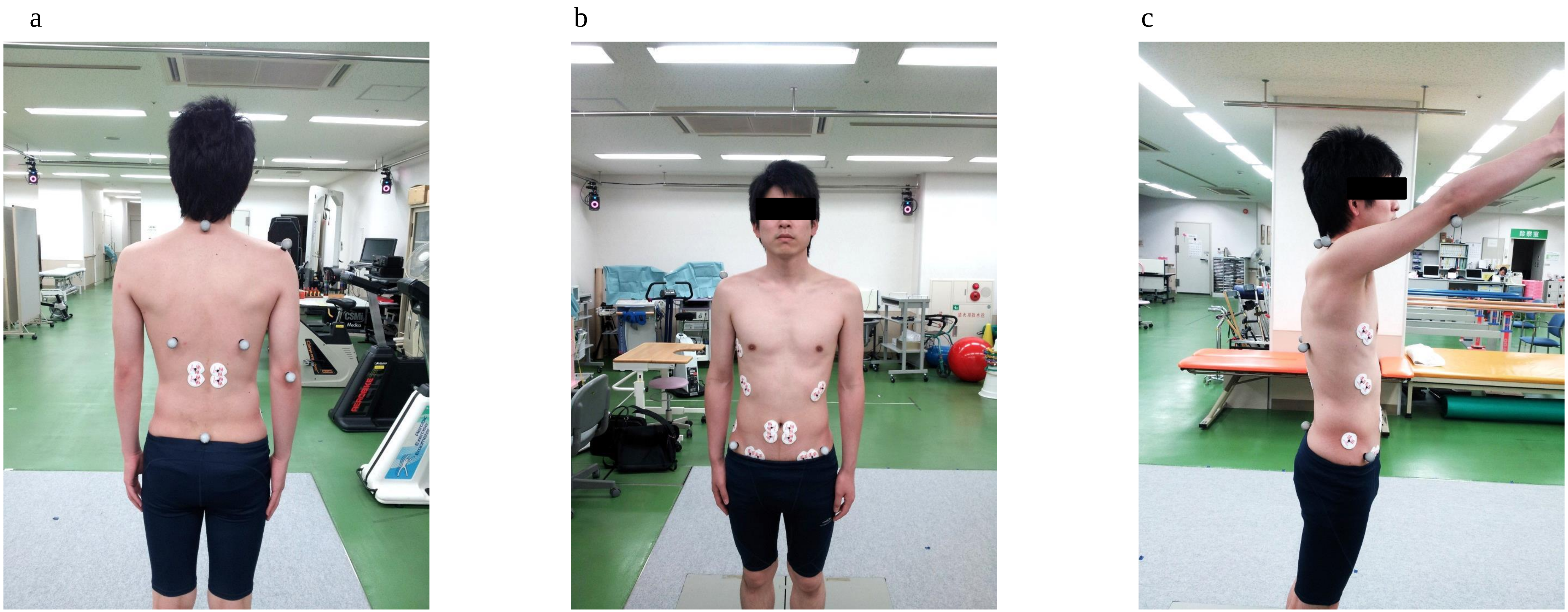

Fig. 1 Model of upper limb used to evaluate muscle activity and movement of trunk. Location of the infra-red markers used for analysis of shoulder motion and trunk motion.

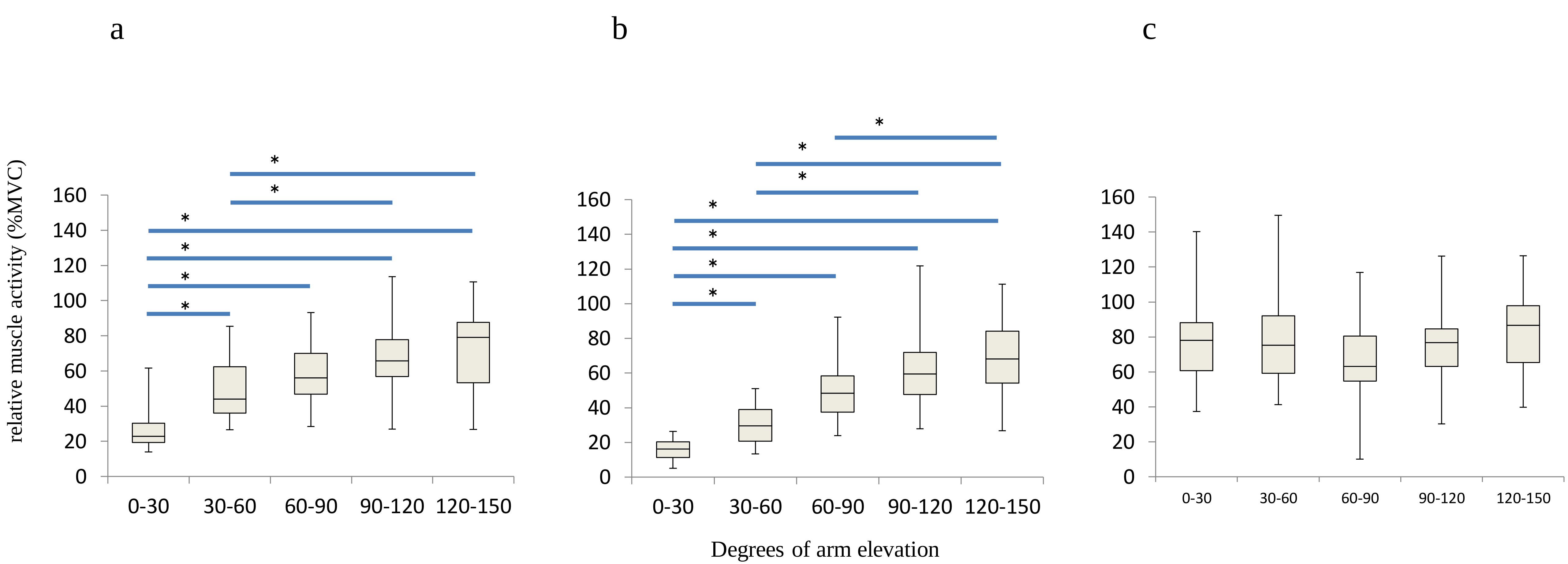

Fig. 2 Box plots representing median, 25th and 75th percentiles, and range of serratus anterior muscle activity for (a) natural, (b) slow, (c) fast for arm elevation. Asterisk indicates a significant difference between angles.

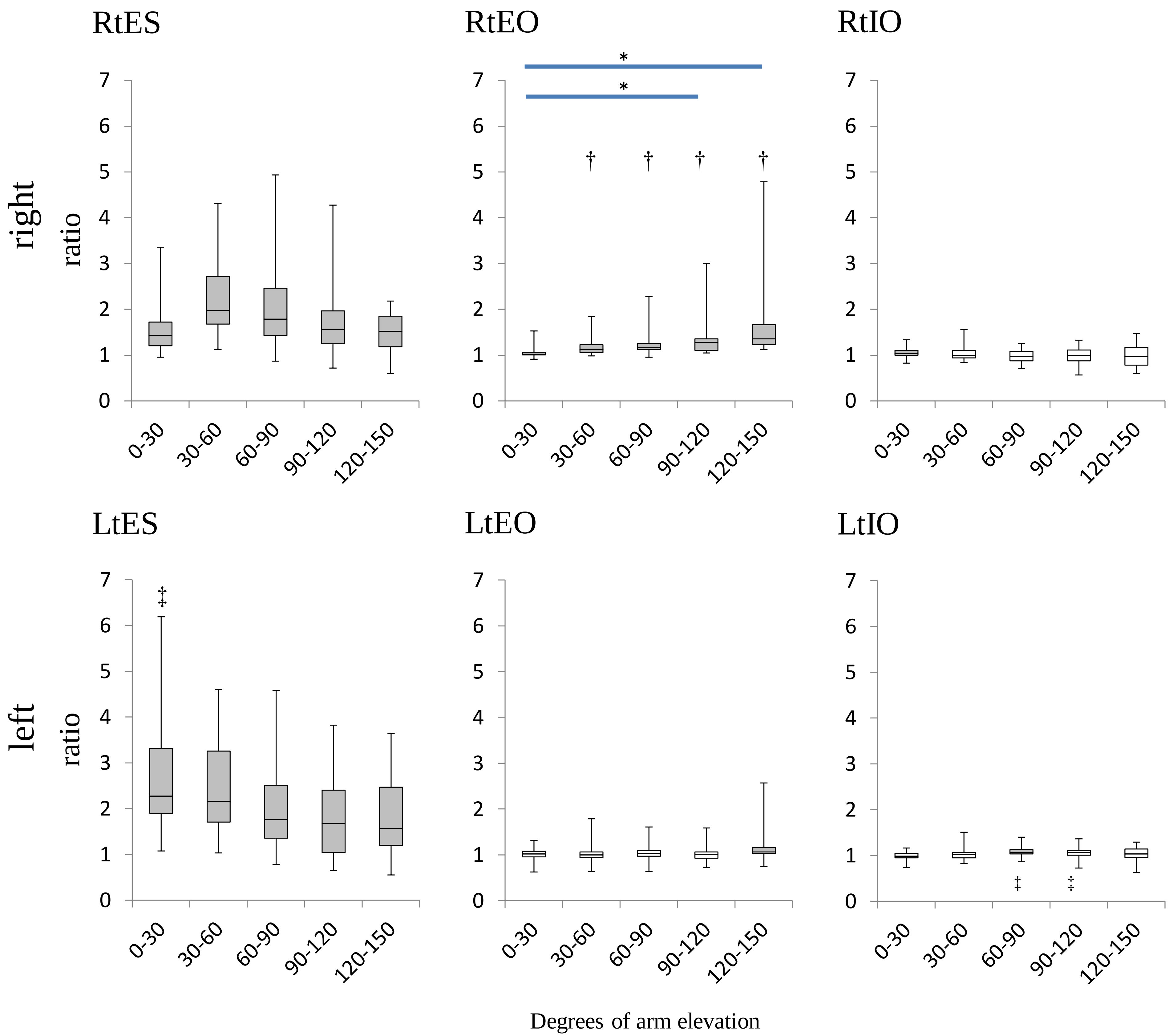

Fig. 3 In natural movement box plots representing median, 25th and 75th percentiles, and range of ratios for (a, e) ES, (b, f) EO, (c, g) IO and (d, h) RA for arm elevation. Filled shapes indicate EMG significantly higher than resting standing posture. Asterisk indicates a significant difference between angles. Dagger indicates a significant increase from the left muscle activity. Double dagger indicates a significant increase from the right muscle activity.

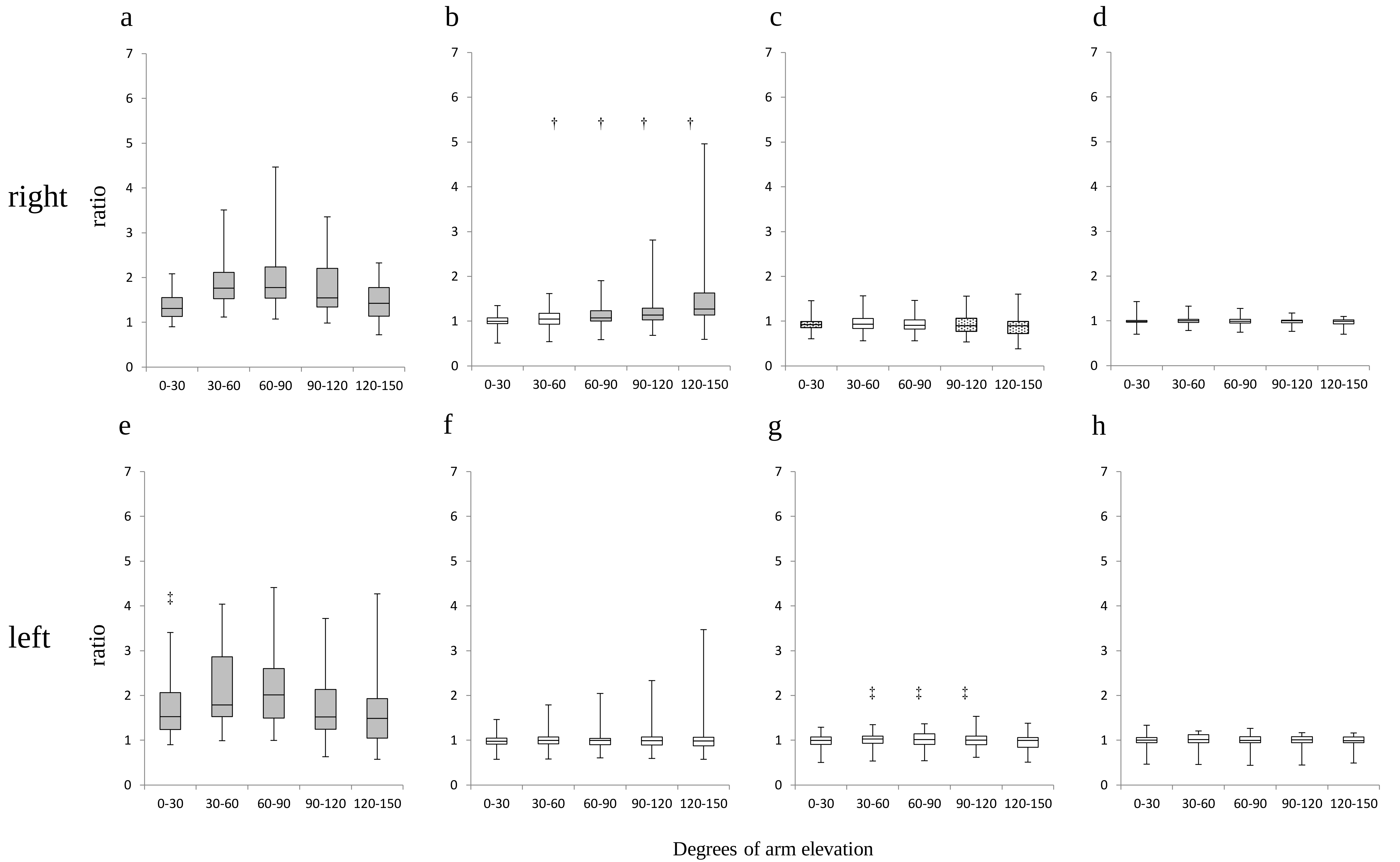

Fig. 4 In slow movement box plots representing median, 25th and 75th percentiles, and range of ratios for (a, e) ES, (b, f) EO, (c, g) IO and (d, h) RA for arm elevation. Filled shapes indicate EMG significantly higher than resting standing posture. Dots shapes indicate EMG significantly lower than resting standing posture. Asterisk indicates a significant difference between angles. Dagger indicates a significant increase from the left muscle activity. Double dagger indicates a significant increase from the right muscle activity.

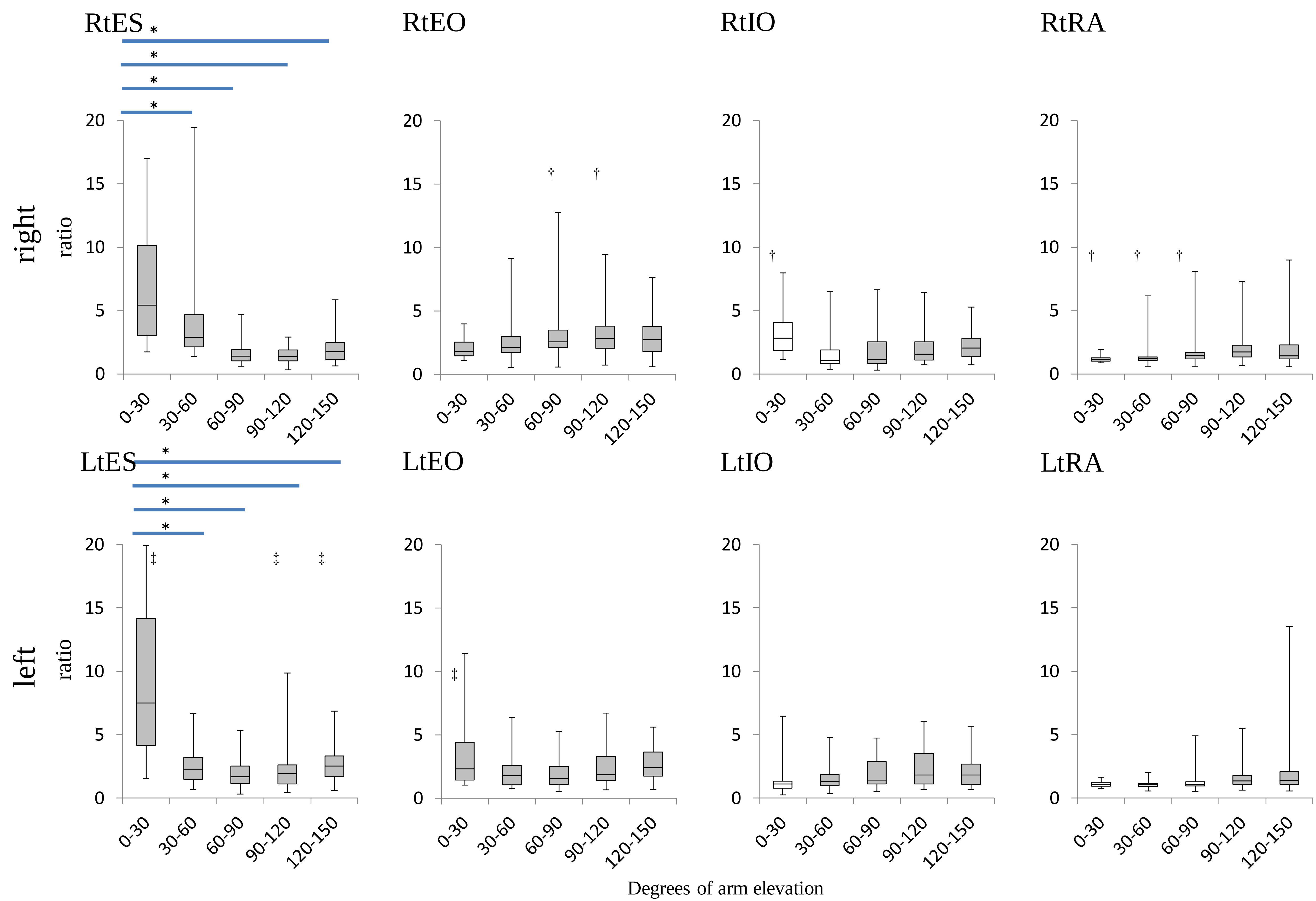

Fig. 5 In fast movement box plots representing median, 25th and 75th percentiles, and range of ratios for (a, e) ES, (b, f) EO, (c, g) IO and (d, h) RA for arm elevation. Filled shapes indicate EMG significantly higher than resting standing posture. Asterisk indicates a significant difference between angles. Dagger indicates a significant increase from the left muscle activity. Double dagger indicates a significant increase from the right muscle activity.

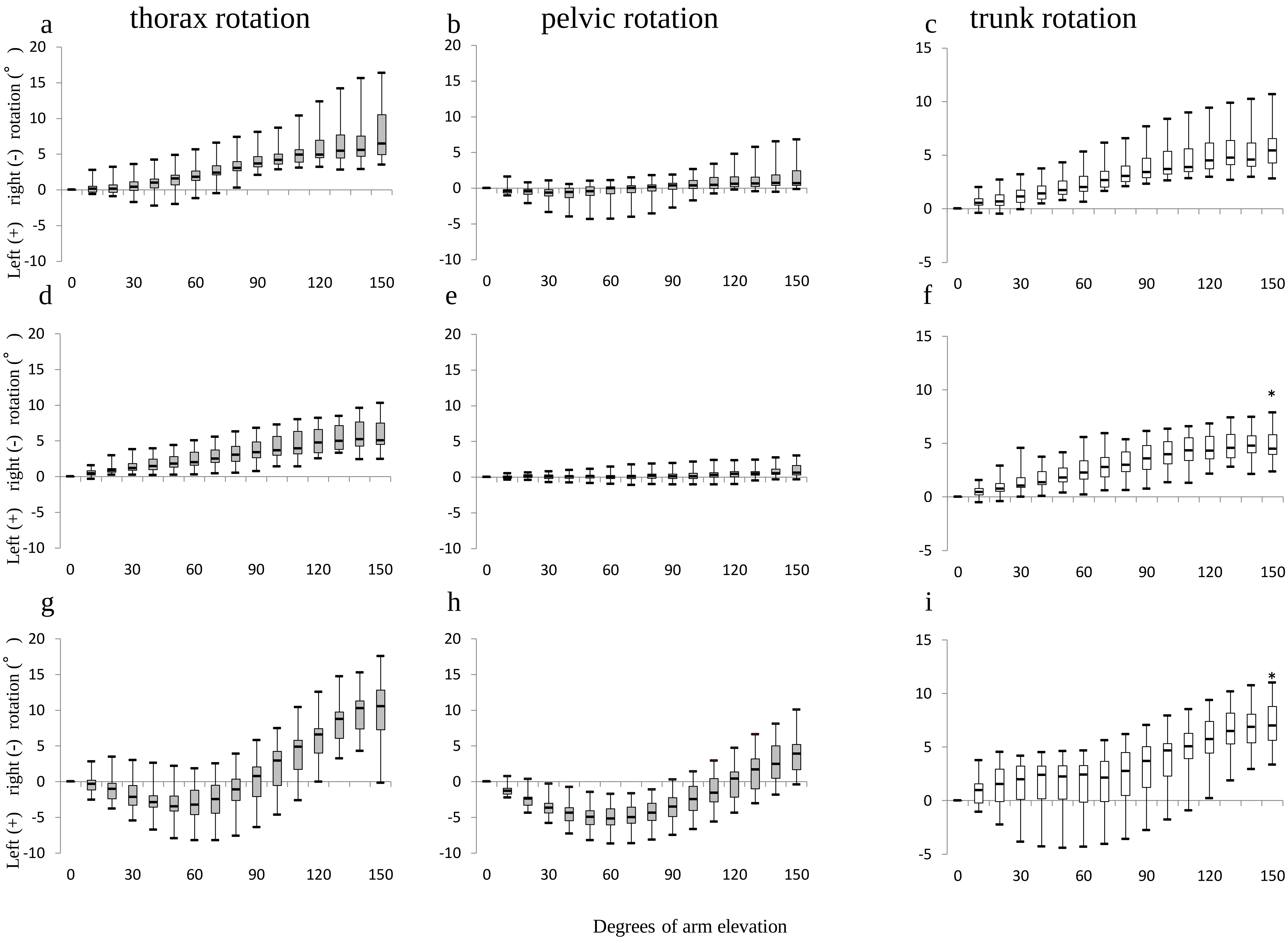

Fig. 6 Box plots representing median, 25th and 75th percentiles, and range of thorax, pelvic and trunk rotation for (a-c) natural, (d-f) slow and (g-i) fast movement. Asterisk indicates a significant difference between fast movement and slow movement.