Stepwise increase of upper limb muscle activity induced by progressive 4 positions of a handstand training

Kinoshita, Kazuaki ; Hoshino, Yuichi ; Yokota, Naoko ; Hashimoto, Masashi ; Nishizawa, Yuichiro ; Kida, Noriyuki

(Citation)
Isokinetics and Exercise Science,30(2):127-133

(Issue Date)
2022-04-11

(Resource Type)
journal article

(Version)
Accepted Manuscript

Stepwise increase of upper limb muscle activity induced by progressive 4 positions of a handstand training

Kazuaki Kinoshita, RPT[1], Yuichi Hoshino, MD, PhD[2]*, Naoko Yokota, RPT[3], Masashi Hashimoto, RPT, PhD[4], Yuichiro Nishizawa, MD, PhD[5], Noriyuki Kida, PhD[6]

Affiliation:

1. Department of Physical Therapy, Faculty of Rehabilitation, Shijonawate Gakuen University
2. Department of Orthopaedic Surgery, Kobe University, Graduate School of Medicine
3. Sports Medicine Center, National Hospital Organization Kyoto Medical Center
4. Faculty of Rehabilitation Naragakuen University
5. Department of Orthopaedic Surgery, Kobe Kaisei Hospital
6. Graduate School of Science and Technology, Kyoto Institute of Technology

* Full address of corresponding author:

Yuichi Hoshino, MD, PhD

Department of Orthopaedic Surgery, Graduate School of Medicine, Kobe University

7-5-1 Kusunoki-cho, Chuo-ku, Kobe, Hyogo 650-0017, Japan

E-mail address: you.1.hoshino@gmail.com

Phone: +81-78-382-5985, Fax: +81-78-351-6944

Paper submitted: June 9, 2021   paper accepted: July 29, 2021

Abstract

BACKGROUND: Handstand is the most important fundamental skill in gymnastics. A gradual and well-balanced increase in muscle loading in a manner is preferred for young beginners and/or recovering gymnasts to safely achieve the muscle strength required to perform a stable handstand.

OBJECTIVE: To examine upper limb muscle activity during different levels of handstand training positions.

METHODS: This study utilized four different positions for progressive handstand training; namely, the 90, 135, elbow stand, and handstand positions. The activities of eight upper limb muscles (upper, middle, and lower trapezius; serratus anterior; anterior and middle deltoid; infraspinatus; and latissimus dorsi were measured by surface electromyography (EMG) for each position. The percentages of EMG in each muscle compared to the values during maximum voluntary contraction were calculated and compared between the positions.

RESULTS: Muscle activity around the shoulder increased gradually throughout the progression of the four handstand training positions. Furthermore, the muscles required for scapular stabilization, such as the upper and middle trapezius and serratus anterior muscles, were activated at levels similar to those for a handstand without performing this movement.

CONCLUSIONS: A progressive handstand training program of four different positions resulted in gradual and well-balanced increases in muscle activity.

Keywords; Handstand, Gymnastics, Muscle activity, Shoulder

2.1. Introduction

The upper extremities withstand considerable forces and moments during gymnasts' performances. [1] For example, the load on their wrists is up to 16 times their body weight. [2] Consequently, more than 80% of gymnasts experience wrist and/or elbow pain in a season, although they do not always leave out practices or competitions because of pain. [2-5] Reckless consideration for pain could increase the risk of injury. Young gymnasts are especially likely to experience unique injuries caused by repetitive stress. [6-8] For example, osteochondritis dissecans (OCD) of the capitellum is one of the most common injuries in gymnasts between 10 and 14 years of age. [9] Therefore, upper limb strength should be sufficiently achieved to ensure the safe performance of gymnastic movements. Just as the muscle strength of the hip joint affects knee and ankle joint kinematics and loading, [10-14] the muscles of the shoulder joint play a key role in supporting the elbow and wrist joints during handstands.

Handstands are the most important fundamental skill for gymnastics. Furthermore, a stable and straight posture during a handstand is particularly important in competition. During a handstand, balance control is achieved mainly using the wrist and shoulder techniques. [15] Although the wrist is mainly used to stabilize a handstand position on the floor, a more difficult task, such as a handstand on still rings, requires even greater activity of the muscles controlling the shoulder joint. [16]

Adult gymnasts demonstrate a more stable handstand than younger gymnasts. [17] Adult gymnasts predominantly use their wrist flexors and anterior deltoid muscles to stabilize their bodies, whereas their young counterparts rely more on wrist and shoulder muscles, which requires complementary activation of the lower body muscles. [17]

Therefore, proper muscle strength around the shoulder joint and scapula is required to ensure handstand stability. A gradual and well-balanced increase in muscle loading is preferable for young beginners and/or recovering gymnasts to safely achieve the muscle strength required to perform a stable handstand. Uzunov introduced four progressive stages of handstand training [18], which are widely known in gymnastics worldwide. Although it is generally believed that appropriate muscle stimulation is achieved in this progressive handstand training, the actual muscle activity has not been scientifically investigated.

Thus, this study examined shoulder and scapular muscle activity during different levels of handstand training to test the hypothesis that these different levels result in significant increases in muscle activities.

2.2. Methods

Subjects

This study included 13 healthy male volunteers (age: 20.5±0.6 years, height: 170.7±7.9 cm, weight: 61.7±7.7 kg, body mass index [BMI]: 21.2±2.3 kg/m^2) who were not registered gymnasts but who were able to perform a stable handstand. All participants understood the purpose of this study and provided informed consent before their participation according to the ethical standards of the Declaration of Helsinki. The study was approved by the Shijonawate Gakuen University Ethics Committee (No. 29-5).

Design and Protocol

This study utilized the four different postures used as progressive handstand training: 1) The 90 position in which the shoulders were flexed at 90° with a straight trunk, legs parallel to the ground, and the body supported by the hands on the floor and toes on an adjustable-level bench. 2) The 135 position, in which the shoulders were flexed at 135° with a straight trunk and legs and the body supported by hands on the floor and toes on the wall. 3) The elbow stand, in which the shoulders were flexed at 180° with the elbows bent to place the forearms on the floor. Both hands were put together to form a triangle with both the elbows and hands. The body was supported by the forearms only, with visual confirmation that the head did not touch the floor. When the subject lost balance, an assistant supported his foot to restore his balance for safety. 4) The handstand, which was defined as a fully straight handstand along the wall. (Fig. 1). The subjects were instructed not to lean on the wall but were allowed to use it to re-establish their balance. An examiner confirmed that their posture was straight with reference to the adjacent wall. The subjects were instructed to maintain their postures for 5 s with a straight body for testing and placed their hands on two weight scales to confirm equal loading on both hands in all testing scenarios. The activities of eight upper limb muscles (upper, middle, and lower trapezius [UT, MT, LT], serratus anterior [SA], anterior and middle deltoid [AD, MD], infraspinatus [IS], and latissimus dorsi [LD]) were evaluated during the testing postures using surface electromyography (EMG)_and waveform analysis software (Myo Research XP, Noraxon). Measurements were performed on only one side of the upper limb. The measurements were repeated three times and the average values were used for analysis. The test was repeated when a subject failed to maintain the position for 5 s or when unbalanced loading on both hands was detected by the weight scales.

EMG recording

The muscle action potentials on the surface electrodes were measured using a Myosystem 1200 (Noraxon, Arizona, USA). The surface EMGs were set to a sampling frequency of 1000 Hz (Blue Sensor P, P-00-S, Ambu, Ballerup, Denmark). The surface EMG electrodes were applied after wiping the skin with an alcohol cotton, with a distance between the electrodes of 2.5 cm. The placement of the electrodes was determined according to previous studies [19-22] as follows: UT, at 50% of the line from the acromion to the spine on vertebra C7; MT, at 50% between the medial border of the scapula and the spine, at the level of T3; LT, at 2/3 on the line from the trigonum spinae to the 8th thoracic vertebra; SA, at the muscle belly of the 6th rib; AD, at one finger width distal and anterior to the acromion; MD, from the acromion to the lateral epicondyle of the elbow corresponding to the greatest bulge of the muscle; IS, parallel to and approximately 4 cm below the spine of the scapula on the lateral aspect over the infrascapular fossa; and LD, 4 cm below the inferior tip of the scapula. The amplitudes of the EMG signals were obtained by deriving the root-mean-square of the signal over a 50-millisecond moving window, resulting in a full-wave rectification and smoothing of the raw signal. For statistical comparisons, the normalized and stable waveforms of the central 3 s were selected and the averaged amplitudes were calculated. The measured values were expressed as percentages of the values at the maximum voluntary contraction (MVC) for standardization (%MVC). The MVC was recorded for each muscle. Each contraction was held for 5 s, with maximal effort against manual resistance. The first and last seconds of the EMG data from each MVC trial were discarded; the remaining 3 s of data were used for analysis. The same investigator was responsible for all MVC measurements to ensure test consistency. The MVC evaluations were conducted as previously described, [23, 24] with reported high intraclass correlation coefficients of 0.86–0.99. [25]

Four types of UT, MT, LT, and SA MVC measurements were performed: the participants were seated with their arms fully extended (1), with 135° of forward flexion, (2) with 90° of shoulder abduction or participants prone with their arms fully extended, (3) with external rotation (thumb up) and with 90° of horizontal abduction, or (4) with 14° of abduction. For each scapular muscle, the highest activity level generated across the standard set of four positions was used for normalization. [26]

Muscle activity evaluations for the AD and MD were performed as recommended by Daniels et al for the Manual Muscle Test (MMT); namely, a neutral arm rotation and no movement. The AD was evaluated in the sitting position with the shoulder at 90°of flexion and the MD with the shoulder at 90°of abduction. [23]

IS activity was tested in the sitting position with the shoulder at 0° of abduction, neutral rotation, and the elbow flexed to 90°. Resistance was applied just above the wrist to create internal shoulder rotation. [27] For the LD, the subjects performed a shoulder extension in the prone position. Resistance was applied to the wrist up to shoulder flexion. [28]

The %MVCs were then evaluated during the four testing positions in random order. The measurements were made with >1-min resting intervals and care was taken to perform testing without subjects' subjective feelings of fatigue.

Data processing

Because the data were not normally distributed, non-parametric analyses were used. Sample size calculations were performed before the study using G*power 3.1.9 (Heine University, Dusseldorf, Germany). We included 13 men after we calculated the sample size using the software, with an α level of 0.05, power analysis of 0.80, and an estimated effect size of 0.25, which resulted in a total sample size of 12. Statistical analysis was performed using IBM SPSS Statistics for Windows, version 20.0 (IBM Corp., NY, USA). Statistical significance was set at $p<0.05$. The %MVCs for each muscle were compared between the four testing positions using Friedman’s test with Bonferroni’s post-hoc analysis to test the mean muscle activations across and between conditions, respectively.

2.3. Results

The results are outlined in Table 1. Muscle activity in the scapular muscles UT, MT, LT, SA, and LD significantly increased from the 90 to the 135° positions (MT, LT, and LD: $p<0.05$, UT and SA: $p<0.01$), while the AD, MD, and IS of the glenohumeral muscle did not show significant changes. Elbow stand showed significantly increased UT and MT activities compared to the 135° position ($p<0.05$, and $p<0.01$, respectively). Significantly increased LT and IS activities were observed during handstand compared to elbow stand (both $p<0.05$), while a significant increase in LT and LD was observed compared to the 90° position. (Fig. 2) Thus, the 90 to 135° positions increased the activation of muscles attached to the scapula, while the 135° to handstand positions increased the activation of muscles of the scapula-brachial joint compared to the circumference of the scapula. In addition, the 135° to the elbow stand positions increased the UT and MT required to raise the scapula, while elbow stand to handstand positions increased the LT and IS activation.

2.4. Discussion

The most striking finding of this study was that the muscle activity around the shoulder joint increased gradually with the progression of the four steps of the handstand positions. In addition, different activation patterns were observed among the muscles; that is, the scapular muscles were the first to be activated, followed by the glenohumeral joint muscles. The muscles required for scapular stabilization, such as the trapezius and serratus anterior muscles, were sufficiently stimulated for a handstand without actually performing this movement. Such a muscle activation pattern, from proximal to distal, might be preferable for achieving a stable posture. A well-controlled loading on the shoulder muscles is preferable for young beginner and/or recovering gymnasts to safely achieve the muscle strength required to perform a stable handstand.

Previous studies have measured shoulder muscle activity. Researchers have noted that scapular muscle activity occurs before upper extremity movement to stabilize and position the scapula for glenohumeral elevation. [29,30] Ekstrom et al. [31] and Hardwick et al. [32] reported that the higher the humerus, the higher was the SA activity. [31,32] The co-contraction of scapula muscles, such as UT and SA for elevation and upward rotation and the MT and LT for depression and downward rotation, stabilize the scapula for stable glenohumeral movements. High levels of coordination between these functional muscle groups are required during the initial phase of shoulder elevation. [33] Ekstrom et al [31] demonstrated that the position in which the participants elevated the humerus above the head in line with the LT muscle fibers activated the LT to 97% of the MVC. [31] Overhead upper limb activities induce scapular muscle activation to hold the scapula in an elevated and upwardly rotated position, as observed in gymnasts' handstand position. Therefore, the scapular muscle shows increased activity with gradually increasing elevation angle. However, the activity increased only in the UT and MT from the 135° position to the elbow stand. The UT elevates the scapula and the MT moves the scapula during adduction. Uzunov [18] reported that the handstand in gymnastics is pushed through the shoulders, so there are no gaps between the arms, shoulders, and ears. [18] In other words, the UT and MT activities are increased in the elbow stand because the scapula requires further elevation and adduction compared to the 135° position.

The LT and IS showed significantly increased activities from the elbow stand to the handstand. As the LT activity did not increase from the 135° to the handstand position, the instability increases in the handstand position because the center of gravity is higher compared to that in the 135° position. Thus, the scapula and glenohumeral joint must be more stable. Therefore, only the LT for scapular stability and IS for the inner muscle showed high activities. The 135° position did not show significantly increased glenohumeral muscle activity compared to the 90° position, whereas the elbow stand and handstand showed increased muscle activity. The intraarticular pressure of the glenohumeral joint gradually increased from 0 to 120°; when it approached the maximum elevation, the pressure rapidly increased and became positive. The intraarticular pressures of the glenohumeral joint were stable under negative pressure but lost joint stability due to positive pressure. [34-36] Therefore, the increased glenohumeral muscle activity might not stem solely from the higher loading of the upper limb but also from the need to stabilize the glenohumeral joint at a higher flexion angle.

The results of this study suggest two clinical benefits of introducing a stepwise four-position program for a handstand. First, this stepwise program results in gradually increased muscle activity. The scapular stabilizers were stimulated first, followed by the glenohumeral stabilizers. The influence of an unstable scapula on the pathology and dysfunction of the shoulder is well known. The scapula must itself be stable enough to provide a stable base for the glenohumeral joint. [37] Impaired scapular stability increases the risk of pathologies such as impingement or rotator cuff tears. [38] This progressive approach might be beneficial for achieving safe and stable handstands, especially for young gymnasts and/or beginners. In addition, each step of the program can be used to assess the strengths of different stabilizers. Second, this program can be applied for injury prevention and rehabilitation of the upper limbs by practicing handstands in stages. Guadagnoli et al. [39] suggested that the training menu should be adjusted to the skill level of each performer. [39] This stepwise program could help gymnasts safely acquire and achieve a perfectly straight handstand. This program can be used by beginners to achieve a handstand and by injured gymnasts to safely and stably resume performing handstands.

This study has several limitations. First, the participants were limited in number and only male. Females or beginners may show different physical muscle activation for handstand performance. However, the results of this study demonstrated a typical pattern of muscle activity in subjects able to perform a stable handstand, which may be useful in considering other types of physical strategies for a handstand. Second, the proper performance of each posture was determined by visual observation and the angle of the shoulder might have varied between subjects despite the possible effect on muscle activities. However, the difference in shoulder angles in the program was 45°, which is a potential error in observational judgment. Consequently, the effects of different postures on muscle activity were observed. Third, the subjects were not experienced gymnasts. Experienced gymnasts may show different muscle activation during handstand.

2.5. Conclusion

A progressive handstand training program utilizing four different postures showed a gradual increase in muscle activity. The scapular muscles were the first to be activated, followed by the glenohumeral muscles with training progression.

3. *Acknowledgements.*— The authors would like to thank all the volunteers that participated in this investigation.

4. *Authors' contributions.*— K. Kinoshita, Y. Hoshino and M. Hashimoto contributed substantially to CONCEPTION, PERFORMANCE OF WORK and PREPARATION OF THE MANUSCRIPT. N. Yokota, Y. Nishizawa and N. Kida contributed substantially to PERFORMANCE OF WORK and INTERPRETATION OR ANALYSIS OF DATA. All authors have participated in the REVISION FOR IMPORTANT INTELLECTUAL CONTENT. K. Kinoshita and Y. Hoshino revised it critically and provided SUPERVISION with this study. All authors read and approved the final version of the manuscript.

5. *Ethical Considerations.* — All the participants understood the purpose of this study and provided informed consent prior to participation according to the ethical standards of the Declaration of Helsinki, and this research was conducted with the approval of Shijonawate Gakuen University Ethics Committee (No. 29-5).

6. *Conflicts of interest.* — The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

7. *Funding.*— The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.

8. References

[1] Hart E, Meehan WP 3rd, Bae DS, d'Hemecourt P, Stracciolini A. The Young Injured Gymnast: A Literature Review and Discussion. Curr Sports Med Rep 2018;17(11):366-75.

[2] DiFiori JP, Caine DJ, Malina RM. Wrist pain, distal radial physeal injury, and ulnar variance in the young gymnast. Am J Sports Med 2006;34(5):840-9.

[3] Caine D, Roy S, Singer KM, Broekhoff J. Stress changes of the distal radial growth plate. A radiographic survey and review of the literature. Am J Sports Med 1992;20:290-8.

[4] DiFiori JP, Puffer JC, Aish B, Dorey F. Wrist pain in young gymnasts: frequency and effects upon training over 1 year. Clin J Sport Med 2002;12:348-53.

[5] Mandelbaum BR, Bartolozzi AR, Davis CA, Teurlings L, Bragonier B. Wrist pain syndrome in the gymnast. Pathogenetic, diagnostic, and therapeutic considerations. Am J Sports Med 1989;17:305-17.

[6] Overlin AJ, Chima B, Erickson S. (2011) Update on artistic gymnastics. Curr Sports Med Rep 2011;10(5):304-9.

[7] Saluan P, Styron J, Ackley JF, Prinzbach A, Billow D. Injury types and incidence rates in precollegiate female gymnasts: a 21-year experience at a single training facility. Orthop J Sports Med 2015;3(4): 2325967115577596.

[8] Westermann RW, Giblin M, Vaske A, Grosso K, Wolf BR. Evaluation of men's and women's gymnastics injuries: a 10-year observational study. Sports Health 2015;7(2):161-5.

[9] Dexel J, Marschner K, Beck H, Platzek I, Wasnik S, Schuler M, et al. Comparative study of elbow disorders in young high-performance gymnasts. Int J Sports Med 2014;35:960-5.

[10] Lawrence RK 3rd, Kernozek TW, Miller EJ, Torry MR, Reuteman P. Influences of hip external rotation strength on knee mechanics during single leg drop landings in females. Clin Biomech (Bristol, Avon) 2008;23(6):806–13.

[11] Jacobs CA, Mattacola CG. Sex differences in eccentric hip-abductor strength and knee-joint kinematics when landing from a jump. J Sport Rehabil 2005;14(4):346–55.

[12] Chaudhari AM, Andriacchi TP. The mechanical consequences of dynamic frontal plane limb alignment for non-contact ACL injury. J Biomech 2006;39(2):330–8.

[13] Lee SP, Powers C. Fatigue of the hip abductors results in increased medial–lateral center of pressure excursion and altered peroneus longus activation during a unipedal landing task. Clinical Biomechanics 2013;28:524-9.

[14] Gafner SC, Hoevel V, Punt IM, Schmid S, Armand S, Allet L. Hip-abductor fatigue influences sagittal plane ankle kinematics and shank muscle activity during a single-leg forward jump. J Electromyogr Kinesiol 2018;43:75-81.

[15] Kerwin DG, Trewartha G. Strategies for maintaining a handstand in the anterior-posterior direction. Med Sci Sports Exerc 2001;33:1182–8.

[16] Yeadon MR, Trewartha G. Control strategy for a hand balance. Motor Control 2003;7:411-30.

[17] Kochanowicz A, Niespodziński B, Marina M, Mieszkowski J, Biskup L, Kochanowicz K. Relationship between postural control and muscle activity during a handstand in young and adult gymnasts. Hum Mov Sci 2018;58:195-204.

[18] Uzunov V. The handstand: A four stage training model. Gym Coach 2008;2:52-9.

[19] Beaudette SM, Unni R, Brown SH. Electromyographic assessment of isometric and dynamic activation characteristics of the latissimus dorsi muscle. J Electromyogr Kinesiol 2014;24:430–6

[20] Cools AM, Witvrouw EE, De Clercq GA, Danneels LA, Willems TM, Cambier DC, et al. Scapular muscle recruitment pattern: electromyographic response of the trapezius muscle to sudden shoulder movement before and after a fatiguing exercise. J Orthop Sports Phys Ther 2002;32:221–9.

[21] Criswell E. Cram's introduction to surface electromyography. 2nd. Massachusetts: Jones and Bartlet Publishers: 2011, p.302–6.

[22] Park SY, Yoo WG. Differential activation of parts of the latissimus dorsi with various isometric shoulder exercises. J Electromyogr Kinesiol 2014;24(2):253-7.

[23] Castillo-Lozano R, Cuesta-Vargas AI. A comparison land-water environment of maximal voluntary isometric contraction during manual muscle testing through surface electromyography. BMC Sports Science, Medicine and Rehabilitation 2013;5:28

[24] Perotto AO. Anatomical Guide for the Electromyographer: The Limbs andTrunk. Springfield: Charlei C Thomas; 1994

[25] J Visser, E Mans, M de Visser, R M van den Berg-Vos, H Franssen, J M B V de Jong, L H van den Berg, J H J Wokke, R J de Haan. Comparison of maximal

voluntary isometric contraction and hand-held dynamometry in measuring muscle strength of patients with progressive lower motor neuron syndrome. Neuromuscul Disord. 2003 Nov;13(9):744-50.

[26] Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools A. Optimal normalization tests for muscle activation of the levator scapulae, pectoralis minor, and rhomboid major: an electromyography study using maximum voluntary isometric contractions. Arch Phys Med Rehabil 2015;96(10):1820-7.

[27] Magee DJ. Orthopedic physical assessment. 5th ed. Philadelphia: W.B. Saunders; 2007

[28] Takaki S, Kaneoka K, Okubo Y, Otsuka S, Tatsumura M, Shiina I, et al. Analysis of muscle activity during active pelvic tilting in sagittal plane. Phys Ther Res 2016;19(1):50-7.

[29] Mendez-Rebolledo G, Gatica-Rojas V, Martinez-Valdes E, Xie HB. (2016) The recruitment order of scapular muscles depends on the characteristics of the postural task. J Electromyogr Kinesiol 2016;31:40-7.

[30] Reed D, Cathers I, Halaki M, Ginn K. Does supraspinatus initiate shoulder abduction? J Electromyogr Kinesiol 2013;23(2):425-9.

[31] Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. J Orthop Sports Phys Ther 2003;33(5):247–58.

[32] Hardwick DH, Beebe JA, McDonnell MK, Lang CE. A comparison of serratus anterior muscle activation during a wall slide exercise and other traditional exercises. J Orthop Sports Phys Ther 2006;36(12):903–10.

[33] Hawkes DH, Khaiyat OA, Howard AJ, Kemp GJ, Frostick SP. Patterns of muscle coordination during dynamic glenohumeral joint elevation: An EMG study. PLoS One 2019;14(2):e0211800.

[34] Hurschler C, Wulker N, Mendila M. The effect of negative intra articular pressure and rotator cuff force on glenohumeral translation during simulated active elevation. Clin Biomech (Bristol, Avon) 2000;15(5):306-14.

[35] Inokuchi W, Olsen BS, Sojbjerg JO, Sneppen O. The relation between the position of the glenohumeral joint and the intraarticular pressure: an experimental study. J Shoulder Elbow Surg 1997;6(2):144-9.

[36] Lind T, Blyme PJ, Stran-Vognsen HH, Bagger J. Pressure-position relations in the glenohumeral joint. Acta Orthop Belg 1992;58 (1):813-8.

[37] Hariharasudhan Ravichandran, Balamurugan Janakiraman, Asmare Yitayeh Gelaw, Berihu Fisseha, Subramanian Sundaram, Hidangmayum Richa Sharma. Effect of scapular stabilization exercise program in patients with subacromial impingement syndrome: a systematic review. J Exerc Rehabil 2020; 16(3):216-226.

[38] McQuade KJ, Borstad J, de Oliveira AS. Critical and theoretical perspective on scapular stabilization: what does it really mean, and are we on the right track?. Phys Ther 2016; 96: 1162-1169.

[39] Guadagnoli MA, Lee TD. Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. J Mot Behav 2004;36(2):212-24.

8. **Tables**

Table I.— Muscle activity (%MVC) of each muscle in the four postures of progressive handstand training.
*: $p<0.05$ compared to 90 position. **: $p<0.01$ compared to 90 position.
+: $p<0.05$ compared to 135 position. ++: $p<0.01$ compared to 135 position.
‡: $p<0.05$ compared to elbowstand.

	90 position	135 position	Elbowstand	Handstand	Effect size ($\eta 2$)
Upper Trapezius (UT)	3.4 ± 1.9	28.3 ± 18.7**	44.6 ± 32.5**+	45.6 ± 29.5**++	0.34
Middle Trapezius (MT)	3.0 ± 2.3	25.0 ± 20.7*	52.8 ± 32.8**++	53.2 ± 27.7**++	0.44
Lower Trapezius (LT)	3.1 ± 1.9	17.5 ± 16.0*	13.8 ± 15.3	27.2 ± 21.5* ‡	0.24
Serratus Anterior (SA)	51.9 ± 19.6	104.3 ± 41.6**	107.3 ± 42.3**	127.2 ± 39.9**+	0.36
Anterior Deltoid (AD)	30.4 ± 15.8	50.2 ± 30.7	54.2 ± 38.9	72.5 ± 38.0**+	0.18
Middle Deltoid (MD)	35.3 ± 16.6	47.6 ± 20.8	57.7 ± 18.9*	65.3 ± 22.3**++	0.25
Infraspinatus (IS)	11.9 ± 4.6	22.2 ± 15.0	23.2 ± 19.7	32.9 ± 21.8*+‡	0.17
Latissimus dorsi (LD)	6.1 ± 5.7	9.1 ± 7.1*	9.1 ± 6.1	17.9 ± 16.4*+‡	0.17

9. Figure captions

Fig. 1. Four postures of progressive handstand training. a) The 90 position, in which the shoulders are flexed at 90 degrees with a straight trunk and legs parallel to the ground, with the body supported by hands on the floor and toes on an adjustable level bench. b) The 135 position, in which the shoulders are flexed at 135 degrees with a straight trunk and legs and the body supported by hands on the floor and toes on the wall. c) An elbow stand, in which the shoulders are flexed at 180 degrees with elbows bent to place the forearms on the floor. Both hands are put together to form a triangle with both elbows and hands. The body is supported by the forearms and the head, with the foot held by a supporter. d) Handstand. A full straight handstand against the wall.

Fig. 2. Changes of muscle activity in each posture. UT: upper trapezius, MT: middle trapezius, LT: lower trapezius, SA: serratus anterior, AD: anterior deltoid, MD: middle deltoid, IS: infraspinatus, LD: latissimus dorsi. *: $p<0.05$, **: $p<0.01$

10. Figures

Fig. 1a

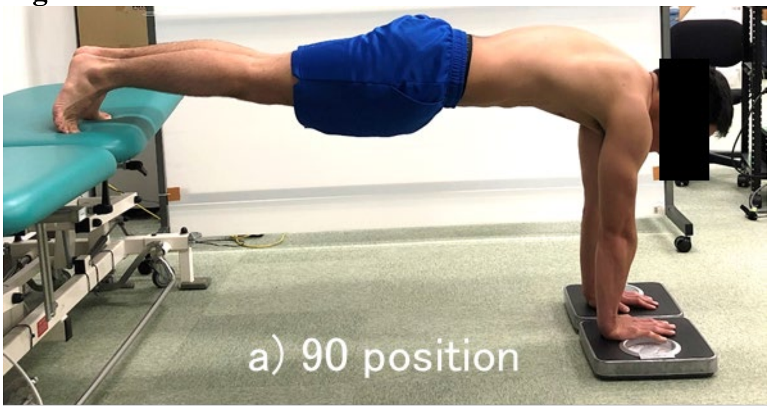


Fig. 1b

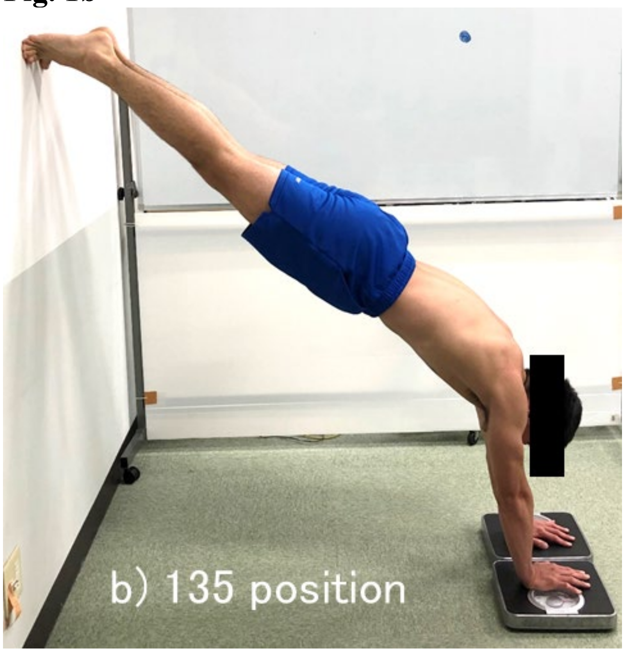


Fig. 1c

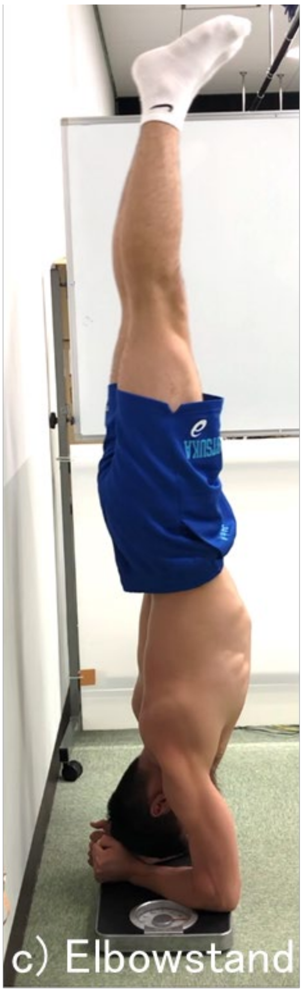
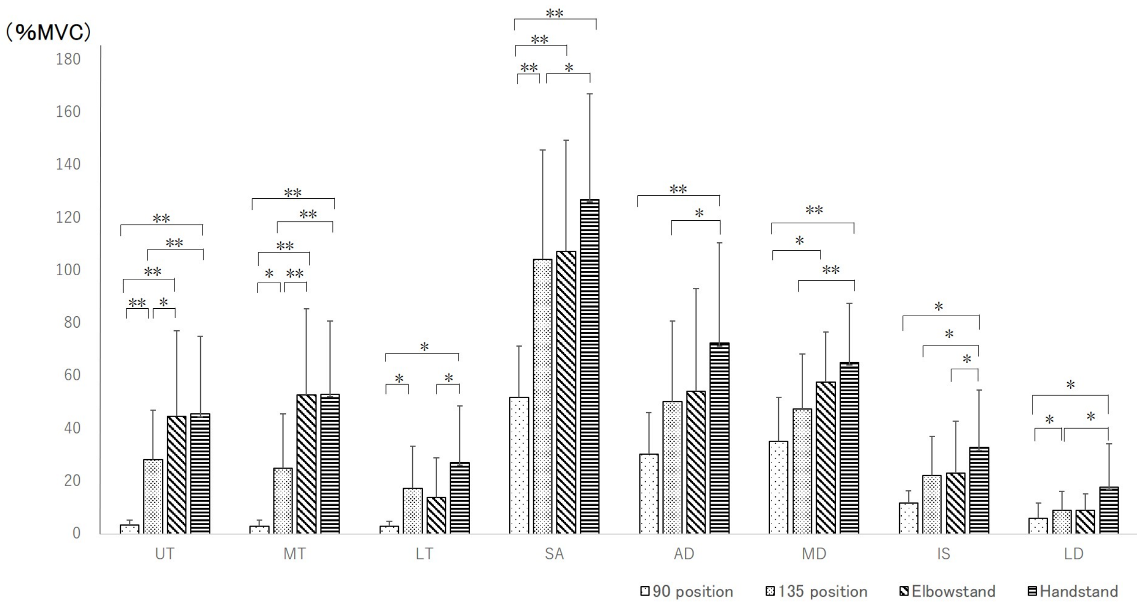


Fig. 1d


d) Handstand

Fig. 2


(%MVC)
0
20
40
60
80
100
120
140
160
180
UT
MT
LT
SA
AD
MD
IS
LD
90 position
135 position
Elbowstand
Handstand