A Flight Helmet-Attached Force Gauge for Measuring Isometric Neck Muscle Strength

Paavo Nyländen, Mikko Virmavirta, Roope Sovelius, Heikki Kyröläinen, Tuomas Honkanen

INTRODUCTION: Fighter pilots must withstand high G_z-forces that can damage the cervical spine. Strength of the cervical musculature is of vital importance when it comes to preventing these G-induced neck injuries. However, there is very little evidence on valid neck muscle strength measurement methods for fighter pilots. The aim of this study was to examine the validity of a commercial force gauge attached to a pilot's helmet for measuring isometric neck muscle strength.

METHODS: A total of 10 subjects performed maximal isometric cervical flexion, extension, and lateral flexion with the helmet-attached gauge and with a weight stack machine, which was used as a reference. Electromyography (EMG) activities were recorded from the right and left sternocleidomastoids and cervical erector spinae muscles during all measurements. Paired *t*-tests, Pearson correlation coefficient, and Wilcoxon's test were used to analyze the data.

RESULTS: Difference of mean force values between the devices was statistically significant in all directions. Pearson correlation coefficient varied between 0.73 and 0.89 and it was highest in cervical flexion. EMG activities were significantly different only in the left CES during flexion.

DISCUSSION: The helmet-attached gauge is a valid tool for measuring isometric neck muscle strength and is best used as a means to compare individual differences in strength levels or to track the progress of strength development.

KEYWORDS: fighter pilots, neck muscles, force measurements.

Nyländen P, Virmavirta M, Sovelius R, Kyröläinen H, Honkanen T. *A flight helmet-attached force gauge for measuring isometric neck muscle strength*. Aerosp Med Hum Perform. 2023; 94(6):480–484.

Fighter pilots are repetitively exposed to high G_z-forces that can cause flight-duty-limiting neck injuries. The large cervical range of motion required by modern aiming technology, such as the joint helmet-mounted cueing system (JHMCS), further augments the G_z-induced neck strain.[12] According to Coakwell et al.,[4] maximal cervical rotation needed by the "check-six" movement is one of the most common causes of acute neck injury under high G_z-loading. Additionally, JHMCS has changed the helmets' weight distribution, which increases the risk of injury.[7] It has also been shown that visual function is a major component of postural control and can have an effect on injury risk as well.[2]

Strong neck muscles can prevent these G_z-induced injuries by stabilizing the cervical spine and preventing transmission of forces to the vertebral structures.[4] For example, it has been shown that functional full-body strength training can decrease neck muscle activation and rating of perceived exertion under high G_z-loading.[9] Strength training interventions can also mitigate neck pain prevalence among fighter pilots.[6] Thus it is important to be able to reliably assess fighter pilots' maximal neck muscle strength.

Selistre et al.[11] carried out a meta-analysis on the validity and reliability of different clinical tests made for neck muscle strength assessments. Cervical flexor and extensor endurance test and a hand-held dynamometer (HHD) showed good to moderate intra- and interrater reliability, but the authors were unable to get unequivocal results on the validity of these tests. Instead, Ashall et al.[1] reported that the validity of the HHD was sufficient when compared with a wall-mounted dynamometer, even though peak forces were systematically lower with the

From the University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland, and the Centre for Military Medicine, The Finnish Defense Forces, Helsinki, Finland.

This manuscript was received for review in July 2022. It was accepted for publication in January 2023.

Address correspondence to: Paavo Nyländen, MSc., Ailakinkatu 15 B 29, Jyväskylä, Keski-Suomi, 40100, Finland; paavo.nylanden@gmail.com

DOI: https://doi.org/10.3357/AMHP.6141.2023

HHD. Furthermore, it has been reported that the HHD showed excellent correlation when isokinetic measurements were used as reference.[10] Other devices that have been validated in scientific literature include the David Back Clinic 140 and the Multi-Cervical Rehabilitation Unit.[3,8]

It is evident that previous studies have examined the validity of different metrics for neck muscle strength in a variety of ways. In addition, most of the studies have concentrated on the reliability of these metrics rather than the validity. The purpose of this study was to examine the validity of a commercial force gauge connected to a fighter pilot's helmet by comparing it with a cervical extension and flexion weight stack device. Force measurements were coupled with EMG recordings from both the sternocleidomastoids (SCM) and cervical erector spinae (CES) muscles. The hypotheses of this study were that the helmet-attached force gauge would correlate well with the weight stack device and that there would be no differences in neck muscle EMG activities.

METHODS

Measurements were conducted within the same week on two separate days. On the first day, subjects performed maximal isometric cervical extension, flexion, and lateral flexion to the left and right with the weight stack machine; on the other day, the same tests were done using the helmet-attached force gauge. Before the measurements, subjects were instructed to perform a brief warm-up with unloaded head movements. All the raw force and EMG signals were collected through an A/D-converter to Signal 4.0 software for analysis. Subjects were randomly recruited from voluntary students of the University of Jyväskylä. A total of 6 male subjects (age: 25 ± 2 yrs.) and 4 female subjects (age: 26 ± 4 yrs.) were recruited.

The Helmet-Attached Force Gauge

The force gauge used in this study was a typical commercial strain gauge built by Sauter AG (Basel, Switzerland). The other end of this gauge was connected to a fighter pilot's helmet via one y-shaped cable. In order to channel the raw force signals to Signal 4.0, this gauge was connected to another strain gauge, and they were calibrated by using weight plates.

The two connected gauges were mounted to a stationary vertical bar. Each subject's torso position was standardized by a foam tube that was placed between the subject and a pad that was connected to the vertical bar. In order to minimize torso movement, the tube had to stay in place. The subject was sitting in a chair without using the back rest and with their hands resting on their thighs. The distance between the gauges and the helmet was adjusted such that the cables were tight and the subject's head was in neutral position during force production.

Subjects were first instructed to do 2–3 warm-up attempts at 50% of their expected maximum effort. After this, subjects executed two maximal isometric contractions that lasted 3 s each with 2 min rest between the attempts. Only the better result was taken into account. This protocol was repeated in all four directions.

The Weight Stack Machine

A David G140 weight stack machine (David Health Solutions Ltd., Helsinki, Finland), made for strengthening the cervical musculature, was used as a reference device. Because of a built-in strain gauge, maximal isometric force can be recorded in this device by locking the head support in place. Analog force signals were channeled from the gauge to Signal 4.0 through an A/D-converter.

Measurement position was standardized by adjusting the seat to a correct height and locking the chest support in place; instructions for the correct position were given by David Health Solutions. Subjects performed warm-up attempts and maximal isometric contractions with the same protocol as with the helmet-attached gauge. The measurement settings with both the helmet-attached force gauge and the weight stack machine are depicted in **Fig. 1**.

EMG Measurements

EMG activities were recorded from the right and left SCMs and CES with Noraxon Telemyo TM2400R (Noraxon Inc., Scottsdale, Arizona). Bipolar silver chloride electrodes were placed on the muscles according to SENIAM guidelines.[5] Signal amplification was set to 2000 and sampling frequency was set to 1000 Hz. The ground electrode was placed on top of the spinous process of the C7 vertebra. Background noise had to stay between ± 10 μV. RMS amplitude was calculated from the raw EMG signals within a 500-ms timeframe by using the peak of the force signal.

Statistical Analysis

All statistical analyses were done by using IBM SPSS 26.0. A Shapiro-Wilk test was used to check the normality of the data. A two-tailed Pearson correlation coefficient was used to correlate the force measurements between the helmet-attached gauge and the weight stack machine, and a paired samples *t*-test was used to compare group means. A paired samples Wilcoxon test was used to compare means of EMG activity.

RESULTS

Differences of mean forces between the devices are presented in **Fig. 2**. The difference was smallest in flexion (Sauter: 165 N ± 79 N, David: 195 N ± 62 N), whereas in all other directions, differences were almost identical. The largest absolute forces were achieved in extension (Sauter: 228 N ± 68 N, David 327 N ± 109 N). Flexion forces were greater than lateral flexion forces with the helmet-attached gauge and vice versa with the weight stack machine. Correlation between the devices was strongest in flexion ($r = 0.89$) and weakest in lateral flexion to the right ($r = 0.73$). Correlation graphs are presented in **Fig. 3**.

The only significant difference in mean EMG activities between the measurement conditions was observed from the left CES during flexion. The right CES also showed a distinct difference, although not statistically significant ($P = 0.07$). Overall, CES showed the highest activity in extension, whereas SCMs showed the highest activity in flexion. Ipsilateral muscles

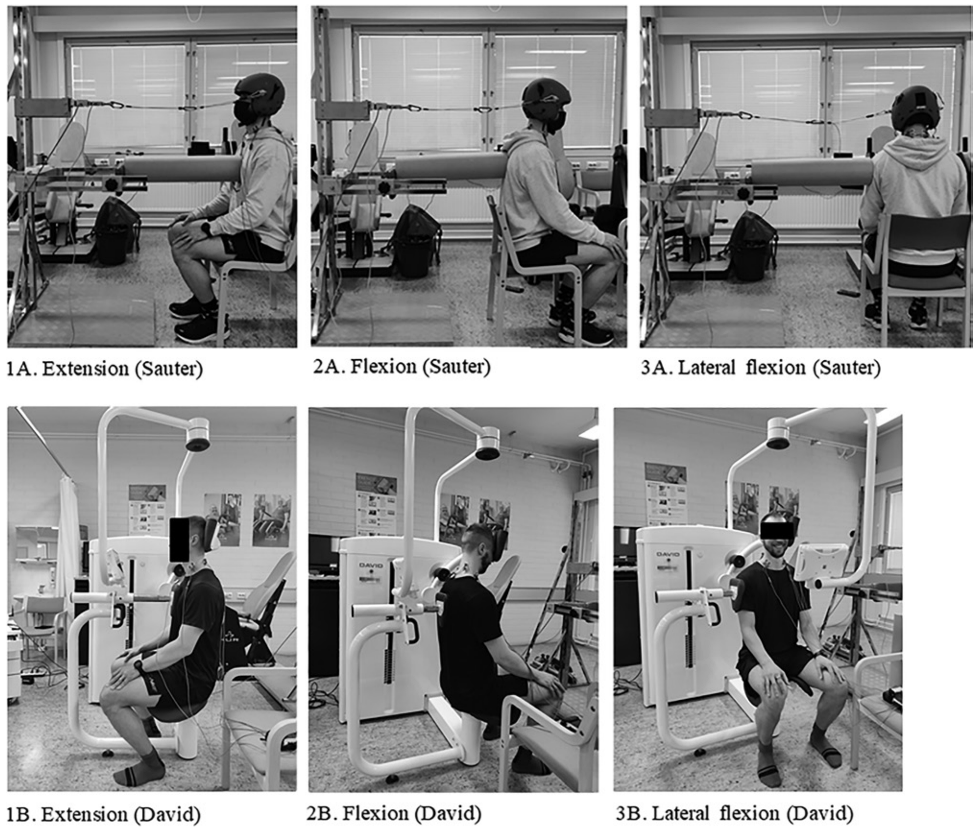

Fig. 1. Measurement positions with the Sauter force gauge (1A-3A) and with the David G140 (1B-3B).

showed higher activity than contralateral muscles during lateral flexion. Mean RMS amplitudes of each muscle in each measurement setting are presented in **Fig. 4**.

DISCUSSION

Maximal isometric neck muscle strength measured with the helmet-attached force gauge was found to have a good to excellent correlation with the weight stack device. Correlation was strongest in cervical flexion and weakest—but still statistically significant—in lateral flexion. Despite the correlation, the helmet-attached gauge showed significantly lower absolute force values than the weight stack device. The only difference in neck muscle EMG activities between the devices was found from the left CES during flexion. These results are in line with previous studies that have investigated the validity of neck muscle strength assessment methods.

It was hypothesized that there would be a strong correlation between the devices and that neck muscles show similar EMG

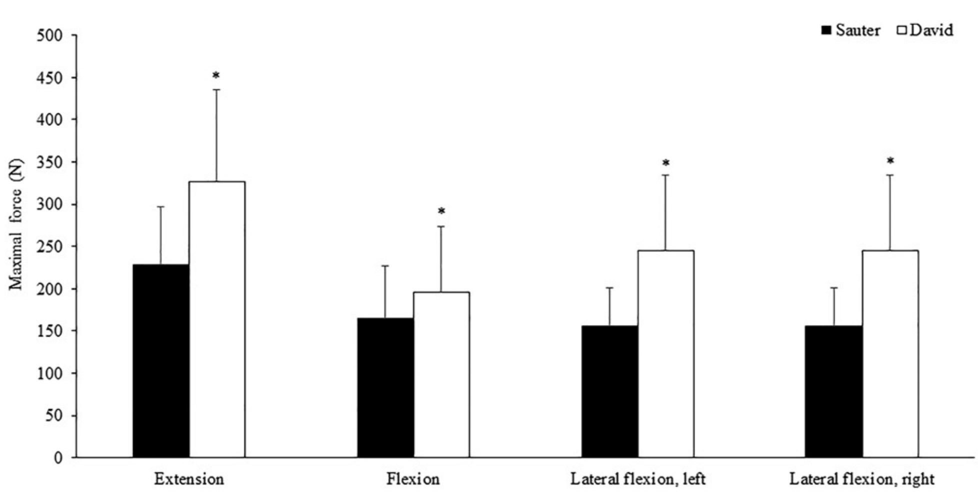

Fig. 2. Mean (+SD) maximal force results measured with the two devices. Error bars represent the standard deviation. *$P < 0.05$.

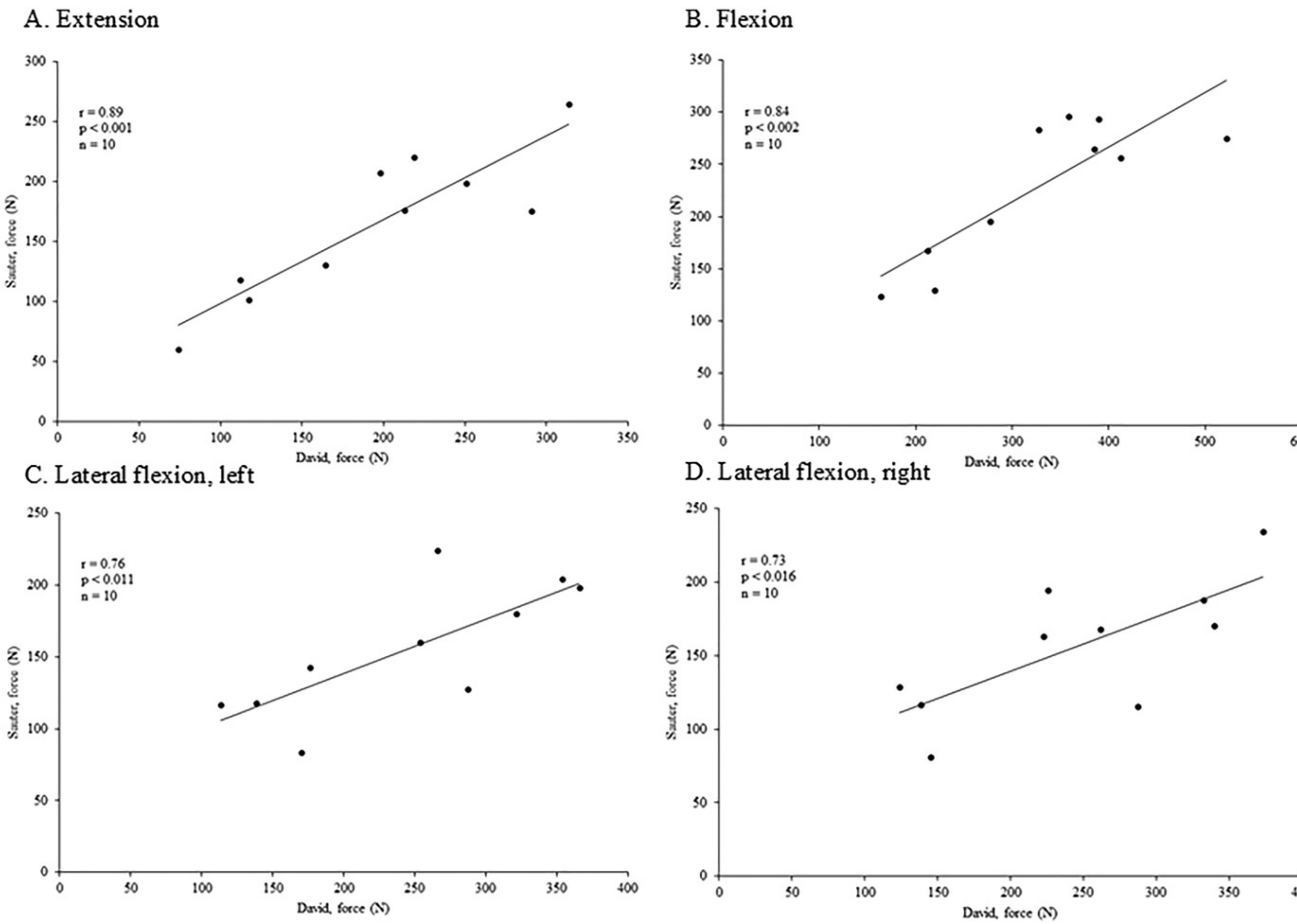

Fig. 3. Force correlations between the Sauter force gauge and the David G140.

activity during force production. The results of this study indicate that this hypothesis was correct. The aforementioned difference in the activity of the right CES during flexion most likely resulted from either EMG crosstalk or subjects' individual differences. This is supported by the fact that the CES function as antagonists to the SCMs in cervical flexion, which mean that their activity should be relatively low during this movement pattern. Another possible explanation for this is that the cables of the helmet-attached gauge allowed the head to subtly tilt, which led to the activation of muscles involved in lateral flexion.

The higher force values of the weight stack device cannot, therefore, be explained by different neck muscle activation patterns. Instead, the location of the built-in strain gauge might have affected the results. Subjects produced force to the upholstered part of the device, which was roughly a couple of feet away from the alleged location of the strain gauge. This might have created unwanted leverage. Due to difficulties in isolating the exact location of the strain gauge, it was not possible to evaluate how much error it might have caused.

The other potential explanation is that the weight stack device had a solid torso support pad, which might have led to unnoticeable isometric thoracic extension or flexion. Because of the elastic foam tube used with the helmet-attached gauge, it was easier to detect excessive torso movement and redo bad attempts. In addition, the pilots' helmet fitted a bit loosely for some of the subjects, which might have also caused small errors.

Another limitation of this study is the fact that the measurements were not conducted on actual pilots. This can probably be seen most clearly in the absolute maximum force value, not in the correlation. Also, the neck muscle activities might have been slightly different with fighter pilots because they are accustomed to neck muscle strain. Finally, a relatively small sample size can be considered a limitation as well.

The helmet-attached force gauge is a valid tool for isometric neck muscle strength measurements. These types of strain gauges are very inexpensive when compared to other devices, such as the weight stack device used in this study. In addition, their portability makes them extra valuable for field testing. The helmet-attached gauge should be used as a tool to examine fighter pilots' individual differences in isometric neck muscle strength, but absolute force values presented by this gauge should be interpreted with caution.

As a clinical tool, the helmet-attached force gauge can be used to track the progress of neck strength development in order to determine whether pilots are at risk of developing

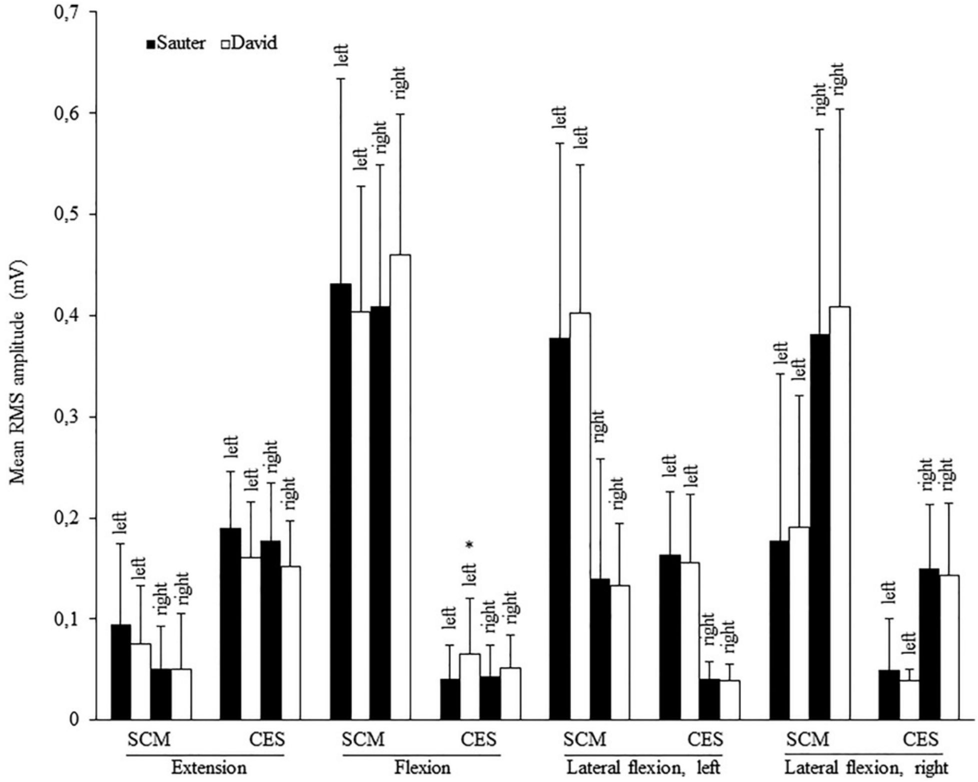

Fig. 4. Mean RMS amplitude for each muscle in all measurement conditions. Error bars represent the standard deviation. $*P < 0.05$.

flight-duty-limiting neck injuries. Also, it should be noted that this force gauge measures only isometric strength, which has its limitations when compared to concentric and eccentric muscle actions that occur during high-performance flights.

ACKNOWLEDGEMENTS

Financial Disclosure Statement: The authors have no competing interests to declare.

Authors and Affiliations: Paavo Nyländen, MSc, University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland; Mikko Virmavirta, PhD, University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland; Roope Sovelius, MD, PhD, Centre for Military Medicine, The Finnish Defense Forces, Helsinki, Finland; Heikki Kyröläinen, PhD, University of Jyväskylä, Faculty of Sport and Health Sciences, Jyväskylä, Finland and Centre for Military Medicine, The Finnish Defense Forces, Helsinki, Finland; and Tuomas Honkanen, PhD, Centre for Military Medicine, The Finnish Defense Forces, Helsinki, Finland.

REFERENCES

1. Ashall A, Dobbin N, Thorpe C. The concurrent validity and intrarater reliability of a hand-held dynamometer for the assessment of neck strength in semi-professional rugby union players. Phys Ther Sport. 2021; 49:229–235.
2. Baldini A, Nota A, Cravino G, Cioffi C, Rinaldi A, Cozza P. Influence of vision and dental occlusion on body posture in pilots. Aviat Space Environ Med. 2013; 84(8):823–827.
3. Chiu TT, Lo SK. Evaluation of cervical range of motion and isometric neck muscle strength: reliability and validity. Clin Rehabil. 2002; 16(8): 851–858.
4. Coakwell MR, Bloswick DS, Moser R. High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviat Space Environ Med. 2004; 75(1):68–80.
5. Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, et al. SENIAM - European recommendations for surface electromyography. 2nd ed. Enschede (Netherlands): Roessingh Research and Development; 1999.
6. Lange B, Toft P, Myburgh C, Sjogaard G. Effect of targeted strength, endurance, and coordination exercise on neck and shoulder pain among fighter pilots: a randomized-controlled trial. Clin J Pain. 2013; 29(1): 50–59.
7. Lange B, Torp-Svendsen J, Toft P. Neck pain among fighter pilots after the introduction of the JHMCS helmet and NVG in their environment. Aviat Space Environ Med. 2011; 82(5):559–563.
8. Peolsson A, Oberg B, Hedlund R. Intra- and inter-tester reliability and reference values for isometric neck strength. Physiother Res Int. 2001; 6(1):15–26.
9. Rausch M, Weber F, Kuhn S, Ledderhos C, Zinner C, Sperlich B. The effects of 12 weeks of functional strength training on muscle strength, volume, and activity upon exposure to elevated G_z forces in high-performance aircraft personnel. Mil Med Res. 2021; 8(1):15.
10. Romero-Franco N, Jimenez-Reyes P, Fernandez-Dominguez JC. Concurrent validity and reliability of a low-cost dynamometer to assess maximal isometric strength in neck movements. J Manipulative Physiol Ther. 2021; 44(3):229–235.
11. Selistre LFA, Melo CS, Noronha MA. Reliability and validity of clinical tests for measuring strength or endurance of cervical muscles: a systematic review and meta-analysis. Arch Phys Med Rehabil. 2021; 102(6): 1210–1227.
12. Sovelius R, Mäntylä M, Huhtala H, Oksa J, Valtonen R, et al. Head movements and neck muscle activity during air combat maneuvering. Aerosp Med Hum Perform. 2020; 91(1):26–31.