Trampoline Exercise vs. Strength Training to Reduce Neck Strain in Fighter Pilots

Roope Sovelius, Juha Oksa, Harri Rintala, Heini Huhtala, Jari Ylinen, and Simo Siitonen

Introduction: Fighter pilots’ muscular strength and endurance are subjected to very high demands. Pilots’ fatigued muscles are at higher risk for injuries. The purpose of this study was to compare the effects of two different training methods in reducing muscular loading during in-flight and cervical loading testing (CLT). Methods: There were 16 volunteer Finnish Air Force cadets who were divided into 2 groups: a strength training group (STG) and a trampoline training group (TTG). During the 6-wk training period, the STG performed dynamic flexion and extension and isometric rotation exercises, and the TTG performed trampoline bouncing exercises. During in-flight and CLT, muscle strain from the sternocleidomastoid, cervical erector spinae, trapezius, and thoracic erector spinae muscles was recorded with EMG. Results: In-flight muscle strain in the STG after the training period decreased in the sternocleidomastoid 50%, cervical erector spinae 3%, trapezius 4%, and thoracic erector spinae 8%. In the TTG, the decrease was 41%, 30%, 20%, and 6%, respectively. In CLT, the results were similar. After a 3-mo follow-up period with intensive high +Gz flying, EMG during CLT was still lower than in baseline measurements. Conclusion: Both training methods were found to be effective in reducing muscle strain during in-flight and CLT, especially in the cervical muscles. There was no statistically significant difference between the training groups. Introduced exercises expand muscles’ capacities in different ways and the authors recommend both strength and trampoline training programs to be included in fighter pilots’ physical education programs. Keywords: trampoline, strength training, +Gz loading, neck injury prevention, neck injuries.

The maneuverability of a modern high-performance aircraft may exceed the pilot’s capabilities to tolerate high +Gz acceleration. High +Gz load with high onset rate may produce neck pain and more serious injuries (11). Especially in the lateral neck, peak strain with magnitude well above the maximal voluntary contraction has been measured, thus presenting a potential risk for negative health effects and injuries (19). The level of peak strain episodes means that fighter pilots’ muscular strength and endurance, particularly in the neck and shoulder area, are subjected to demands clearly higher than those of the average population. When sorties are repeated several times per day, aerial combat maneuvering exercises cause fatigue, especially in the neck muscles (20). Fatigued muscles perform with less power, leading to increased strain under equivalent loading, which may in turn increase the risk for neck injuries.

Individual factors affecting the pilot’s muscle +Gz load tolerance include strength and motor skill. It has been reported in the literature that increased muscle strength may reduce muscle strain under +Gz loading (2,6,7) and thus diminish the incidence of acute in-flight neck pain (10,13,18). Portero (21) reported the beneficial effect of a strength-training program which increases neck muscle size and strength during lateral flexion, and decreases the fatigability of the superficial muscles of the neck. The training effects were evaluated in their study in three ways: strength; muscles’ cross-sectional area in computerized tomography; and fatigability evaluated with a decrease in mean power frequency of the electromyogram.

Trampoline training has been considered as a tool to create a “G environment” for fighter pilots’ physical training. The purpose of trampoline training is to improve general motor skills and to enhance muscle balance. However, as relatively low-intensity, repetitive muscular loading, it has the potential to improve muscle tone and endurance. Muscular fatigue and post-exercise muscular soreness in the neck/shoulder, fore-neck, and abdominal area have also been reported when we evaluated users’ experiences with this new training method.

The aim of this study was to compare two different training methods for reducing fighter pilots’ neck strain under +Gz loading and to evaluate how permanent the possible effects of the training methods were after a 3-mo follow-up. The question was: is it more efficient to do exercises that increase the general muscle strength or those that improve motor skill and muscle balance?

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METHODS

Materials

There were 16 volunteer Finnish Air Force cadets who were divided into 2 groups: a strength training group (STG) and a trampoline training group (TTG). Mean age was 22.1 ± 0.6 yr in the STG and 22.6 ± 0.9 yr in the TTG, height 178.5 ± 4.6 cm and 177.5 ± 4.9 cm, weight 77.4 ± 6.5 kg and 76.3 ± 6.8 kg, and body mass index 24.3 ± 1.1 kg · m⁻² and 24.2 ± 1.5 kg · m⁻² respectively. The subjects were informed of the details of the experimental protocol and the study was granted approval by the Finnish Defense Force Medical Research Register, the Finnish Air Force Headquarters Research License, and the Ethical Committee of Central Finland District.

The program was part of the cadets’ physical training program. Prior to starting the training period all subjects took part in an introduction phase when training methods and exercises were practiced to ensure that all subjects had appropriate skills when the actual training was performed. The training program lasted for 6 wk and consisted of 2–3 exercise sessions per week. Training assessments were held to evaluate the successfulness of the training program. The STG did cervical dynamic flexion and extension exercises and isometric rotation exercises. Each training session consisted of 2–4 sets of each exercise. Sets were 20–40 reps with the resistance of approximately 15–30% of the measured maximal isometric force in the neutral position. Reps and resistance were increased progressively in each successive training week. The program consisted of two 3-wk periods of easy, moderate, and hard training weeks. Endurance type, relatively low exercise intensity was chosen to achieve increased endurance strength of the muscle groups exercised and to avoid over-training or cervical discomfort caused by too heavy loading.

The trampoline training program consisted of basic trampoline exercises including basic, hand and knee, and back bouncing. A round trampoline with a diameter of 4.3 m (JumpKing, Inc., Portland, OR) was used. Exercises were performed up to subjectively evaluated fatigue, normally in 30–60 s in one set, and there were similar 30–60-s recovery times between the sets. In the beginning of the training period, the set was performed twice, and after 2 wk, it was repeated three times. On a separate occasion, vertical acceleration measurements (n = 4) during bouncing were performed with a MoTec ADL Datalogger and triple axis G-sensor (Printsport Oy, Lievestuore, Finland) fixed to the flying helmet.

All subjects flew test flights with a BAE Hawk MK 51 jet trainer at the beginning and on completion of the training period. The flights were similar training sorties and consisted of aerobatics and basic tactical maneuvering. They were performed according to the sortie charts where the order of maneuvering and basic tactical maneuvering were stated completely. The number of times the levels of +0.25, +2.5, +3.5, +4.5, +5.5, and +7.0 Gz were exceeded during the flight was recorded by the aircraft’s Gz-meter coder.

In addition to in-flight measurements, muscle strain was also measured during a cervical loading test (CLT). In this test, cervical flexor and extensor muscles were loaded separately. Lateral loads were not tested due to a higher injury risk since a loaded vertebral column and muscles have less range of movement in that direction. Each neck movement, or strain against a load, involves multiple muscles working together, and the same muscle is participating in various different types of movement. Thus all muscles involved in anterior flexion movement or in straining against a posterior load have been considered flexors and all muscles involved in extension or strain against an anterior load have been considered extensors. In the test, each subject lay supine on the test table with shoulders on the edge of the test table wearing a helmet with an external load hanging on an 8-cm long elastic rope. The load for each subject was 25% of the maximal cervical extension force and 10% of the maximal cervical flexion force. The load was dropped from the frontal level (extensors) or from the occipital level (flexors) 15 times. The rope stretched approximately 6 cm when the load was dropped, and it incurred impact loading on the muscle group involved. The test was also performed 3 mo later (during a follow-up period) after a period of intensive flight training with high +Gz loading. The purpose of using the CLT was to exclude the effect of learning and improved...
flying skills during the training period and follow-up. One subject had an in-flight neck injury prior to the scheduled test day, another was rejected from flight training during follow-up, and these two did not perform the follow-up measurements.

During the test flights and CLT, EMG activity of the right and left sternocleidomastoid, cervical and thoracic erector spinae, and trapezius muscles were measured using bipolar surface electrodes. Measured EMG was proportional to maximal voluntary contraction (MVC) EMG level and muscle strain was determined as a percent of MVC (%MVC). Muscle strain was determined using a portable eight-channel EMG device (ME3000P, Mega Electronics Ltd., Kuopio, Finland).

The bipolar EMG recordings were made using pregelled surface electrodes (Medicotest M-OO-S, Olstykke, Denmark). The electrodes were placed longitudinally on the muscles; the distance between the measurement surfaces of the electrodes was 2 cm. The ground electrodes were placed on inactive tissue. The measured signal was preamplified 1000 times. The signal-band between 20 and 500 Hz was full-wave rectified and averaged with a 100-ms time constant. The sites of the electrodes were marked on a clear plastic film with the aid of anatomical marks (moles, scars, etc.), thus ensuring that the electrodes were replaced in exactly the same place after the training period and for follow-up measurements.

The muscle strength of the cervical flexor, extensor, and rotator muscles was measured with an isometric neck strength measurement system (INSMS, Kuntováline Oy, Finland) (25) before and after the training period (pre- and post-test). The subject was seated facing toward the apparatus while testing rotation and flexion forces (Fig. 1). While testing extension forces the subject was seated facing away from the apparatus. The load-cell was placed against the occipital at the same height as it was while measuring flexion force. After warm-up, the subject was asked to push/turn with maximal force three times in each direction with a pause of 45 s between each effort. The best one of three efforts was chosen for data analysis.

Statistics

Mean differences with 95% CI are given as descriptive statistics. A t-test was used to compare in-flight +Gz loads between training groups or Flight 1 and Flight 2. ANOVA with repeated measures were used to determine training effects, i.e., muscle strain after the training period and between training groups. In all tests, p < 0.05 was considered statistically significant.

RESULTS

Vertical acceleration during basic trampoline bouncing varied between 0 and +4 Gz. A sample of the acceleration curve as a function of time is shown in Fig. 2. Comparison of +Gz loading during the test flights is shown in Fig. 3. +Gz loading was similar between training groups (p = 0.21) and between flights in the beginning and on completion of the training period (p = 0.23).

Maximal muscle force was increased in both groups in all measured directions after the training period. All test subjects enhanced their flexion and extension forces during the training period. Improvement in flexion force was significantly better in the TTG; otherwise statistically significant differences between the training groups were not seen (Table I).

In-flight muscle strain (%MVC) decreased after the training period in both groups and most significantly in the cervical muscles, especially in the sternocleidomastoid muscles. In the trapezoid and thoracic erector spinae muscles, the effect of training was not so clearly seen. There was no statistically significant difference in

![Fig. 2. Vertical acceleration during basic trampoline bouncing.](image-url)

![Fig. 3. +Gz loading during test flights. The aircraft's Gz-meter coder recorded the number of times the given Gs were exceeded during the flight.](image-url)
in-flight muscle strain between the training groups (Table II).

Results were similar in the CLT measurements. Both training methods decreased muscle strain in the cervical muscles, in both the sternocleidomastoid and in the cervical erector spinae. In the lower muscles such a clear difference was not seen. Again, between training groups there was no statistically significant difference in any measured muscle (Table III).

There was a tendency toward reduced EMG activity during the CLT in all muscles from the beginning to the end of the follow-up period (Fig. 4). The positive effects of the training period in muscle loading was sustained in the cervical area in both training groups (STG and TTG), but in the thoracic erector spinae muscles the results were not so clear. No statistically significant difference was seen between the training groups.

**DISCUSSION**

The results of this study indicate that training decreased muscle strain in-flight and during the CLT, especially in the lateral neck area. Both methods seemed to be efficient and their effect was still seen after a 3-mo follow-up period. The in-flight measurements were taken during ordinary flight training sorties. It is not possible to reach the accuracy of a centrifuge in $+G_z$ loading when a human is piloting an aircraft, but analysis of the $+G_z$ loading during flights evinced comparable loads between training groups as well as between the before and after training periods. Therefore, the results obtained in this study can be considered as reliable and as reflecting changes in the functional capacity of the pilots rather than in differences in external loading.

Training intervention was short, but it has been reported that with 6 wk training it is possible to increase muscle force (1,14,17), and improved muscle force has been reported to diminish in-flight strain or neck pain under $+G_z$ loading (2,6,10,18,21). The improvement in maximal muscle force in this study was small but statistically significant in both training groups, thus confirming previous findings. However, because the measurements were isometric and performed in the neutral position, the maximal forces measured probably did not show the entire increase in muscle power. Muscle force can vary greatly depending on the phase of movement (15,23,24).

Since both these training methods included rather low-intensity exercises, the increase in maximal muscle force was relatively small. It should also be considered that every training method is site- and intensity-specific, and that the accuracy of the measurements may cause small changes in the measured results. However, in this study all test subjects increased their flexion and extension forces during the training period. This supports the presumption that the changes seen in maximal forces are due to the training. In the literature, submaximal strength training or endurance training has also been reported to have a positive effect on maximal strength (3,4,12). In fact, it is likely that due to low-intensity training (both the STG and TTG), the submaximal endurance and motor coordination of the neck/shoulder area muscles were enhanced. It may be assumed that strength training would have more effect on submaximal endurance and trampoline training on motor coordination than vice versa. However, based on these results this remains a speculation. Training may cause adaptations to the many neural elements that are involved in the control of movement. Increased neuromuscular performance and intermuscular coordination may increase mechanical efficiency in maintaining cervical stability and thus have a beneficial effect in decreasing in-flight and CLT muscle strain. In this sense both training methods were successful. Even a small

**TABLE II. THE EFFECT OF TRAINING ON MUSCLE STRAIN (aEMG) DURING TEST FLIGHTS DESCRIBED AS CHANGES IN %MVC.**

<table>
<thead>
<tr>
<th>Muscles</th>
<th>STG</th>
<th>TTG</th>
<th>Flight 1 vs. Flight 2</th>
<th>STG vs. TTG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta$%MVC CI (95%)</td>
<td>$\Delta$%MVC CI (95%)</td>
<td>p</td>
<td>p</td>
</tr>
<tr>
<td>SCM</td>
<td>$-50.3$ $-54.0$ to $-12.4$</td>
<td>$-40.8$ $-43.4$ to $13.2$</td>
<td>$0.049$</td>
<td>$0.637$</td>
</tr>
<tr>
<td>CES</td>
<td>$-2.6$ $-13.1$ to $5.1$</td>
<td>$-30.5$ $-39.4$ to $18.8$</td>
<td>$0.053$</td>
<td>$0.080$</td>
</tr>
<tr>
<td>TRA</td>
<td>$-4.3$ $-36.2$ to $3.0$</td>
<td>$-20.0$ $-26.0$ to $8.6$</td>
<td>$0.428$</td>
<td>$0.675$</td>
</tr>
<tr>
<td>TES</td>
<td>$-7.9$ $25.4$ to $94.2$</td>
<td>$-6.1$ $-38.6$ to $10.0$</td>
<td>$0.933$</td>
<td>$0.637$</td>
</tr>
</tbody>
</table>

STG = strength training group; TTG = trampoline training group.
SCM = sternocleidomastoid; CES = cervical erector spinae; TRA = trapezius; TES = thoracic erector spinae.
decrease in muscle strain during flight sorties may diminish muscle fatigue. Less fatigued muscles need shorter recovery times after contraction, i.e., when loaded. This also aids maintenance of muscles' safety margins during high onset rate $G_z$ loading.

Both training methods were successful in reducing in-flight muscle strain. Training was most effective in the cervical area (sternocleidomastoid and cervical erector spinae), but a positive effect was also seen in the lower muscles (trapezius and thoracic erector spinae muscles). This may be due, in part, to the exercises. In the strength training program, both dynamic and isometric exercises were performed, mostly with cervical muscles, so the effect was naturally greatest in the muscle groups specifically practiced. Then again, there were neck flexor (back bouncing) and neck extensor specific exercises (hand and knee bouncing) in the trampoline training program, too.

In this study the muscles' in-flight %MVC levels were not very high, which differs from some other reports (8,9,16,19). This may be due to the nature of the test flights. The sorties were basic aerobatics and maneuvering with single aircraft. During air combat flights pilots need higher $+G_z$ maneuvering and move their heads to follow the other aircrafts' moves. This increases the load on the cervical muscles, especially the sternocleidomastoid muscles that also rotate, bend laterally, and resist extension of the head from the neutral position. However, both training methods had a positive effect on these critical muscles. A slight increase in strength resulted in a slight decrease of strain in the cervical erector spinae muscles. In the lower part of the spine, where the muscles stabilize the posture rather than perform movements against $+G_z$ loading, the results were more variable.

A similar change in muscle strain was seen in the CLT as during in-flight EMG-measurements. This supports the hypothesis that improved muscular capacity due to training decreases muscle strain under $+G_z$ loading. The test also excluded the effect of cadets' improved flying skills during the training period as a factor of change to muscle strain: improved flying skills or learning had no effect on loading in the CLT. The %MVC levels were higher in the CLT than during test

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**TABLE III. THE EFFECT OF TRAINING ON MUSCLE STRAIN ($\text{aEMG}$) IN THE CERVICAL LOADING TEST (CLT) DESCRIBED AS CHANGES IN %MVC.**

<table>
<thead>
<tr>
<th>Muscles</th>
<th>STG</th>
<th>TTG</th>
<th>Pretest vs. Post-test</th>
<th>STG vs. TTG</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCM</td>
<td>-17.3</td>
<td>-21.7 to 8.7</td>
<td>-6.7</td>
<td>-29.7 to 3.1</td>
</tr>
<tr>
<td>CES</td>
<td>-15.7</td>
<td>-25.8 to 8.8</td>
<td>-22.0</td>
<td>-38.6 to 10.0</td>
</tr>
<tr>
<td>TRA</td>
<td>-30.0</td>
<td>-91.9 to -20.3</td>
<td>-9.5</td>
<td>-29.9 to 14.5</td>
</tr>
<tr>
<td>TES</td>
<td>-23.7</td>
<td>-41.8 to -1.8</td>
<td>-26.4</td>
<td>-39.0 to -11.8</td>
</tr>
</tbody>
</table>

STG = strength training group; TTG = trampoline training group.

SCM = sternocleidomastoid; CES = cervical erector spinae; TRA = trapezius; TES = thoracic erector spinae.

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**Fig. 4.** EMG activity during CLT in all muscles in the beginning (pretest), on completion of the training period (post-test), and after 3 mo (follow-up).
flights, which may be due to the more impulsive and impact type loading in the CLT than the moderate, more sustained in-flight accelerations during the flights. On the other hand, in-flight recorded data also included flying between maneuvers. Even though %MVC values were higher in the CLT, these results indicate that the CLT is a sensitive method for simulation of in-flight loading over the cervical area. It is an inexpensive and simple on-site alternative to test flights and centrifuge tests, and especially useful in follow-ups.

On completion of the 3-mo follow-up period, the muscles’ electrical activities during the CLT were similar to those after the training period. Decreased muscle strain in the cervical muscles was still seen, and there was no statistically significant difference between training methods. During the follow-up period, the cadets had an intensive air combat training phase with 3–4 high +G\textsubscript{z} sorties per day. Due to strenuous flying activities, the cadets recuperated after flight with little additional physical activity and no specific training program. What the training effect of flying itself was during follow-up remains to be discussed. It has been reported that the overall muscular neck strength of pilots did not differ significantly from that of non-pilots, nor did exposure to +G\textsubscript{z} forces lead to specific changes in isometric muscle strength (5,22). Still, those results may reflect the difficulty of measuring out all the specific changes in muscular tone and strength in the complex cervical column rather than the ineffectiveness of G\textsubscript{z} loading on musculature.

In conclusion, neither of the described training methods was superior to the other, but both had positive results. Trampoline training seems to be a suitable method for diminishing in-flight muscle strain in the neck area. Exercises enhance the motor control ability of the cervical muscles, and thus pilots do not need to use as much of their muscle strength as previously. Training improves the skills related to the maintenance of situational balance, control of movement, and muscular stabilization, and this may cause a positive effect to in-flight muscle strain. In addition, strength training, even with a slight increase in maximal muscle force, has a positive effect on neck muscle strain under +G\textsubscript{z} loading. Both training methods expand the muscles’ capacity in different ways. The greater the muscle capacity between maximum capacity and capacity needed during +G\textsubscript{z} loading, the smaller the risk of cervical injuries. A combined strength and trampoline training program has been included in fighter pilots’ physical education programs in Finland.

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