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Repetitive Stress and Strain Injuries: Preventive Exercises for the Musician

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Professional and amateur musicians commonly practice and play their instruments experiencing the physical pain of repetitive stress injury (RSI). Through improved understanding of the etiology and the acceptance of numerous lifestyle changes, including the addition of preventive exercises into the practice routine, the musician may be able to limit the effect of RSI on his or her life. The musician's intrinsic motivation to practice and to repeat motor patterns to perfection compounds the exposure to repetitive trauma [1]. Practice and performance postures are often less than optimal and serve as risk factors for increased RSI. Years, decades, and even centuries of customary practice patterns and schedules preclude the insinuation of ergonomically designed seating and instruments, safer and more comfortable practice methods, and playing positions. Both practice seating and performance seating are often folding or stackable chairs, or flat wooden benches. Lifestyle choices further contribute to higher risk for RSI. Lengthy practice sessions are customary, with short interruptions for fast foods, caffeine, or nicotine breaks. The musician may be unwilling to seek medical help early, because he or she is concerned that the physician will require the limitation of practice or performance times, or worse, instruct the musician to stop playing altogether. In addition, there is a social/work ethic concern about the label of an injured musician [2–5].

On the opposite side of the issue is the knowledge that the most effective treatment of RSI is prevention. Early detection and immediate intervention, within days or weeks of onset, may be effective in most cases for the most complete recovery [3]. Delays in seeking assistance, and delays in the initiation of appropriate care, contribute to severity of the injury and the need for long rest/recovery periods, surgery, or lengthy rehabilitation. Throughout the course of RSI, the musician experiences the loss of practice

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and performance ability, increased pain, and may lose the ability to perform on the instrument of choice completely [3].

Discussing repetitive injury in those whose craft involves precise repetition of motor patterns involves careful consideration, as muscle damage from repetitive trauma is thought to be dose-related. The longer the exposure to an injurious activity, the more likely pain and long-term harm will develop [6]. A phenomenon known as delayed-onset muscle soreness (DOMS) sometimes complicates the ability to notice the early onset of injury [2]. DOMS, well known in sports medicine, also applies to RSI of the musician. Because the onset of muscle pain may be delayed from 2 to 48 hours, the musician may continue playing well beyond the point of injury. As soreness ensues, the musician will adjust playing posture or technique to compensate for this pain. Muscles, tendons, and ligaments unaccustomed to demanding activity are more likely to be injured [2].

Etiology

The literature is replete with repetitive stress injury diagnoses. For the purposes of this article, neurological and muscle diagnoses will be included in the category repetitive stress injury. Other authors have correlated specific diagnoses to the postures and techniques associated with playing specific instruments. These may include repetitive grasping of the strings and neck of the violin, guitar, and cello, which may increase the risk of median and ulnar neuropathies (neurological) or lateral epicondylalgia (muscle). Percussionists are more likely to experience muscular inflammations. Postural requirements, such as supporting the violin with the chin while bowing, may increase risk for thoracic outlet syndrome and neck pain. DeQuervain's tendonitis may be a result of the acute flexion of the thumb for bowing. Balancing on the bench seat of an organ while playing with both hands and feet may contribute to the development of low and thoracic back pain [3–5,7,8].

Localized pain, weakness, cramping, and dystonia characterize muscle injuries. Tendonitis or tenosynovitis, epicondylitis, and focal dystonia are in this group. Muscle damage diagnosed as tendinitis is caused by microhemorrhages, tears at the tendon periosteal junction, and sprains and strains of the proximal tendon [2,6,9]. Extreme fatigue contributes to muscle ischemia and tendon creep [10], increasing the risk of muscle damage. Symptoms generally are localized, and the onset is often traceable to a specific incident.

The etiology of muscle dystonia is understood less well. The pianist is most at risk for this disability involving extra, unintentional movement of the fingers and painful cramping during use [11]. Muscle groups, such as the intrinsic hand muscles and long flexors of the thumb and fingers, contract uncontrollably, resulting in marked flexion of the digits, which is relieved only by discontinuing the activity and redirecting or resting the digits. Pianists are also prone to dystonia of the feet, and trombone players are at risk for dystonia of the facial muscles [8].

There is controversy regarding whether such neural injuries as carpal tunnel syndrome and thoracic outlet syndrome are related to activity. Increased incidence of these diagnoses has been demonstrated to correlate to specific activities [8,12,13]. Neural injuries generally are thought of as nerve entrapments [14–17]. The peripheral nerves pass through muscular and connective tissue compartments as they traverse the distance between the spinal cord and the distant limbs. The nerves must glide throughout their length to limit tension on the individual axons. Connective tissue adhesions limit the excursion of the nerve [18,19]. As adhesions increase, pain may be reported at points along the nerve. This may radiate proximally or distally.

MacKinnon and colleagues have shown that sensory axons in mixed nerves are more vulnerable to injury, because they are located in the fascicles on the periphery of the nerve [18]. Sensory disturbances such as paresthesias, nocturnal numbness and tingling, and hypersensitivity often are reported early in the course of these injuries. As the nerve injury progresses, muscle weakness and atrophy may occur.

Through their course, peripheral nerves travel through sites of common entrapment, including muscular and connective tissue compartments. The prolonged awkward postures of playing many instruments may lead to increased muscle tone and, perhaps, risk of peripheral nerve entrapment. Chronic hypertonicity may result in hypertrophy of these compartmental muscles, compressing the nerves within this more limited space. Further, connective tissue adhesions are more likely, as restrictions within the compartments limit neural glide and blood supply.

Poor posture and subsequent substitution patterns also contribute to compartmental pressure on the nerves [20,21]. Thoracic outlet syndrome is an example of one such injury. Loss of proximal scapular stabilization may lead to rotator cuff tears. Good balance and postural muscle sequencing are essential for proximal stability. Loss of normal muscular sequencing has been implicated in scapular instability [21–25]. Arm pain and weakness are natural consequences of this proximal instability.

Diagnosis

Early accurate diagnosis of a repetitive stress injury is imperative, as is early intervention. Medical history is the number one method of diagnosis. It is important to differentiate between muscle inflammation and neural irritation [26]. Early symptoms in muscle inflammation include localized pain, fatigue, and soreness that may begin during practice, or from 1 to 48 hours afterward. The onset of symptoms may follow a change in frequency or length of rehearsal, a new instrument, different seating, seasonal changes that expose the musician to cold drafts, or a slight injury followed by onset of soreness. Untreated, symptoms may escalate from little effect on either practice or performance, to shortening the tolerated length of

practice/performance, to constant pain during practice/performance, and finally to ending practice/performance and affecting activities of daily living [3,5,7,8].

Neural symptoms often have an insidious onset. The irritated nerve defines the distribution of paresthesias. One cardinal sign of carpal tunnel syndrome is paresthesias that occurs at night. Median nerve symptoms include the thumb, index finger, long finger, and radial half of the ring finger. Ulnar nerve symptoms include the ulnar-half of the ring and small fingers. Special tests include Phalen's and Tinel's sign. Although these may be useful, they are not conclusive. Both examination techniques may have false-positives and -negatives [27]. The diagnostic gold standard is the nerve conduction study, which quantifies slowing of the propagation of the neural action potential. Nerve conduction studies require careful interpretation. Carpal tunnel syndrome, for example, continues to be a clinical diagnosis. Combining clinical and electrodiagnositc tests with the medical history is effective in the accurate diagnosis of peripheral nerve injuries [27].

Prevention

The prevalence of RSI in musicians is such that primary treatment for RSI must be prevention. The most effective treatment is education and implementation of healthy lifestyle habits. Good nutrition, hydration, and the avoidance of caffeine, nicotine, and other stimulants are the building blocks of this treatment program. Awareness of muscle fatigue, onset of soreness or mild pain during or shortly after practice, and the will to take frequent rest breaks as soon as these become apparent help prevent RSI [5,7,8]. Aerobic exercise increases peripheral circulation and blood available for neural nutrition. Endurance training, with free weights, elastic bands or tubing, or exercise machines, prepares the musician for long hours of practice and performance, and helps ensure that the muscles and joints are more than up to the stresses and strains required. Endurance exercises can be incorporated into practice sessions. Consistent practice schedules help maintain muscle strength and limit painful overuse. Gradually increasing demands of practice and performance with a new instrument also may limit the risk of overuse injury.

There are many conditioning programs, such as Pilates, Feldenkrais, and yoga. Each is worth implementing as the base of the prevention program. Specific suggestions for exercise prescription will be illustrated [20]. Overall balance maintains the appropriate postural muscle sequencing and enhances core body stability. Prepractice and performance warm-ups are essential. Playing scales or slowly playing simple movements as the practice session begins allows the fingers to prepare for the challenges of playing [7,8]. Stretching has become somewhat controversial. Current research suggests only performing vigorous stretching when the muscles are warmed up to

prevent muscle damage from a rebound effect that increases hypertonicity. The exercises should be performed very gently, and within the pain-free range of motion. Postures should be entered slowly, and maintained for 30 to 60 seconds. Long practices should be interrupted by frequent sessions of gently stretching and range-of-motion exercises to improve circulation and relieve fatigue. Care must be taken to avoid pain, bouncing, or forcing the muscles to overstretch [28] (Figs. 1–4).

Movement enhances blood flow through the extremities, relieves fatigue, and bathes joints in synovial fluid. Microbreaks that include range of motion of the neck and extremities at regular short intervals are recommended to help improve comfort, reduce pain, and limit risk of overuse. Gentle stretching programs may be initiated throughout the day, more frequently during practice sessions, and before and following performances. These have some benefit in reducing discomfort and increasing peripheral circulation.

Stretches that have been recommended in numerous websites, textbooks, and journals [7,8,20–23,25,28,29] are simple and gentle. They can be done between sets, and frequently during practice and rehearsal. Note that stretching has been show to be potentially harmful if performed too vigorously, and has not been shown to provide protection from DOMS or RSI [2].

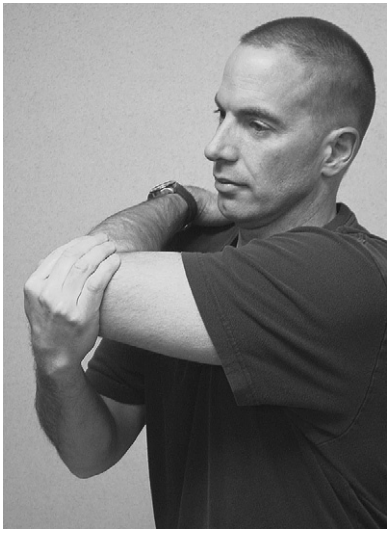

Fig. 1. Each of these stretches may be performed either standing or sitting. In either position, the shoulders are to be positioned in line above the pelvis, the chin tucked in as if trying to make a double chin. One hand is place on the opposite shoulder, and the opposite hand is placed behind the bent elbow to push, gently, stretching the posterior capsule.

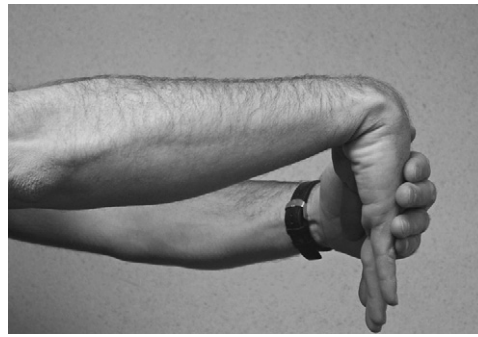

Fig. 2. The arms are flexed to 90°. The wrist of the stretched arm is flexed actively, and then the opposite hand is placed on the back of the first hand to stretch it gently into further flexion.

Ergonomics

Modifications in the instrument, seating, lighting, and even temperature regulation, such as avoiding cold drafts, contribute to effective prevention of overuse injuries. Occupational therapists are trained to assess the individual and match him/her with available adaptive devices. Additionally, they may be able to recommend alterations to instruments [30]. Ergonomically designed seating is available for use while playing specific instruments. Appropriate seating allows the feet to be firmly planted on the floor with the ankles, knees, and hips at a 90° angle. The lumbar lordosis should be supported, and the height of the seat pan requires adjustment that facilitates playing of the instrument. A firm, upholstered seat pan should have sufficient depth to position the musician's back against the back of the chair and the edge, allowing 1 to 2 in clearance to the back of the knees. The edge of the seat pan should be rounded, limiting pressure against the thighs or the back of the knees [31].

Fig. 3. To stretch the forearm extensors, the stretched arm is extended, and the wrist is extended actively. The opposite hand is placed on the palm perform a gentle stretch to the wrist.

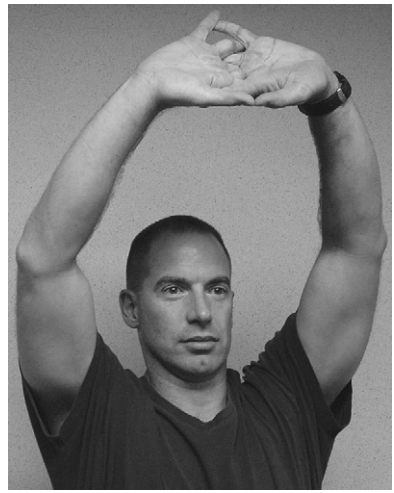

Fig. 4. This is a composite stretch for the shoulders, elbows, wrists, and hands. Starting position is with the fingers interlaced, elbows bent, with the hands resting on the lap. Keeping the fingers interlaced, turn the palms out and extend the elbows. Bring the hands slowly over the head and hold. Return to the resting position slowly.

Treatment and preventive exercises

Early intervention by medical care specialists, such as a physician or occupational or physical therapist, will provide the musician with information about the disorder, ergonomics, healthy lifestyle changes, and an overall exercise regime that may be helpful in stopping the progression of the injury. The initial evaluation takes note of range-of-motion limitations, especially in joints that are more proximal. Poor balance, as in standing on one leg for less than 30 seconds with eyes open or 15 seconds with eyes closed [25], may indicate a sequencing deficit that creates inhibition patterns in postural muscles. Regional strength is tested through grip strength and manual muscle testing. Muscle tone in the neck, upper back, shoulder, and upper limb should be assessed through palpation and manual muscle testing. Hypertonicity in the neck and back supports the notion of a sequencing disorder and suggests the patient may be substituting extremity muscles for posture stabilization over the proximal trunk muscles.

Treatment should include outpatient intervention and a home program. The first intervention includes rest and avoidance of painful activity. Splinting, adaptive techniques, or absolute rest may help to accomplish this. Anti-inflammatory treatments may include heat, ice, massage, counter strain, trigger point release, electrical stimulation, myofascial release, iontophoresis with steroids, ultrasound, or laser therapy. Strengthening of the effected region may follow; however it is essential that the patient be warned to avoid pain. Muscle damage is already present, and working in pain should

be avoided to preclude exacerbation of the injury [7,26,32,33]. Emphasis upon trunk posture and scapular stabilization is essential throughout the strengthening phase [20].

Trunk stabilization

One of the elementary exercises for trunk stability is known as the pelvic clock [25]. Patients lie supine with the hips and knees bent to about 45°, feet flat on the surface. They imagine a clock on their abdomen, with the 12 o'clock position toward the head, 6 o'clock toward the feet. Patients then are directed to rock the pelvis toward the 12 and 6 o'clock positions on the imagined clock, using only the abdominal muscles. As patients master this motion, they are instructed to rock the pelvis to point toward each of the hour positions. Patients then are taught the same exercise standing. They stand facing a wall with the feet shoulder-width apart, the hands placed on the wall at shoulder level with the elbows bent slightly (Fig. 5).

Facilitation of the postural muscles and re-establishing normal muscle sequencing for balance and proximal trunk stabilization require gross motor stimulation. Initiation of this treatment is done through balance exercises on a Swiss ball [34–36]. The patient sits on a ball large enough for him or her to sit with the hips, knees, and ankles at a 90° angle. The patient uses abdominal muscles to perform a pelvic clock. As balance is achieved, and

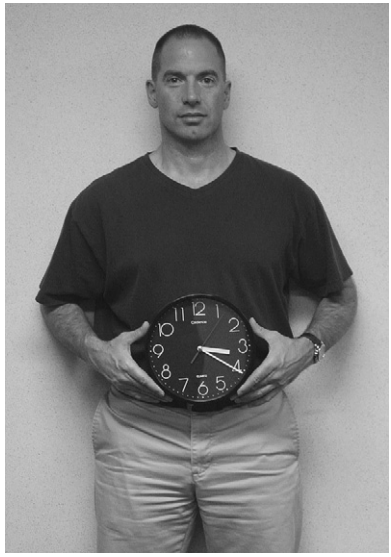

Fig. 5. This illustrates the athletic stance, feet shoulder-width apart, pelvis tucked in a forward pelvic tilt. The illustration of the clock face provides a reference for positioning. The pelvis is rocked in the direction of each of the numerals on the clock face with the abdominal muscles. The instruction to avoid use of the leg muscles for positioning is emphasized.

the patient reports being ready for the next step, the patient is instructed to bounce, making sure maintain at least slight contact with the ball. Balance and coordination exercises escalate, first asking the patient to raise the knees reciprocally every third bounce (hands are on the sides of the ball); then the hands are raised to shoulder level, also in a reciprocal pattern at the same rate. These moves are combined with the patient bouncing, and then raising one knee and the opposite arm reciprocally. Increasing the frequency of the knee and arm raises makes the exercise more complex (Fig. 6).

Shoulder stabilization

Awareness of the position of the scapula during shoulder range-of-motion exercises may assist the patient in establishing improved patterns of shoulder stability [37]. The patient may need to be retrained in engaging latissmus dorsi, levator scapulae, the rhomboids, serratus anterior and posterior, and the rotator cuff muscles in sequence. One exercise that assists with this retraining is the shoulder clock. The patient is placed in side lying position with a pillow that supports the head in a neutral position. The patient keeps the hips perpendicular to the mat throughout the exercise.

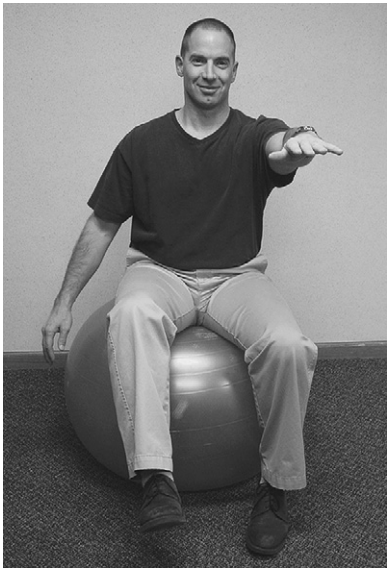

Fig. 6. The weight is centered on the ball. The pelvic clock is an introductory exercise that assists with establishing balance and flexibility on the exercise ball. As balance and comfort improve, bouncing, marching in place, and raising the arms reciprocally are introduced one at a time. These motions are performed in combination as comfort and balance allow. They are made more difficult by increasing speed, height of the limbs in the reciprocal pattern, and complexity of the arm motions. Clapping in rhythm may be introduced as an additional level of difficulty.

The therapist supports the scapula with one hand, while directing the motion of the arm closest to the ceiling with the other. The patient starts with both hands together, arms flexed at the shoulder to 90°, elbows in extension (3 o'clock). The patient is directed to stretch the upper arm so the hand is just past the lower hand. He or she then moves her arm to the 2 o'clock position, and the therapist give feedback regarding the position and stability of the scapula. As the patient moves past the 12 o'clock position, he or she will find it necessary to pivot the upper body so the shoulders are resting on the mat. He or she will pivot back to the original position to complete the circle (Fig. 7).

Upper quadrant strengthening

Shoulder range of motion against gravity is the first step in progressive resistive exercises. Isometric shoulder, elbow, and wrist exercises are added, with emphasis on the musician's ability to limit fatigue or pain by limiting effort. Codman exercises are a widely used program for improving shoulder range of motion. These should be performed early in the strengthening progression with 1 lb weights. As long as the individual is pain-free, low-weight free weight exercises are added and advanced slowly.

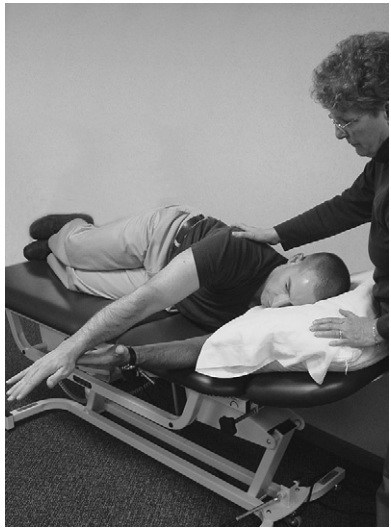

Fig. 7. The shoulder clock is performed while lying on one side. The head is supported in mid-line on a pillow. The pelvis is maintained in this position throughout the exercise. The therapist manually repositions the scapula, facilitating positions of stability. The free arm is rotated slowly into forward flexion, and the trunk is rotated to allow a full swing of the arm through a full rotation. At each hour on an imaginary clock face, the therapist provides manual feedback to encourage scapular stabilization. After several practices with the therapist, the musician may perform this exercise as part of the exercise regime.

Stress-loading exercises are weight-bearing exercises described as closed chain or weight-bearing. The musician stands next to the exercise ball, bends over slightly bending the knees, places the open hands palm down on the ball about shoulder-width apart. The musician increases the percentage of body weight borne through the extended arms gradually, paying close attention to the position of the scapula reviewed in the arm circle exercise. The exercise is graded by lifting the ball to shoulder height and pushing against the ball just hard enough to maintain its position on the wall. The musician traces a small circle with the ball, moving it by walking hand over hand. As the exercise becomes easier, increase the size of the circle. Finally, when the circles are performed without pain, and can be continued for at least 5 minutes, the pattern is changed from a circle to tracing a large X on the wall. The center of the X is about chest high and at the midline of the body. The ball is rolled up and down along the legs of the X. As the exercise advances in difficulty, the musician must take care to avoid excess fatigue and pain. It may take several weeks to work through each level of the graded activity (Fig. 8).

Upper limb progressive resistive exercises are introduced when the inflammatory pain has subsided [21]. Eccentric strengthening is effective, but if done too aggressively, it increases the risk of inflammation. The progression of the exercise program is initiated with light resistance and low weights. One session is comprised of exercises that use resistance bands, free weights, and exercise putty.

Posture is very important when performing strengthening exercises. The musician is instructed to stand with feet shoulder-width apart, bend the

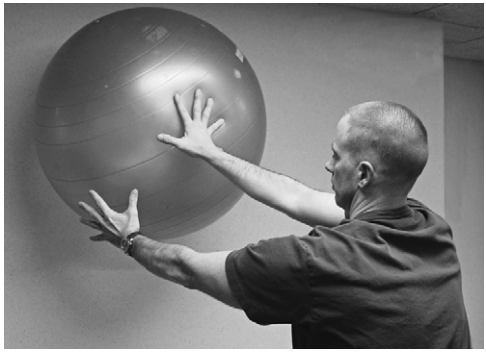

Fig. 8. Stress loading is a weight-bearing activity throughout the upper limb. It is introduced with the Swiss ball on the floor, in front of the musician. The hands are placed on the ball approximately shoulder-width apart, and the weight of the upper body is borne by the hands on the ball. Scapular stabilization is emphasized. The exercise is graded by lifting the ball to shoulder level on a wall, and instructions are given to press the hands into the ball just enough to hold it to the wall. The hands walk it so it traces a small circle. As comfort and strength allow, the circle is enlarged, and finally a large X pattern is traced using the same technique of walking the ball with the hands.

knees slightly, rock the pelvis into the 12 o'clock position, tuck the chin, and adduct the scapulas with arms at the side, a position sometimes referred to as an athletic stance.

Exercise bands made of latex or rubber are graded beginning at very light resistance. There are many brands of these bands, and they are available through medical supply and athletic stores (Figs. 9–11). Each of the exercises is repeated 10 times. The exercises are advanced weekly by increasing the repetitions by sets of 10 up to three sets. Then increase the repetitions to 15. These sessions are performed two to three times a day. Exercises are initiated at 1 lb, and graded up 1 lb at a time to 3 lbs maximum. Emphasis for increasing difficulty is on increasing repetitions.

Exercise putty is one of the products inspired by silly putty. This versatile therapy media strengthens flexion and extension of the hand muscles. Exercises have been designed to strengthen intrinsic muscles and connective tissue structures of the joints. Rolling, pulling, making a donut shape and placing all the digits inside the loop and stretching the fingers and thumb out as if indicating the number five, pinching, and squeezing are among the countless ways to exercise. It is important to limit the length of the exercise. Typically 5-min sessions are assigned, two to three times a day. It is important to stop this and any other exercise at the point of fatigue. No one should be directed to use a tennis ball for strengthening.

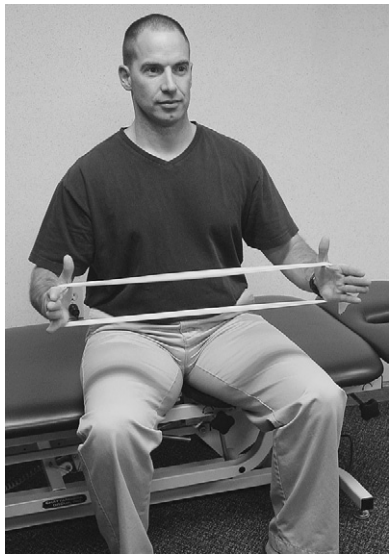

Fig. 9. Loop the band around the back of the hands. The loop is made so it is just long enough so the hands are shoulder-width apart with no tension on the loop with the wrists locked in a neutral position and the elbows at 90° of flexion. The exercise is initiated by spreading the hands apart, as if demonstrating the size of a fish caught, just far enough to be challenging, but not so far as to pull the wrists into flexion.

Fig. 10. While seated, chin tucked, loop the band around the ball of the foot; place one elbow on the knee on the same side, grasping the band firmly in the hand with the wrist locked in a neutral position. Perform bicep curls, keeping the wrist locked in a neutral position throughout the exercise.

Neural tension

Neural tension is a significant problem in RSI. As adhesions develop along the length of the peripheral nerve, the nerve is unable to glide through its full excursion. Evidence is noted when there is a complaint of pain or paresthesias in composite range of motion of an extremity, but not during isolated range of motion of a single joint [22,23]. Provocative positions have been defined to evaluate neural tension signs of each peripheral nerve. Paresthesias and pain are the primary complaints. It is possible to use the same positions for treatment. As patients assume the symptomatic position, they are instructed to move in and out of the position that causes the symptom. This maneuver is termed, nerve gliding. It is particularly important for the patient to be instructed to avoid pain, extremes of numbness and tingling, and to be alert for increased paresthesias or pain [7,21,29,38].

Summary

There are many articles that support stretching, strengthening, good nutrition, hydration, rest, and ergonomics along with many other concepts that may be helpful in preventing repetitive stress injuries. The most conclusive literature proposes early recognition of onset of symptoms, and

Fig. 11. Resume the standing position after fastening the band to a stable structure, such as the doorknob of a closed door. Grasp the band with both hands; keep the wrists in neutral. Extend the elbows in a rowing motion, bringing them straight down to the side.

immediate reduction or cessation of the causal activity. This is not well accepted by the musician, because this means an interruption of practice and performance. Just like any worker or athlete at risk for RSI, however, the musician must learn to recognize early signs and take the steps to limit damage to muscular and neural tissues. More studies are needed to provide evidence for effective treatment and prevention of RSI.

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References

[1] Brandfonbrener A. Musculoskeletal problems of instrumental musicians. Hand Clin 2003; 19(2):231–9.
[2] Cheung K, Hume P, Maxwell L. Delayed onset muscle soreness: treatment strategies and performance factors. Sports Med 2003;33(2):145–64.
[3] Chong J, Lynden M, Harvey D, et al. Occupational health problems of musicians. Can Fam Physician 1989;35:2341–8.
[4] Fry H. Incidence of overuse syndrome in the symphony orchestra. Med Probl Perform Art 1986;1:51–5.
[5] Fry H. Overuse syndrome of the upper limb in musicians. Med J Aust 1986;144:182–5.

[6] Prasartwuth O, Taylor JL, Gandevia SC. Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles. J Physiol 2005;567: 337–48.
[7] Norris R. The musician's survival manual: a guide to preventing and treating injuries in instrumentalists. St. Louis (MO): MMB Music Incorporated; 1993.
[8] Safety & Health in Arts Production & Entertainment (SHAPE). Preventing musculoskeletal injury (MSI) for musicians and dancers. Available at: http://www.shape.bc.ca/resources/pdf/msi.pdf. Accessed August 11, 2006.
[9] Slater H, Arendt-Nielsen L, Wright A. Sensory and motor effects of experimental muscle pain in patients with lateral epicondylalgia and controls with delayed onset muscle soreness. Pain 2005;114:118–30.
[10] Maganaris CN. Tensile properties of in vivo human tendinous tissue. Biomed Eng 2003; 31(6):710–7.
[11] Leijnse JNAL. Anatomical factors predisposing to focal dystonia in the musician's hand - principles, Theoretical examples, clinical significance. J Biomech 1997;30(7):659–69.
[12] Personick ME. Brief: types of work injuries associated with lengthy absences from work. Compensation and working conditions online. Available at: www.bls.gov/opub/cwc/1997/fall/brief3.htm. Accessed August 11, 2006.
[13] Stevens J, Witt J, Smith B, Weaver A. The frequency of carpal tunnel syndrome in computer users at a medical facility. Neurology 2001;56(11):1431–2.
[14] Stroller D, Brody GA. The wrist and hand/carpal tunnel syndrome. In: Stroller DW, editor. MRI in orthopedics and sports medicine. 2nd edition. Philadelphia: Lippincott-Raven; 1997. p. 852–963.
[15] Seradge H, Bear C, Bithell D. Preventing carpal tunnel syndrome and cumulative trauma disorder: effect of carpal tunnel decompression exercises. An Oklahoma experience. J Okla State Med Assoc 2000;93(4):150–3.
[16] Rempel D. Musculoskeletal loading and carpal tunnel pressure. Repetitive motion disorders. Rosemont (IL): American Academy of Orthopedic Surgeons; 1995. p. 123–32.
[17] Okutsu I, Hamanaka I, Chiokura Y, et al. Intraneural median nerve pressure in carpal tunnel syndrome. J Hand Surg [Am] 2001;26B(2):155–6.
[18] Mackinnon S, Dellon A. Anatomic investigations of nerves at the wrist: I. Orientation of the motor fascicle of the median nerve in the carpal tunnel. Ann Plast Surg 1988;21: 32–5.
[19] Shafer-Crane GA, Meyer RA, Schlinger MA, et al. Effect of occupational keyboard typing on magnetic resonance imaging of the median nerve in subjects with and without symptoms of carpal tunnel syndrome. Am J Phys Med Rehabil 2005;84(4):258–66.
[20] Liemohn W. Exercise prescription and the back. New York: McGraw-Hill Medical Publishing Division; 2001.
[21] Karageanes SJ. Principles of manual sports medicine. Philadelphia: Lippincott Williams and Wilkins; 2004.
[22] Butler D. Mobilisation of the nervous system. Melbourne (Australia): Churchill Livingstone; 1991.
[23] Butler D. The Sensitive nervous system. Adelaide (Australia): Norgroup Publications; 2000.
[24] Magee D. Orthopedic physical assessment, 4th edition. Philadelphia: W.B. Saunders; 2002.
[25] Greenman P. Principles of manual medicine. 2nd ed. Baltimore (MD): Williams and Wilkins; 1996.
[26] Ranney D. Work-Related chronic injuries of the forearm and hand; their specific diagnosis and management. Ergonomics 1993;36(8):871–80.
[27] Gomes I, Becker J, Ehlers J, et al. Prediction of the neurophysiological diagnosis of carpal tunnel syndrome from the demographic and clinical data. Clin Neurophysiol 2006;117(5): 964–71.
[28] Andersen J. Stretching before and after exercise: effect on muscle soreness and injury risk. J Athl Train 2005;40(3):218–20.

[29] Coppieters M, Bartholomeeusen KE, Stappaerts KH. Incorporating nerve-gliding techniques in the conservative treatment of cubital tunnel syndrome. J Manipulative Physiol Ther 2004;27(9):560–8.
[30] Norris R. Applied ergonomics; adaptive equipment and instrument modification for musicians. Md Med J 1992;42(3):271–5.
[31] Thibodeau P, Melamut SJ. Ergonomics in the electronic library. Bull Med Libr Assoc 1995; 83(3):233–9.
[32] Bottas R, Linnamo V, Nicol C. Repeated maximal eccentric actions causes long-lasting disturbances in movement control. Eur J Appl Physiol 2005;94:62–9.
[33] Nie H, Kawczynski A, Madeleine P. Delayed-onset muscle soreness in neck/shoulder muscles. Eur J Pain 2005;9(6):653–60.
[34] Marshall P, Murphy BA. Core stability exercises on and off a Swiss ball. Arch Phys Med Rehabil 2005;86(2):242–9.
[35] Lehman G, Gordon T, Langley J, et al. Replacing a Swiss ball for an exercise bench causes variable changes in trunk muscle activity during upper limb strength exercises. Dyn Med 2005;4:6.
[36] Lehman G, Hoda W, Oliver S. Trunk muscle activity during bridging exercises on and off a Swiss ball. Chiropr Osteopat 2005;13:14.
[37] Zehr E, Collins DF, Frigon A, et al. Neural control of rhythmic human arm movement: phase dependence and task modulation of Hoffmann reflexes in forearm muscles. J Neurophysiol 2003;89(1):12–21.
[38] Pinar LEA, Ada S, Gungor N. Can we use nerve gliding exercises in women with carpal tunnel syndrome? Adv Ther 2005;22(5):467–75.