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Neuromuscular control and musculoskeletal injuries in musicians: a critical review

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ABSTRACT

Musicians are highly vulnerable to musculoskeletal injuries due to the repetitive and sustained physical demands of playing instruments. While neuromuscular control is crucial in stabilising joints and muscles to prevent such injuries, its role in developing and preventing MSIs has received limited attention. In this review, we synthesise findings from studies examining the impact of neuromuscular control and training interventions on MSIs in musicians. Evidence suggests that proprioceptive training, motor control exercises, and dynamic stability drills can enhance joint stability and reduce injury risk, positively affecting performance outcomes. However, much of the existing research is limited by cross-sectional designs. Future studies should focus on longitudinal approaches to better understand the neurocognitive mechanisms underlying these benefits and explore the practical implications of integrating neuromuscular training into musicians' routines for long-term physical health and career sustainability.

KEYWORDS: neuromuscular control; musculoskeletal injuries; musicians; proprioception; motor control; injury prevention.

INTRODUCTION

Musculoskeletal injuries (MSIs) are common among musicians (Cardoso et al., 2019; Lephart et al., 1997; Zaza, 1998). Many playing-related musculoskeletal disorders (PRMDs) in musicians are linked to various factors: (i) intrinsic factors such as joint hypermobility, age, and gender (Ranelli et al., 2011; Yeung et al., 1999); (ii) extrinsic factors including warm-ups, playing hours, playing position, posture, and playing techniques (Foxman & Burgel, 2006; Kaufman-Cohen & Ratzon, 2011); and (iii) psychosocial factors like stage fright and anxiety (Williamon & Thompson, 2006). Recent studies highlight the prevalence of musculoskeletal disorders among professional musicians and young music students (Frizziero et al., 2018; Hamedon et al., 2019; Overton et al., 2018; Rensing et al., 2018). Promoting awareness of conscious practices and preventive strategies is crucial for young music students when learning to play musical instruments (Cardoso et al., 2023).

Neuromuscular control, defined as the body's ability to coordinate muscle activation to maintain joint stability and control during movement, is vital in preventing MSIs. Impairments in neuromuscular control can lead to compensatory movement patterns, increased mechanical load on joints and muscles, and injury. Neuromuscular control involves proprioception, motor control, and joint stabilisation, which are critical for maintaining proper movement mechanics. Proprioception refers to the body's ability to sense its position and movement in space, allowing for the coordination of movements that prevent injury (Lephart et al., 1997). Conversely, motor control is the process by which the central nervous system coordinates muscle activation to produce smooth and controlled movements (Riemann & Lephart, 2002). In musicians, deficits in neuromuscular control can lead to inefficient movement patterns and poor joint alignment, increasing the risk of MSIs. For example, musicians with weak core stability may compensate by misusing their arms and shoulders, placing excessive strain on these muscles and joints. Additionally, impaired proprioception can result in delayed or inaccurate motor responses, increasing the risk of injury (Wilke et al., 2011). Neuromuscular

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control is essential for maintaining proper posture, executing precise movements, and stabilising joints under the physical demands of playing an instrument.

Given musicians' high susceptibility to musculoskeletal injuries (MSIs), understanding the role of neuromuscular control in injury prevention is crucial. This critical review examines how neuromuscular control contributes to injury prevention and highlights the potential benefits of neuromuscular training interventions for musicians.

MUSCULOSKELETAL INJURIES IN MUSICIANS

Musicians are particularly vulnerable to musculoskeletal injuries (MSIs) due to the specific physical requirements of playing musical instruments (Ajidahun et al., 2017; Clemente et al., 2018; Foxman & Burgel, 2006; Frizziero et al., 2018; Hamedon et al., 2019; Kaufman-Cohen & Ratzon, 2011; Overton et al., 2018; Ranelli et al., 2011; Rensing et al., 2018; Yeung et al., 1999). Their repetitive and sustained movements strain muscles, tendons, and joints continuously, leading to musculoskeletal injuries (MSIs). These conditions are often linked to overuse, poor posture (Foxman & Burgel, 2006; Kaufman-Cohen & Ratzon, 2011), and the extended periods musicians spend practising and performing without adequate rest and recovery (Zaza, 1998). Common MSIs among musicians include tendinitis, repetitive strain injuries (RSI), and carpal tunnel syndrome (Watson, 2009), depending on the instrument played and the specific movements required. Tendinitis, an inflammation of the tendons, frequently affects musicians who perform repetitive actions, such as violinists and pianists. In pianists, for instance, the wrist and finger tendons are particularly prone to injury due to the repetitive flexion and extension required for playing complex passages, often leading to tendinitis in the forearm or wrist (Foxman & Burgel, 2006). Similarly, guitarists and violinists frequently suffer from tendinitis in the shoulders or elbows due to the continuous movements required for bowing or fretting. Repetitive Strain Injuries (RSI) are another common issue, especially among string players and pianists. RSI develops from prolonged, repetitive motions that cause microtrauma to muscles and tendons, eventually resulting in pain and dysfunction. For string players, the asymmetrical body positioning (such as holding the violin or cello in place for long periods) creates muscle imbalances, leading to shoulder and neck strain (Steinmetz et al., 2015). These injuries are exacerbated by improper posture and inadequate ergonomic support during performance. Carpal Tunnel Syndrome is also prevalent among pianists, guitarists, and woodwind players who engage in repetitive wrist motions. This condition occurs when the median nerve, which runs through the carpal tunnel in the wrist, becomes compressed due to inflammation from overuse. Symptoms include numbness, tingling, and weakness in the hand and fingers, which can significantly impair a musician's ability to play (Watson, 2009). Musicians with carpal tunnel syndrome may struggle with grip strength, finger dexterity, and control, ultimately affecting their performance quality.

Musculoskeletal injuries in musicians are often caused or exacerbated by poor biomechanics and posture (Ajidahun et al., 2017; Cardoso et al., 2019; Clemente et al., 2018; Frizziero et al., 2018; Hamedon et al., 2019; Kaufman-Cohen & Ratzon, 2011; Overton et al., 2018; Ranelli et al., 2011; Rensing et al., 2018). Posture is critical in distributing physical stress evenly across the musculoskeletal system. Musicians who adopt poor posture, such as slumping shoulders, hyperextending the wrists, or craning the neck, place undue strain on specific areas, leading to muscle imbalances and overuse injuries (Foxman & Burgel, 2006; Kaufman-Cohen & Ratzon, 2011). For example, pianists who sit too low or too high relative to the keyboard may develop wrist and shoulder strain. In contrast, violinists who raise their arms above shoulder level for extended periods are at risk for shoulder and upper back injuries. The repetitive motions involved in playing instruments also contribute to MSIs. String players, for example, often develop shoulder, neck, and upper back strain due to the constant positioning required to hold their instruments. The asymmetric posture necessary for playing instruments like the violin or cello places uneven stress on the body, causing muscle imbalances. This stress is compounded by the repetitive movements of the bowing arm and the fine motor control required in the fretting hand, leading to overuse injuries if not managed properly. Similarly, pianists are at high risk of MSIs due to the repetitive flexion and extension motions needed to play complex passages. The frequent wrist flexion involved in playing the piano can cause tendinitis, while repetitive finger movements strain the flexor tendons, potentially leading to injuries such as De Quervain tenosynovitis (Foxman & Burgel, 2006). The biomechanical demands of playing the piano require musicians to maintain precise hand positioning and wrist alignment, which, if improperly managed, can result in chronic pain and disability. Woodwind and brass players also face unique biomechanical challenges (Clemente et al., 2018). These musicians often hold their instruments in front of their bodies for extended periods, leading to upper back, neck, and shoulder strain. The sustained force required to blow into the instrument can cause strain in the muscles of the face, jaw, and neck, potentially resulting in

temporomandibular joint (TMJ) disorders (Steinmetz et al., 2015). These painful injuries can significantly impact performance, sometimes resulting in chronic conditions that may force musicians to curtail or even end their careers prematurely (Foxman & Burgel, 2006). These injuries highlight the importance of understanding the biomechanical demands placed on musicians and the role of neuromuscular control in mitigating these risks.

NEUROMUSCULAR CONTROL IN INJURY PREVENTION

Neuromuscular control is an essential aspect of injury prevention across various physical activities, as it involves the body's ability to regulate and coordinate muscle activation, stabilise joints, and maintain proper movement mechanics. This control is crucial for ensuring that movements are efficient, smooth, and capable of adjusting to changes in load or position without causing excessive strain on muscles, tendons, and joints. Neuromuscular control integrates several key elements (proprioception, motor control, and joint stabilisation), which together contribute to reducing the risk of injury and improving overall physical function:

- Proprioception is the body's ability to sense its position and movement in space. This awareness is provided by sensory receptors located in muscles, tendons, and joints, which send signals to the brain about the body's orientation and the forces acting on different parts of the musculoskeletal system (Lephart et al., 1997). Proprioception plays a central role in injury prevention by allowing the body to detect changes in position or load and make real-time adjustments to avoid harmful movements or misalignment. For example, in athletic activities like running or jumping, proprioceptive feedback helps individuals maintain proper alignment of their lower limbs, reducing the risk of knee or ankle injuries. When proprioception is impaired, such as after a previous injury, the body may struggle to sense misalignments or shifts in movement patterns, increasing the likelihood of further injury. Proprioceptive training exercises, such as balance drills or exercises on unstable surfaces, are commonly used to improve joint stability and restore the body's ability to react to changes in movement, ultimately reducing injury risk (Riemann & Lephart, 2002).
- Motor control refers to the process by which the central nervous system (CNS) coordinates muscle activation to produce controlled, precise movements. The brain can send the right signals to the muscles to initiate, sustain, and adjust movements in response to environmental or internal cues. In injury prevention, motor control ensures that the appropriate muscles are activated in the correct sequence and with the necessary force to maintain joint stability and perform complex tasks efficiently (Riemann & Lephart, 2002). Deficits in motor control can lead to inefficient movement patterns that place excessive stress on certain joints or muscles, making them more susceptible to overuse injuries. For example, poor motor control in the lower back and core muscles can result in compensatory movements in the legs and arms, leading to strain on the knees or shoulders. Inadequate motor control during fast or dynamic movements, such as cutting or pivoting in sports, can result in joint misalignment and increase the risk of injuries like anterior cruciate ligament (ACL) tears. Motor control exercises that activate stabilising muscles, particularly around the core, hips, and shoulders, are often incorporated into injury prevention programs. These exercises teach the body to engage the correct muscle groups for efficient movement, reducing the risk of compensatory movements that coul lead to injury (Bliven & Anderson, 2013).
- Joint stabilisation refers to the ability of the muscles surrounding a joint to provide support and maintain proper alignment during movement. Stable joints are less prone to injury because they can better handle the mechanical forces applied to them during physical activity. Joint instability, on the other hand, increases the likelihood of misalignment, excessive wear, and injury, particularly in dynamic or high-impact activities like sports. Neuromuscular control is essential for maintaining joint stability because it ensures stabilising muscles are activated appropriately during movement. For instance, during a jumping or landing movement, the stabilising muscles around the knee joint (such as the quadriceps and hamstrings) must work together to absorb impact and maintain proper knee alignment. If these muscles do not activate properly or lack strength, the knee may collapse inward, increasing the risk of ligament injuries such as ACL tears (Lephart et al., 1997). Strengthening exercises, particularly those targeting the core, hips, and lower limbs, are crucial for stabilising joints and preventing injuries. These exercises often involve dynamic movements that challenge the body's ability to maintain joint alignment under changing conditions, such as single-leg squats, lunges, or plyometric drills. By improving joint stability, these exercises help protect

against injury by ensuring that the body can withstand mechanical stresses during athletic performance (Riemann & Lephart, 2002).

Injury prevention is relevant for uninjured individuals and is critical in rehabilitation and recovery following an injury. After an injury, neuromuscular control is often compromised, as sensory receptors may be damaged, and muscle coordination can become impaired. This increases the risk of re-injury if neuromuscular function is not adequately restored (Hrysomallis, 2007). Rehabilitation programs frequently incorporate neuromuscular training to restore proprioception, improve motor control, and strengthen stabilising muscles. For example, rehabilitation exercises may focus on regaining balance and proprioceptive awareness after an ankle sprain through balance board training or single-leg exercises. Similarly, motor control exercises that emphasise coordinated muscle activation around the knee joint after an ACL injury are crucial for regaining full function and preventing future injuries (Lephart et al., 1997).

Neuromuscular control, encompassing proprioception, motor control, and joint stabilisation, plays a fundamental role in injury prevention. It allows individuals to maintain proper movement mechanics, stabilise joints, and react to changes in movement or load, which are critical for reducing the risk of injury in various physical activities. Improving neuromuscular control through targeted training programs can enhance balance, coordination, and joint stability, protecting the body from the cumulative stresses of repetitive movements and dynamic actions. In sports, daily life, or rehabilitation, neuromuscular control is key to maintaining musculoskeletal health and preventing injury.

NEUROMUSCULAR TRAINING FOR MUSICIANS

Neuromuscular control is essential to injury prevention and performance optimisation for musicians. It refers to the body's ability to regulate muscle activity, stabilise joints, and coordinate movements through proprioception, motor control, and joint stabilisation. Each element plays a crucial role in maintaining proper movement mechanics, particularly in the context of musicians' repetitive and physically demanding tasks. Proprioception provides essential feedback to the central nervous system about the joint position, movement, and force, allowing the body to adjust muscle activity to maintain balance and prevent injury (Lephart et al., 1997). In musicians, proprioception enables fine motor control, which is crucial for executing precise and coordinated movements required for playing an instrument. Musicians may experience difficulties maintaining proper posture and movement patterns when impaired proprioception leads to inefficient and potentially harmful body mechanics. For example, a violinist with poor proprioception might not be aware of subtle misalignments in their bowing arm, leading to excessive strain on the shoulder and elbow joints. Over time, these small misalignments can accumulate, resulting in overuse injuries such as tendinitis or repetitive strain injuries (Wilke et al., 2011). Additionally, poor proprioception can cause delays in motor responses, making it harder for musicians to adjust their movements in real time, further increasing the risk of injury.

Motor control is the process by which the central nervous system (CNS) coordinates muscle activation to produce smooth, controlled movements. It involves complex interactions between sensory feedback (proprioception) and motor output, allowing the body to adjust movement based on environmental and internal cues (Riemann & Lephart, 2002). In musicians, motor control is critical for achieving the precise timing and coordination needed to play an instrument effectively. Deficits in motor control can result in inefficient or compensatory movement patterns. For example, a musician with weak core muscles may rely too heavily on their upper body to maintain stability while playing, leading to excessive strain on the shoulders and arms. This compensation can create muscle imbalances and joint instability, increasing the likelihood of musculoskeletal injuries (MSIs) (Ackermann & Adams, 2003; Chan et al., 2013; Kaufman-Cohen & Ratzon, 2011).Proper motor control allows musicians to distribute physical effort evenly across the body, reducing localised strain and improving overall movement efficiency. Musicians who struggle with motor control may also have difficulty transitioning smoothly between different playing techniques or maintaining consistent muscle activation during long practice sessions. For instance, a pianist with poor motor control might experience inconsistent finger strength and dexterity, leading to uneven pressure on the keys and increased fatigue. Over time, this can lead to injuries such as tendinitis or carpal tunnel syndrome, which is common among musicians who perform repetitive movements without adequate muscle coordination (Foxman & Burgel, 2006).

Joint stabilisation refers to the ability of the muscles surrounding a joint to provide support and maintain alignment during movement. Stable joints are less likely to experience excessive wear and tear, critical for preventing MSIs, particularly in musicians who engage in repetitive and sustained movements (Wilke et al., 2011). Neuromuscular control plays a vital role in joint stabilisation by ensuring muscles activate at the right time and with the appropriate force to maintain

joint alignment. For musicians, joint stability is crucial in the wrists, shoulders, and spine, which are frequently involved in playing instruments. For example, a pianist must maintain stable wrist and finger joints to produce smooth and controlled keystrokes. At the same time, a violinist relies on shoulder and neck stability to hold their instrument in the correct position for extended periods (Zaza, 1998). When joint stabilisation is compromised, musicians may experience joint misalignment, leading to increased friction, inflammation, and eventual injury. Weak core muscles are often a significant contributing factor to poor joint stabilisation in musicians. The core muscles (abdominals, obliques, and lower back) stabilise the entire body. When these muscles are weak, musicians may struggle to maintain proper posture, leading to compensatory movements in the upper body that place excess strain on the arms, shoulders, and neck (Ackermann & Adams, 2003; Chan et al., 2013; Kaufman-Cohen & Ratzon, 2011). Strengthening the core through targeted neuromuscular training can improve joint stabilisation, reduce compensatory movement patterns, and decrease the risk of MSIs.

Musicians are particularly vulnerable to neuromuscular deficits due to the physical demands of playing instruments. The repetitive movements, prolonged static postures, and high levels of precision required can lead to fatigue and muscle imbalances, which can compromise neuromuscular control (Foxman & Burgel, 2006; Kaufman-Cohen & Ratzon, 2011; Watson, 2009). For example, a cellist who spends long hours seated may develop tight hip flexors and weak gluteal muscles, which can affect pelvic stability and lead to lower back pain. Similarly, a flautist may create imbalances between the dominant and non-dominant arms, leading to shoulder instability and increased risk of injury. When neuromuscular control is compromised, musicians may adopt inefficient movement patterns that increase their risk of MSIs. For example, a pianist with poor core stability may overcompensate by using their arms and shoulders to support their posture, leading to excessive strain on these muscles and joints. Additionally, impaired proprioception can result in delayed or inaccurate motor responses, making it difficult for musicians to adjust their movements in real time and increasing their risk of injury (Wilke et al., 2011).

THE EFFECTIVENESS OF NEUROMUSCULAR INTERVENTIONS

Improving neuromuscular control is essential for preventing MSIs in musicians and enhancing their performance (Ajidahun et al., 2019; Baader et al., 2005; Chan et al., 2013; Enke & Poskey, 2018; Kimoto et al., 2019; Lephart et al., 1997; Young & Winges, 2017). Changes in neuromuscular control due to musculoskeletal dysfunction could negatively affect the fine motor skills required for optimal musical performance.

Chan et al. (2013) research report positive results in this field. Their exercise programme for managing PRMDs in the members of professional orchestras included neuromuscular control (a crucial role in the skill development of string players) and strength and endurance training. Exercise-based injury prevention and rehabilitation programs in sports that incorporate proprioceptive and neuromuscular control elements show promising results in musculoskeletal injury recovery (Ajidahun et al., 2019; Schiftan et al., 2015; Steffen, 2013; Van Vliet & Heneghan, 2006). These positive effects are attributed to feed-forward activation, where neural pathways are trained to anticipate movement for better joint control, which is vital in injury prevention and rehabilitation (Van Vliet & Heneghan, 2006).

Through targeted exercises, neuromuscular training programs typically focus on improving proprioception, motor control, and joint stabilisation. For example, balance training exercises, such as standing on one leg or using a balance board, can improve proprioception and joint stability by challenging the body to maintain alignment during movement (Lephart et al., 1997). Strengthening exercises, particularly those that target the core muscles, can improve motor control by providing a stable foundation for movement and reducing compensatory muscle activity. Dynamic stability exercises, such as planks, bridges, or resistance band training, can further enhance joint stabilisation by teaching the body to activate stabilising muscles during movement. These exercises are particularly beneficial for musicians, as they help develop the strength and coordination needed to maintain proper posture and joint alignment during long practice sessions (Riemann & Lephart, 2002). By incorporating these exercises into their regular practice routines, musicians can improve their neuromuscular control, reduce the risk of injury, and enhance their overall performance.

Neuromuscular training interventions aim to improve proprioception, motor control, and dynamic stability, helping musicians develop better control over their movements and reduce injury risk (Chan et al., 2013; Enke & Poskey, 2018; Kimoto et al., 2019; Wilke et al., 2011; Young & Winges, 2017). These interventions include balance exercises, core strengthening, and dynamic stabilisation drills. Such exercises enhance the body's ability to respond to changes in position and load, allowing musicians to maintain proper alignment and prevent overuse injuries (Ajidahun et al., 2019; Schiftan

et al., 2015; Steffen, 2013; Van Vliet & Heneghan, 2006; Watson, 2009).

- Proprioceptive Training: Proprioceptive exercises focus on improving body awareness and joint stability. These exercises are crucial for musicians, as they help maintain proper posture and reduce the risk of joint misalignment. Examples include balance board training or exercises performed on unstable surfaces, which challenge the body to adapt to changing conditions and improve proprioception (Ackermann & Adams, 2003; Chan et al., 2013; Kaufman-Cohen & Ratzon, 2011).
- Motor Control Exercises: Motor control exercises strengthen the small stabilising muscles around the joints, which are crucial for maintaining control during fine motor tasks, such as playing an instrument. Core strengthening exercises, for example, help musicians stabilise their spine and pelvis, reducing the strain on their upper limbs and allowing for more efficient movement (Lephart et al., 1997).
- Dynamic Stability Drills: Dynamic stability exercises involve movement and balance challenges that improve the body's ability to stabilise joints during motion. These drills are essential for musicians, as they help develop the capacity to maintain control during complex, high-speed movements required for playing an instrument. Examples include dynamic planks or single-leg balance exercises with arm movements, which target stability and coordination (Riemann & Lephart, 2002).

Research showed the effectiveness of neuromuscular training re-education programs and the impact in reducing the incidence of MSIs in musicians (Ajidahun et al., 2019; Enke & Poskey, 2018; Kimoto et al., 2019; Schiftan et al., 2015; Steffen, 2013; Van Vliet & Heneghan, 2006; Wilke et al., 2011; Young & Winges, 2017). These findings suggest that neuromuscular training can enhance proprioception, motor control, and dynamic stability, helping musicians maintain better posture and reduce the strain on their muscles and joints during practice and performance. In addition, neuromuscular training has been shown to improve overall physical function, which may positively impact a musician's technical abilities. By developing a more stable and responsive musculoskeletal system, musicians can improve their endurance, reduce fatigue, and prevent the overuse injuries commonly associated with lengthy practice sessions (Ackermann & Adams, 2003; Chan et al., 2013; Kaufman-Cohen & Ratzon, 2011).

Neuromuscular control is a critical factor in preventing musculoskeletal injuries among musicians. This review highlights the importance of proprioception, motor control, and joint stability in maintaining proper movement mechanics and reducing the physical strain of playing an instrument. Neuromuscular training interventions, such as proprioceptive exercises, motor control drills, and dynamic stability exercises, have improved movement efficiency and reduced the risk of injury in musicians. However, there are several limitations to the current research. Most studies on neuromuscular control and injury prevention in musicians are short-term and involve small sample sizes. Long-term studies are needed to determine the sustained effects of neuromuscular training and to identify the most effective interventions for different types of musicians and instruments. Furthermore, more research is required to understand the specific neuromuscular demands of other instruments, as the physical requirements for playing a violin differ significantly from those for playing a piano or wind instrument.

CONCLUSIONS

Neuromuscular control is a critical factor in preventing musculoskeletal injuries among musicians. The reviewed studies highlight the importance of proprioception, motor control, and joint stability in maintaining proper movement mechanics and reducing the physical strain of playing an instrument. Neuromuscular training interventions, such as proprioceptive exercises, motor control drills, and dynamic stability exercises, have improved movement efficiency and reduced the risk of injury in musicians. Neuromuscular control is vital in preventing musculoskeletal injuries in musicians by improving joint stability, motor control, and proprioception. Neuromuscular training interventions that target these areas can reduce the risk of injury and improve movement efficiency, allowing musicians to maintain optimal physical health and performance. Music educators and healthcare professionals should incorporate neuromuscular training into musicians' practice routines to promote injury prevention and long-term career sustainability.

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