PREVENTION OF MUSCULOSKELETAL INJURIES IN ORCHESTRA MUSICIANS

Céleste ROUSSEAU

A thesis submitted in partial fulfilment of the requirements of Liverpool John Moores University for the degree of Doctor of Philosophy

This research programme was carried out in collaboration with the Royal Liverpool Philharmonic Orchestra and partly funded by Help Musicians United Kingdom

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Supervisors: Prof. Vasilios BALTZOPOULOS – Prof. Gabor BARTON – Peter GARDEN

« Mais vous avez les oreilles pourries à ce point-là, vous entendez pas que ça ressemble à rien ?
- Les harmonies ne sont pas très heureuses mais je n'avais pas mis ça sur le compte de l'accordage ».

Arthur et Bohort, Kaamelott, Livre IV

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Finally, I would like to dedicate this thesis to my grandparents, and particularly to my grandfather, who is probably really proud of me and would be looking forward to reading this manuscript if only I could send it to him wherever he is.

THESIS SUMMARY

Playing-related musculoskeletal disorders are very common in musicians and, depending on their severity, they could potentially endanger their whole career. Understanding the main risk factors leading to their development or relapse is one of the very first milestone for developing useful assessment tools, treatment guidelines or preventive programmes. Although research and clinical practice have evolved considerably and have increased our ability to manage musicians' injuries, there is still a lack of detailed understanding of risk factors leading to potential injuries. The overall purpose of this work was to increase knowledge of injury risk factors predisposing musicians for developing playing-related musculoskeletal disorders in order to better prevent these injuries.

The first study aimed to develop a comprehensive theoretical model about the risk factors for developing injuries related to the instrumental practice while being an orchestra musician. This model classified risk factors into nine categories and fifty-five different items to consider when looking after musicians. The main aim of this first step was to provide foundations to then develop tools to better investigate and assess musicians' health, providing useful resources to both healthcare practitioners and musicians (professionals, students, teachers, etc.) to enhance preventive interventions for playing-related musculoskeletal disorders.

Based on this model, two separate tools were developed and tested to assess musicians' health: the Injury Risk Factors Questionnaire for Musicians, a self-report survey to screen a large number of risk factors and a comprehensive physical examination. Moreover, based on this risk factor model and on a literature review, the Postural Analysis Tool for Musicians has been described in order to better investigate musicians' posture and playing technique.

Among psycho-social factors, pain beliefs are described in the general population as being potentially associated with chronic pain. The third study focused on investigating pain beliefs in musicians, which highlighted the potential need to explain better to musicians, and particularly musicians who report PRMDs, what really are pain mechanisms.

Finally, the extraordinary situation we lived through in the past two years has overwhelmed the music industry to a dramatic extent. In order to monitor how the Covid-19 pandemic affected musicians' health, questionnaires were sent to orchestra musicians before and after their return-to-work following the first lockdown. Pain prevalence were lower than those reported in literature, as well as number of playing hours per week which showed a significant reduction.

This study highlighted the need to plan the return-to-work in order to avoid an important PRMDs emergence by increasing the musicians' playing load suddenly.

These findings provide important knowledge about injury risk factors and expand the possibilities for protecting musicians' health.

PUBLICATIONS AND CONFERENCES PRESENTATIONS

PUBLICATIONS

- Rousseau, C., Taha, L., Barton, G., Garden, P., & Baltzopoulos, V. (2023). Assessing posture while playing in musicians – A systematic review. *Applied Ergonomics*, 106, 103883. doi: 10.1016/j.apergo.2022.103883.
- Rousseau, C., Barton, G., Garden, P., & Baltzopoulos, V. (2021) Development of an injury prevention model for playing-related musculoskeletal disorders in orchestra musicians based on predisposing risk factors. International Journal of Industrial Ergonomics, 81, 103026.
- Rousseau, C., Poulnot, E., Barton, G., Garden, P., & Baltzopoulos, V. Pain beliefs in musicians.
  - ⇨ Under review in Medical Problems of Performing Artists.

CONFERENCES

- Rousseau C. "Prévention des troubles musculo-squelettiques chez les musiciens d'orchestre", Journée Scientifique de l'ILFOMER, 3rd June 2022, Limoges, France.
- Rousseau C., Taha L., Barton G., Garden P., & Baltzopoulos V. "Assessing posture while playing in musicians – a systematic review", Interaction Musicien/Instrument, Société de Biomécanique, Société Française d'Acoustique, 20th May 2022, Paris, France.
- Rousseau C., Barton G., Garden P., & Baltzopoulos V. "Development of an injury prevention model for playing-related musculoskeletal disorders in orchestra musicians based on predisposing risk factors", Interaction Musicien/Instrument, Société de Biomécanique, Société Française d'Acoustique, 20th May 2022, Paris, France.
- Rousseau C. "Musicien.ne.s et troubles musculo-squelettiques", Journée Dijonnaise de la Kinésithérapie, Dijon, France.
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- (Cancelled due to Covid-19 situation) Rousseau C., Barton G., Garden P., & Baltzopoulos V. "Injury risk factors in musicians: development of a theoretical model and a comprehensive questionnaire to improve risk detection and injury prevention", *Performing Arts Medicine Association (PAMA) 20th Symposium,* New Orleans, USA. **AGB Award Runner-Up** (Oral presentation).
- Poster video presentations for the European Society of Movement Analysis in Adults and Children (ESMAC) Conference (September 2020):
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    - Rousseau C., Chi J.-Y., & Ackermann B. "Immediate effect of scapular stabilisation exercises on shoulder and forearm muscles while playing the violin"
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    - Oral presentation: Rousseau C., Chi J.-Y., & Ackermann B., "Immediate effect of exercises of scapular stabilisation on shoulder and forearm muscle activation while playing the violin";
    - Panel discussion: "Doctoral degree and physiotherapy".
- Rousseau C., Chi J.-Y., & Ackermann B. "Immediate effect of scapular stabilisation exercises on shoulder and forearm muscles while playing the violin", *Performing Arts Medicine Association (PAMA) 19th Symposium*, Los Angeles, USA, 28th June to 1st July 2019, **AGB Award Honorable Mention**. (Oral presentation).
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- Rousseau C., Barton G., Garden P., & Baltzopoulos V. "Development of an injury prevention model for playing-related musculoskeletal disorders in orchestra musicians based on predisposing risk factors", *Doctoral Academy Conference*, Liverpool, UK, 8th May 2019. (Poster presentation)

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

LIST OF TABLES

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

List of abbreviations

ADD: Anxiety Depression Detector
ASPAH: Australian Society of Performing Arts Healthcare
BAPAM: British Association for Performing Artists Medicine
BMI: body mass index
CFS: Chalder Fatigue Scale
DASH: Disabilities of the Arm, Shoulder and Hand
DNF: Deep Neck Flexors
EG: exercise group
EMG: electromyography
FD: focal dystonia
FHP: forward head posture
GC: control group
GPAQ: Global Physical Activity Questionnaire
HADS: Hospital Anxiety and Depression Scale
HPLP II: Health Promoting Lifestyle Profile II
IRFQM: Injury Risk Factors Questionnaire for Musicians
MDA: Médecine des Arts
MP: metacarpophalangeal (joint)
MPIIQM: Musculoskeletal Pain Injury and Interference Questionnaire for Musicians
MPQM: Musculoskeletal Pain Questionnaire for Musicians
MLPHQM: Musculoskeletal Load and Physical Health Questionnaire for Musicians
NMQ: Nordic Musculoskeletal Questionnaire
PA: physical activity
PE: physical examination
PAMA: Performing Artists Medicine Association
PATM: Postural Analysis Tool for Musicians
PBQ: Pain Beliefs Questionnaire
POI: Postural Observation Instrument
PSQI: Pittsburgh Sleep Quality Index
PRMDs: playing related musculoskeletal disorders
RCT: randomised controlled trial
REBA: Rapid Entire Body Assessment
RLPO: Royal Liverpool Philharmonic Orchestra
RTW: Return-to-work
SOE: Scapular Orientation Exercise
SPIN: Social Phobia Inventory
SQUASH: Short QUestionnaire to ASsess Health enhancing physical activity
STAI: State-Trait Anxiety Inventory
WHO: World Health Organisation

CHAPTER 1:

GENERAL INTRODUCTION

1. Being a musician: a high-risk occupation for musculoskeletal injuries

Occupational musculoskeletal disorders are "disorders of the musculoskeletal system in which occupational activity may play a role in their development, maintenance or aggravation […] primarily affecting muscles, tendons and nerves" (INRS, 2021). As playing a music instrument is considered as a high-risk occupation for developing musculoskeletal disorders (Kok et al., 2015; Silva et al., 2015), specific playing-related musculoskeletal disorders have been defined as "pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to" (Zaza et al., 1998). The injury's influence on the playing is very important for instrumentalists. Indeed, the musicians who were interviewed by the authors about this definition stated that "musicians won't admit there's a problem until playing is affected", "if [they] could play, then [they] don't really care" or outlined the importance of being "somehow distracted by the injury" (Zaza et al., 1998).

Prevalence rates of playing-related musculoskeletal disorders are difficult to assess, as a uniform definition is often lacking and periods of recall are very heterogeneous as well (Kok et al., 2015; Silva et al., 2015). However, systematic reviews found high rates ranging between 62% and 93% for lifetime prevalence (Kok et al., 2015). Moreover, Silva et al. (2015) stated that, from all samples they studied, about 75% of musicians suffered from pain in the previous year or sooner and 54% reported pain affecting their playing capacity (Silva et al., 2015).

Although research and clinical practice have evolved into a large extent and have increased our ability to manage musicians' injuries, there is still a lack of detailed understanding of risk factors leading to potential injuries. A wide heterogeneity of methods has been highlighted by several authors who tried to draw conclusions by reviewing systematically the existing literature (Baadjou et al, 2016; Wu, 2007). Indeed, application of different definitions or use of diverse tools or questionnaires or development of non-validated surveys, sometimes even integration in different paradigms (biomedical versus biopsychosocial) lead researchers to great difficulties when they attempt a comparison. However, both literature findings and experts in musicians' health agree on several major injury risk factors, such as maintaining constraining postures for a long duration, without motion freedom or opportunity of taking breaks, whilst performing complex and highly repetitive movements (Chan & Ackermann, 2014). This major issue can be compounded by the instrument's weight, technique and repertoire physical demands. This could be also combined with several other risk factors that have been described widely in the general population such as stress, anxiety, depression, poor physical conditioning or unhealthy lifestyle or more specific ones such as music performance anxiety (Chan & Ackermann, 2014).

Common medical problems reported by musicians have been thoroughly described (Homer & Homer, 2019). One of the main reported issues is the overuse syndrome (or repetitive strain injuries), potentially affecting all musicians who happen to overload their soft tissue beyond their current capacities (Fry, 1986a). Moreover, musicians are not exempted from possibly developing nerve compressions or irritations, leading to tingling or numbness, as well as inflammatory pathologies, such as tendinitis (Homer & Homer, 2019; Schaefer & Speier, 2012). Finally, and even if this disorder does not affect a large part of professional musicians, focal dystonia needs to be considered as well as it is one of the most concerning issues that could happen to an instrumentalist, representing a potential threat to their career (Altenmüller & Jabusch, 2010).

As briefly introduced by mentioning focal dystonia, injuries affecting the musculoskeletal system may have a substantial impact on musicians' lives and career (Rickert et al., 2014; Schoeb & Zosso, 2012; Guptill, 2011). Musicians begin playing their instrument at a very young age (Brandfonbrener, 2009) and music becomes a large part of their lives, making considerable efforts in order to play better, as stated in a qualitative study about representations of body and health in musicians, "hard work is their mantra and music is their joy" (Schoeb & Zosso, 2012). The burden of being an injured professional musician is quite broad: employability can be an important concern; culture of silence is widespread and playing through pain occurs very often (Rickert et al., 2014; Guptill, 2011). All of these consequences of playing-related injuries need to be carefully considered by healthcare professionals while treating musicians or developing preventive interventions.

Thus, as both researchers and healthcare practitioners face in their daily practice an important lack of information regarding risk factors predisposing musicians to develop playing-related musculoskeletal disorders, it is also challenging to design proper interventions or to apply appropriate treatments to musicians whose injuries' sources are still not thoroughly understood.

2. Purpose and outline of this thesis

The overall purpose of this research work was to increase our knowledge of injury risk factors predisposing musicians for developing playing-related musculoskeletal disorders in order to better prevent these health issues. Therefore, the main objectives of this thesis were to build a comprehensive model of injury risk factors in musicians to then be able to assess them better in individuals by developing tools to identify them more specifically. Furthermore, the work aimed to investigate more specific injury risk factors, such as posture while playing which is still controversial or pain beliefs which have not been investigated in musicians.

As systematic reviews pointed out the methodological problems of most epidemiological studies, it has been decided to build a theoretical model about injury risk factors in musicians based on a narrative review, combined with musicians' and health experts' interviews. Based on this model and as specific injury risk factors screening tools for musicians are still missing, as it will be discussed in Chapter 3, a toolkit has been developed aiming to screen these risk factors, composed from three different components: a 90-items questionnaire, a physical examination and a postural assessment. This toolkit is described and applied to a sample of musicians from the Royal Liverpool Philharmonic Orchestra in Chapter 4.

As previously mentioned, there is still little known about musicians and potential risk factors for developing injuries. Among them, psycho-social factors partly explaining chronic pain in the general population have not been often investigated. In order to help increasing our knowledge on pain beliefs and the relationship with pain and its chronic nature, a study has been conducted in Chapter 5 to investigate pain beliefs in orchestra musicians.

Due to the Covid-19 situation, initial PhD plans were not achievable. However, the cultural sector has faced a large disruption and consequences are dramatically serious (which is probably still the case when you are reading these words). Research protocols, described in Chapter 6, have been set to understand what the effects of the Covid-19 related situation were on both physical and mental health in musicians as well as on their instrumental practice, their life habits and their work life. Addressing health issues which could emerge because of the Covid-19 disruption may be very helpful for musicians and administrative teams to organise a safe return-to-work and help prevent musculoskeletal injuries due to sudden increase in load following long periods of inactivity due to lockdowns and restrictions. Finally, major findings of this work are summarised in Chapter 7 and discussed to provide guidelines and recommendations as well as perspectives for further research and work in the future.

CHAPTER 2:

PLAYING-RELATED MUSCULOSKELETAL DISORDERS – A LITERATURE REVIEW

1. Being a musician

1.1. "Begin the beguine"

Playing an instrument at an elite level is considerably demanding on different levels and every musician, amateur to professional, could tell you more about their personal perpsective (Schoeb & Zosso, 2012). Indeed, being able to play a musical instrument results from hours of practicing extremely repetitive movements such as bowing up and down 740 times in a 2-minute aria from Händel's Messiah (Horvath, 2001) while maintaining an awkward and often asymmetrical posture (Ramella et al., 2014), with both arm elevated (Nyman et al., 2007). Repetitive movements and uncomfortable positions are "visible" elements of the playing-related load, but they are only the tip of the iceberg.

Music playing leads to complex activities at the brain level as well. Acute hearing, sense of pitch, tempo, rhythm as well as being able to combine plentiful muscles, from the largest to the smallest and around different body locations, are remarkable capacities that need to be trained from childhood and all along musicians' lives (Dawson, 2011). This training leads measurable differences in brain organisation (e.g.: excellence in auditory-motor coordination associated with the highest volume of grey matter in the Broca's area in professional musicians, especially in those who begun playing their instrument in early childhood, etc.) that are noticeable between musicians and non-musicians (Dawson, 2011). Moreover, for musicians themselves, music represents more than a job and this has been particularly pointed out by interviewing musicians about their life, health and art (Schoeb & Zosso, 2012). Musicians described their job as a "tough" occupation but also as a vocation, with strong emotional aspects that make them very sensitive if not vulnerable. Several studies have also highlighted mental health complications in musicians, such as stress, depression and anxiety (Baadjou et al., 2016; Chan & Ackermann, 2014; Kenny & Ackermann, 2013) and more specific issues like perfectionism (Araujo et al., 2017; Chan & Ackermann, 2014) or performance anxiety (Kenny & Ackermann, 2013; Kenny, 2011).

Finally, becoming a musician often starts in childhood. Young musicians begin their instrumental practice very early, particularly piano and upper string players (Brandfonbrener, 2009), who spend hours on their instrument in parallel with their general studies (Debès, 2004). Due to several reasons, including number of playing hours, hypermobility or instrument type, children are not exempted from developing injuries related to their music playing and practicing (Chan & Ackermann, 2014; Ranelli et al., 2011).

All these reasons explain why musicians are often compared to athletes in the literature and by several health experts around the world (Chan & Ackermann, 2014, Baadjou et al., 2015). In light of the experience of some musicians in the past, it is now widely known that health injuries could end their career as Robert Schumann who was forced to abandon playing the piano due to his suspected hand focal dystonia, or for amateurs to give up a hobby that was important to them (Jankovic & Ashoori, 2018; Gardou, 2006).

1.2. Playing a musical instrument professionally

The number of various musical instruments seems impossible to determine as there are countless across the history of humanity all over the world. Oldest known instruments were 5-holes flutes, existing at least 35 000 years ago and since then became more and more various. Without taking into account the accuracy of organology (science of musical instruments and their classifications three instrument families will be described as they are commonly reported:

- String instruments: bowed (e.g.: violin), plucked (e.g.: guitar) or struck (e.g.: piano)
- Wind instruments: woodwind (e.g.: saxophone, oboe) or brass (e.g.: trumpet, trombone)
- Percussion instruments (e.g.: drums, marimba).

Being a professional instrumentalist involves different work and life habits all musicians share such as:

- Performing repetitive movements and holding an instrument that may be quite heavy by maintaining uncomfortable and sometimes asymmetrical posture for a long duration (see Figures 2.1 and 2.2) (Chan & Ackermann, 2014; Ramella et al., 2014; Nyman et al., 2007)
- Practicing a great number of hours per day (including both private practice as well as concerts, rehearsals, recordings and other types of performances) (Kok et al., 2016; Baadjou et al., 2016; Chan & Ackermann, 2014), quantified in a systematic review around 25 hours a week or 4 to 5 hours a day (Kok et al., 2016)
- Carrying heavy instrument(s) from a place to another which can be an issue for harpists, double bassists, cellists or drummers
- Touring, involving multiple shows per week potentially in different cities or even countries and therefore many travelling hours (Ackermann, 2002).

Figure 2.1: Symmetrical posture while playing the clarinet

Figure 2.2: Asymmetrical posture while playing the violin

1.2.1. Playing a musical instrument in an orchestra

A symphonic or philharmonic orchestra is defined as "an orchestra capable of performing symphonies, especially the large orchestra comprising strings, brass, woodwind, harp and percussion" (Harper & Collins).

Depending on whether they are playing on stage or in the pit, the position of orchestra instrumentalists will slightly change from one orchestra to another. An example is presented below in Figure 2.3 with the Royal Liverpool Philharmonic Orchestra (RLPO), and then in Figure 2.4 with a more specific description of the instruments we could find in such orchestras.

Figure 2.3: Concert of the Royal Liverpool Philharmonic Orchestra

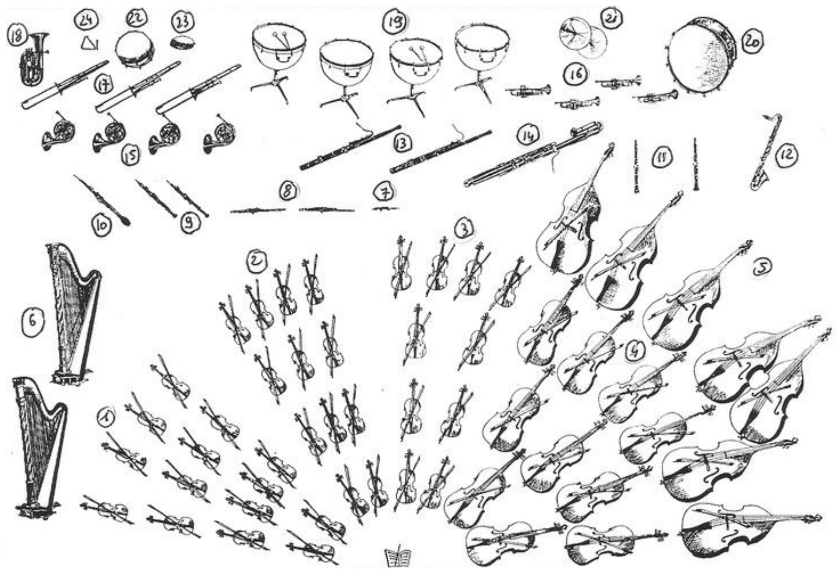

Figure 2.4: Graphical description of the symphonic orchestra instruments

In addition to generic issues common to all musicians (prolonged static posture, repetitive movements, instrument holding, etc.), orchestra musicians have specific ones such as:

- Playing in the pit or on stage and related problems (Kenny et al., 2016)
- Very limited flexibility in terms of practice schedule and great number of playing hours (Chan & Ackermann, 2014; Wu, 2007)
- Restricted possibility to choose individuals to work with (concerns desk sharers, conductor, administrative team, etc.).

The next subsection will describe the different biomechanical aspects of playing different orchestra instruments. This description is not meant to be exhaustive but will describe the most frequently encountered instruments and related biomechanical aspects as the background to injures that are considered in this thesis.

String instruments

Bowed strings are classified in two categories, depending on the posture while playing: violin and viola are called upper (or higher) strings while cello and double bass are called lower strings.

Upper strings

Violin and viola require asymmetrical posture of the body (see Figure 2.2). In an orchestra, upper strings musicians are commonly sitting, sharing their stand with one of their colleagues, something that will alter their freedom of movements, depending also on which side they are sitting (Spahn et al., 2014). The instrument is maintained between the chin and the left shoulder, elevated and protracted, which creates a high activation load on the left upper trapezius (McCrary et al., 2016b) but also an important use of orofacial structures, which could lead to impairments around the temporo-mandibular joint (Clemente et al., 2015). The left upper limb is more static than the right one, left shoulder is slightly flexed and abducted, elbow flexed, forearm in maximal supination and wrist flexed to permit the fingering on strings (Shan & Visentin, 2003). The bowing right arm performs more dynamic movements and requires a larger range of motion from the shoulder, elbow and wrist to move the bow back and forth against the strings (Shan & Visentin, 2003). Ergonomics tools such as shoulder- or chin-rest have a great importance in managing physical load around the neck and shoulders, these will be described later in this chapter (Chi et al., 2020).

Lower strings

Although Ramella et al. (2014) classified cello as symmetrical while double bass is considered asymmetrical, based on their own definition of an "optimal posture", here the cello will be regarded as an assymmetrical instrument because of the different shoulder positions and hand functions required to play, as well as the maintained left-rotated torso postures (Hopper et al., 2017). While the left shoulder is mainly static, positioned in external rotation, flexion and abduction to allow the placement of the fingers on the strings quite high on the instrument neck, the right one is more dynamic, flexed, abducted, internally rotated and protracted, to draw the bow against the strings from top to heel and reverse (Hopper et al., 2017; Rickert et al., 2013). This prolonged position, associated with important muscle activation (up to 20% in the supraspinatus for example), has been considered as one of the main factors potentially leading to overuse and explaining the high prevalence of right shoulder pain among cellists (Rickert et al., 2013; Rickert et al., 2012). This is quite similar to the position when playing the double-bass, which could be played upright or semi-seated, requiring greater flexion of the lumbar or low-thoracic spine (see Figure 2.5). Both are adapting

Figure 2.5: Double bassist (Yves Rousseau)
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the height of their instrument depending on their anthropometrics by altering the endpin length, which allow musicians to play comfortably.

Wind instruments

Wind orchestra instrument are described in Figure 2.4 (woodwinds and brass). One of their major differences, besides postural specificities, concerns the mouthpieces: they could be single opening (e.g.: flute) or cup embouchures (e.g.: trombone), simple (e.g.: clarinet) or double reed (e.g.: oboe) (Clemente et al., 2019). Producing a sound with a wind instrument needs coordinating three different actions: moving the lips to control the sound, blow and control the air required to produce this sound and fingering/sliding to produce the right notes (Cossette et al., 2000).

Brass

Playing the trumpet needs an elevation of both arms, the weight of the instrument is supported by the left arm, while the right hand is fingering the pistons, elbow flexed and forearm in neutral position (see Figure 2.6) (Price & Watson, 2018). The trombone is supported mostly by the left arm also, elbow and shoulder flexed, whereas the right arm is more dynamic because of moving the slide. This movement requires movement of all the right upper limb as well as scapular protraction and retraction (Price & Watson, 2018). The French horn is supported by both upper limbs and pistons are played with the left fingers, with right shoulder and elbow flexed to reach them. The right shoulder is slightly abducted and elbow 90°-flexed to place the right hand in the bell (Price & Watson, 2018). French horn demands less elevated posture than trumpet. All brass instruments require very high blowing pressures that may lead to several health issues such as respiratory, visual, cardiac or orofacial troubles (Chesky et al., 2002). Injury to the *orbicularis oris* muscle, or "Satchmo syndrome" is also very common (Chesky et al., 2002).

Figure 2.6: Trombonist (Jean-Louis Pommier)

Woodwinds

Playing the flute is often considered as one of the instruments that involve the most awkward posture. It requires asymmetrical posture and the weight of the instrument is supported by both arms (see Figure 2.8). Compared to other wind instruments, the flute has to be held farther from the body, against gravity, which requires having both upper limbs elevated over a long time.

(Lonsdale et al., 2014). Oboe, clarinet and English horn require a more symmetrical position (see Figure 2.1 above): musicians hold their instrument closer to the body, needing less shoulder flexion. Both elbows are flexed and wrists are kept in neutral position to finger the keys of the instrument (Baadjou et al., 2017; Banzhoff et al., 2017). Moreover, these three instruments are commonly played (without additional support) by holding the instrument mainly on the right thumb, which could lead to discomfort and pain (Young & Winges, 2017). Finally, the bassoon (see Figure 2.7), largest and heaviest woodwind instrument with the contrabassoon, is also considered as an asymmetrical instrument (Ramella et al., 2014), held obliquely across the body (Brusky, 2010) in an awkward position, particularly on the shoulders: one is slightly flexed whereas the other is more in extension (Dawson, 2012).

Figure 2.7: Bassoon player (Wladimir Weimer)

Figure 2.8: Flutist (Pierre-Yves Merel)

Percussion

One of the main things to keep in mind about percussion is the great variety of instruments included in this family (Dahl, 2018), such as drum set (most commonly seen in modern music) or mallet, hand, and marching percussions. This important heterogeneity makes percussionists difficult to compare. As described above in Figure 2.4, the common percussion instruments in symphonic orchestras are: snare and bass drums, tambourine, tympani, crash cymbals and triangle. Drum set (see Figure 2.10), vibraphone (see Figure 2.9) or tympani share the common requirement for the player to perform combined movements from both upper and lower limbs that could also lead to injuries in the lower limb (Lee & Altenmüller, 2014).

Figure 2.9: Vibraphone player (Franck Tortiller)
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1.2.2. Other instruments widely played in the world

Guitars

Guitar is one of the most practiced instruments over the world and its repertoire is one of the widest from classical music to jazz, including rock, heavy metal, pop or traditional music (Zuhdi et al., 2020). However, guitarists' playing and health are not often investigated in epidemiological studies (Zuhdi et al., 2020). Depending on the repertoire, posture could massively change from one guitarist to another, as well as ergonomics: from the height bench in seated classical guitarists (Valenzuela-Gòmez et al., 2019) to the strap in upright rock ones (Woldendorp et al., 2013). Criteria to avoid uncomfortable or binding posture have been described in a paper (Valenzuela-Gòmez et al., 2019), such as positioning the instrument on the thigh, supporting both feet and place the guitar neck at eye level to avoid torso lateral bending and flexion or excessive hip and neck flexion, as well as shoulder abduction. However, these posture criteria need wider investigations: the tool used to evaluate guitarists' posture was quite standardised but not specifically designed to describe the guitar posture and did not take into account how much the musician could be moving while playing (Valenzuela-Gòmez et al., 2019).

Drum sets

Drummers are special percussionists see Figure 2.10). Playing the drum set supposedly combines very fast movements from both arms and legs (Dahl, 2018). Drummers could reach 1200 strokes in one minute by using both sticks and need therefore a very compliant joint at the wrist level to allow fast and precise movements (Dahl, 2018). The drum set is also a very demanding instrument in terms of cardiovascular demands with increased heart rate (De La Rue et al., 2013): Clem Burke, known as the drummer from Blondie, has shown peak heart rate of 186 bpm while performing, very close to his age predicted value (183bpm) (Smith et al., 2008 in De La Rue et al., 2013).

Figure 2.10: Drummer (Vincent Tortiller)
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Keyboards

Keyboards include different types of instruments such as the piano, the harpsichord or the organ. First of all, it is important to consider that children begin their piano practice on the same instrument size as adults would do, unlike violinists or cellists. Sitting posture while playing the piano could be compared to that of computer keyboard users. However, playing the piano requires a much higher activation in *extensor carpi radialis* compared to those commonly observed in computer workers' (Baeyens et al., 2020). Moreover, Wood (2014) has pointed out the existence of several risk factors mentioned by musicians themselves such as technique flaws, exam demands in terms of workload or excessive keyboard use (coupled with computer use). Finally, Chi et al. (2020) in their systematic review have pointed out that the size of the hand could potentially be a risk factor for injuries in pianists, as small-handed pianists would be limited due to their anthropometrics combined with the standardised key size.

2. Playing-related musculoskeletal disorders (PRMDs)

2.1. History and definition of PRMDs

Looking back in the distant past and the history of medicine, it seems that Bernardino Ramazzini, Italian doctor and pioneer in describing work accidents, was one of the very first to raise awareness about musicians' health in 1700 with his treatise "De Morbis Artificum" (Patissier & Ramazzini, 1822). In recent times, interest has arisen about musicians' health during the second half of the twentieth century, with the first edition of the international peer-reviewed journal Medical Problems of Performing Artists sees its first edition in 1986 (PAMA website). At the same time, the Performing Arts Medicine Association (PAMA) has been created in the United States of America (PAMA website) in 1989. This initiative has then been followed by organisations in different countries, such as *Médecine des Arts* (MDA) in France as well as the British Association for Performing Arts Medicine (BAPAM) and more recently, the Australian Society of Performing Arts Healthcare (ASPAH) in 2006 (ASPAH website).

In 1998, Zaza et al., by combining musicians' opinions and healthcare practitioners' advice, defined playing-related musculoskeletal disorders as "pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to". In this definition, importance has been given to the fact that PRMDs should affect playing, be individually identified, be unusual as well as be severe. That explains why Zaza et al. (1998) have excluded all mild aches and complaints from this definition.

Since then, this definition has been commonly used to define musicians' issues related to their physical health (Baadjou et al., 2016; Ackermann et al., 2012) and this will be the way we will describe PRMDs in this thesis.

2.2. Pathophysiology of playing-related musculoskeletal disorders

Medical problems that are commonly found in musicians have been frequently described in the literature. Several authors have drawn extensive narrative reviews of the musculoskeletal troubles which musicians suffer from, such as overuse syndrome, hypermobility, inflammatory pathologies such as bursitis or tendinopathies, nerve compressions as well as focal dystonia, which is more considered as a movement disorder rather than a musculoskeletal one (Homer & Homer, 2019; Schaefer & Speier, 2012).

2.2.1. Overuse syndrome and inflammatory pathologies

Overuse syndrome has been firstly defined in musicians in the late 1980s as "pain and loss of function in muscles and joint ligaments, typically brought on by an increase in the duration and intensity of practice or play" (Fry, 1986a). The same author also described grades of severity (Fry, 1986b) detailed in Table 2.1 below.

Table 2.1: Description of overuse syndrome grades according to Fry (1986b)

Grades	**Description**
Grade 1	Pain is in one site of playing. This must be consistent rather than occasional, and pain ceases when the musician stops playing.
Grade 2	Pain in multiple sites on playing. Physical signs of tissue tenderness is minimal. May have transient weakness or loss of control. No interference with other uses of the hand.
Grade 3	Pain in multiple sites. Pain persists away from the instrument, some involvement in other uses of the hand that now cause pain. May have weakness, loss of control, loss of muscular response or dexterity.
Grade 4	As for Grade 3. All common uses of the hand cause pain – housework, driving, writing, turning faucets or door knobs, hair grooming, dressing, washing or drying, but these uses are possible as long as the pain is tolerated.
Grade 5	As for Grade 4 with loss of capacity to use the hand because of disabling pain.

This syndrome is likely to be due to overloading soft tissues such as muscles and tendons beyond what they can sustain (Schaefer & Speier, 2012). The main reported symptom is pain and could potentially be associated with weakness or loss of motor control, without sensory dysfunction (Schaefer & Speier, 2012). Nonetheless, it is not considered as a proper precise diagnosis as it lacks histologic evidence (Schaefer & Speier, 2012). Moreover, overuse syndrome (sometimes called repetitive strain injury – Bird, 2013; Heinan, 2008) could lead to another diagnosis and *vice-versa* (Bird, 2013). Indeed, inflammatory pathologies such as tendinopathies (or tendinitis) present often with overuse syndrome (Moore et al., 2008). Examples of these pathologies are various in musicians and could affect different body locations such as the shoulders (e.g.: shoulder impingement syndrome, rotator cuff dysfunction, etc.), elbows (e.g.: medial and lateral epicondylitis) or hands (e.g.: De Quervain tenosynovitis) (Homer & Homer, 2019; Schaefer & Speier, 2012).

2.2.2. Joint hypermobility

Famous musicians have been identified as probably hypermobile considering the technically challenging pieces they both wrote and played, asking for great hand ranges of motion, such as Paganini (violin) or Rachmaninov (piano) (Bird & Knight, 2012). Having hypermobile joints could both be an advantage for musicians, allowing them to achieve greater than typical range of motion while playing difficult and demanding repertoire, but it represents also an important disadvantage as being hypermobile requires also to increase muscles contraction to sufficiently stabilise joints (Schaefer & Speier, 2012). Moreover, joints mobility may be hereditary or acquired, which makes hypermobility in musicians difficult to define: are musicians particularly hypermobile because of nature or nurture? Assessed with the Beighton 9-points score (Bird & Knight, 2012), hypermobility has often been described as a potential risk for developing injuries in musicians (Schaefer & Speier, 2012).

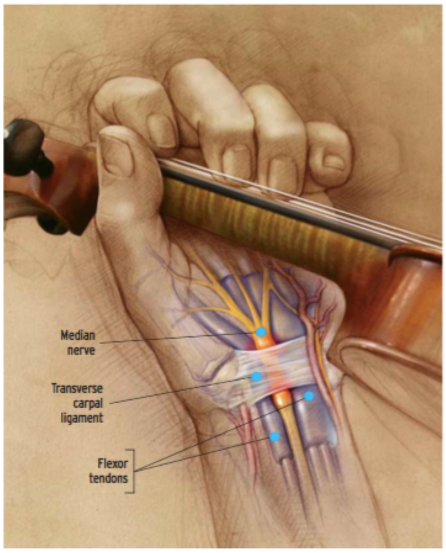


Figure 2.11: Violinist's carpal tunnel syndrom (from Heinan, 2008, © Christy Krames)

2.2.3. Peripheral neurological disorders

Numbness or tingling alerts clinicians about a potential nerve involvement. Compressions or irritations of the median (e.g.: carpal tunnel syndrome, see Figure 2.10), ulnar (e.g.: irritation around the medial elbow) and radial nerves are quite common in musicians (Homer & Homer, 2019; Schaefer & Speier, 2012). First assessment of these pathologies is clinical. Electromyography could be useful to confirm the initial diagnosis (Lederman, 2006) but its sensitivity is quite limited for mild cases (Homer & Homer, 2019). Thoracic outlet syndrome is sometimes reported but still controversial: it is quite difficult to properly diagnose and could be confused with cervical radiculopathy, quite common in musicians as well (Homer & Homer, 2019; Schaefer & Speier, 2012).

2.2.4. *Focal dystonia*

Focal dystonia (FD) has been defined as a "task-specific movement disorder, muscular incoordination or loss of voluntary motor control of extensively trained movements while a musician is playing the instrument" and affects about 1% of professional musicians (much higher than dystonia prevalence in general population – Altenmüller, 2003), potentially disabling or even ending a musician's career (Altenmüller & Jabusch, 2010). Even if mechanisms underlying the development of musicians' cramp (as it is often called – Altenmüller et al., 2012) have not been fully understood so far, evidence tends to suggest it as a result from impaired neural functioning, motor control and sensory processing, as well as dysfunction in brain plasticity (Altenmüller et al., 2012; Altenmüller & Jabusch, 2010). Typically, FD is not associated with pain, except when prolonged spasms provoke aches around the concerned muscles, which could potentially mimic overuse syndrome (Altenmüller & Jabusch, 2010). FD is also specific to instruments: woodwind and brass players can develop embouchure dystonia while hands in violinists and pianists are mainly affected (Altenmüller & Jabusch, 2010). Even lower limb dystonia has been described: Lee and Altenmüller (2014) discussed in a case report what they called "heavy metal curse", that is to say a drummer thigh dystonia.

Neuromuscular re-education has been described as one of the possible treatments for focal dystonia with moderate effectiveness particularly affecting hands according to a recent review (Enke & Poskey, 2018).

2.3. Prevalence of playing-related musculoskeletal disorders

The prevalence of PRMDs has mainly been investigated with self-reported questionnaires. For this reason, PRMDs will not be classified according to their proper potential diagnosis but only considering the painful symptoms and musculoskeletal complaints.

Despite a large number of epidemiological studies about musicians from different styles and repertoires, difficulties have arisen when attempting to compare the various incidence or prevalence values, as the methodologics of these studies are heterogeneous. Different systematic reviews have investigated pain prevalence in musicians at different periods of recall (Kok et al., 2015; Silva et al., 2015; Zaza, 1998) as well as for different specific types of instruments (Correa et al., 2018; Moraes & Papini, 2012; Bragge et al., 2006). Unfortunately, among these reviews, most authors observed a lack of studies presenting high methodological qualities (small sample size, ways to assess pain, recruitment, etc.) as well as a wide range of populations (students, professionals, types of repertoire and work conditions) and periods of recall or PRMD definitions (Correa et al., 2018; Kok et al., 2015; Silva et al., 2015; Bragge et al., 2006).

However, despite the lack of common tools and definitions to investigate musculoskeletal complaints in musicians, Silva et al. (2015) estimated that about 75% of musicians suffered from pain in the past year (or less) and about 54% reported pain affecting their ability to play their instrument, while Kok et al. (2015) reported playing-related lifetime prevalence ranging between 62% and 93% and 12-month prevalence between 41% and 93%.

In terms of instrument differences, string players are often described as the instrument section most affected by PRMDs, particularly upper string, violinists and violists (Sousa et al., 2017; Kaneko et al., 2005). Nonetheless, other musicians are not exempt from PRMDs: brass, woodwind and percussion players are also frequently affected (Ackermann et al., 2012; Abreu-Ramos & Micheo, 2007; Chesky et al., 2002). Table 2.2 summarises findings from different epidemiological studies which were chosen because they were focusing on different instrumentalists (mainly orchestra instruments) from different populations (students, children, professionals) in order to compare pain prevalence.

Table 2.2: Pain prevalence according to instrument or group and prevalence time in epidemiological studies focusing on commonly played musical instruments

Authors	Population	Instrument group	Sample	Lifetime prevalence (%)	Month- or point prevalence (%)
Chesky et al., 2002	Brass players	Brass	739	61	
Kaneko et al., 2005	Orchestra musicians	Strings	157		68,8
		Brass	31		54.8
		Woodwind	37		64.9
		Percussion	11		54.5
Abreu-Ramos & Micheo, 2007	Orchestra musicians	Upper strings	32	78.1	
		Lower strings	15	93.3	
		Brass	13	69.2	
		Woodwind	11	81.8	
		Percussion	3	100	
Brandfonbrener, 2009	Music students	Keyboards	31	87	
		Strings	73	86	
		Brass	42	86	
		Woodwind	71	87	
		Percussion	7	100	
Ranelli et al., 2011	Children	Keyboards	130	52	44
		Upper strings	131	66	56
		Lower strings	68	76	68
		Brass	132	58	52
		Woodwind	212	76	63
		Percussion	22	68	59
		Guitar	63	71	56

Ackermann et al., 2012	Orchestra musicians	Strings Brass Woodwind Percussion	237 58 67 58	76.8 81.7 88.1 91.7	
Kochem & Silva, 2017	Professional violinists	Upper strings	106	86.8	77.4
Sousa et al., 2017	Orchestra musicians	1st violin 2nd violin Violas Cello Double bass Brass Woodwind Percussion	16 16 14 13 11 20 17 4	81.2 69.8 78.6 46.2 54.5 60 47.1 50	

Concerning the main body locations of PRMDs, literature suggests unsurprisingly that musicians commonly suffer from pain around the spine and upper limbs, with higher percentages around the lower back, neck and shoulders (Kok et al., 2015; Silva et al., 2015). In orchestra musicians, several epidemiological studies have pointed out that the main painful locations were the neck, back and shoulders (Ackermann et al., 2012; Leaver et al., 2011; Abreu-Ramos & Micheo, 2007). Finally, according to Ackermann et al. (2012), the right upper limb is more affected by PRMDs among woodwind players and percussionists, whereas among brass players, lower and upper strings, the left upper limb is the most affected. Moreover, amateur musicians are not exempt from reporting PRMDs as they may play their instrument at a very high level and many hours a week (Kok et al., 2017) as well as having a job aside, potentially demanding in terms of physical or psychological load, which could also influence the development of PRMDs (Kok et al., 2018).

2.4. Predisposing risk factors of playing-related musculoskeletal disorders

Risk factors for developing playing-related musculoskeletal disorders have been widely investigated in the literature (Cruder et al., 2019; Ballenberger et al., 2018; Wood, 2014; Kaufman-Cohen & Ratzon, 2011). As for pain prevalence, an important heterogeneity is observed in terms of methodological aspects from one epidemiological study investigating injury risk factors to another, which makes them very difficult to compare and to combine.

Chan and Ackermann's (2014) narrative review has combined several studies to describe the most commonly reported risk factors in two different categories: physical and psychosocial risk factors. Among the physical ones, the authors discriminated modifiable from non-modifiable risk factors. Table 2.3 below has been retrieved from their paper.

Table 2.3: Physical and psychosocial factors influencing the development and perpetuation of performance-related musculoskeletal disorders (Chan & Ackermann, 2014)

Physical risk factors		Psychosocial risk factors
Non-modifiable	Modifiable	
• Instrument played • Anthropometrics • Gender • Playing conditions – temperature, length of rehearsals and performances • Joint laxity – past trauma or generalized • Challenging repertoire	• Overload – sustained high levels of playing or sudden increases in playing load • Lack of rest breaks in rehearsals and private practice • Poor posture • Poor biomechanics • Joint hypomobility • Instrumental technique and pedagogical style • Lack of physical conditioning • Poor injury management	• General and/or performance anxiety • Depression • Pressures from self, peers, educational institution or work organisation • Work and/or non-work related stress • Social phobia • Personality traits – e.g. somatization tendencies, extreme perfectionism

Once again, systematic reviews about these factors have been very clear: lack of quality and homogeneity in terms of methodology lead to the impossibility of drawing firm conclusions. However, few injury risk factors seem to be frequently described in these reviews as increasing the risk of developing PRMDs such as:

- Gender: females seem to be more at risk than males (Corrêa et al., 2018; Baadjou et al., 2016; Kok et al., 2015; Wu, 2007);
- Number of playing hours (Corrêa et al., 2018; Wu, 2007);
- Previous injury or trauma (Baadjou et al., 2016; Wu, 2007);
- Work/playing-related stress and stressors (Baadjou et al., 2016; Vervainioti & Alexopoulos, 2015; Wu, 2007).

3. Assessment of playing-related musculoskeletal disorders and their predisposing risk factors

Schemann et al. (2018) have examined how upper string players' health, potential pain as well as physical and psychological impairments have been investigated in previous years. From this large systematic review (as upper strings are one of the most investigated music instruments if not the main one) and other literature references, we will briefly describe in this section the questionnaires, physical and postural examination that have been used, without the instrument as well as while playing, to evaluate both PRMDs' prevalence as well as their predisposing risk factors.

3.1. Questionnaires

3.1.1. Frequently used in epidemiological studies

The previously mentioned systematic review has listed a great number of scales and surveys that have been used in musicians to allow them to self-report different elements (Schemann et al., 2018). They include: numeric rating or visual analogue scale used to report pain, body charts to locate pain, the use of the Borg scale to rate the perceived exertion while playing or different questionnaires such as the Disabilities of the Arm, Shoulder and Hand (DASH) or the Nordic Musculoskeletal Questionnaire (NMQ).

3.1.2. Specific for musicians

Several tools have been specifically developed to assess musicians' health and wellbeing. First of all, a very large questionnaire investigating a wide numbers of injury risk factors has been developed: the Musculoskeletal Load and Physical Health Questionnaire for Musicians, including a modified version of the QuickDASH to investigate pain prevalence (Ackermann & Driscoll, 2010). More recently, the Musculoskeletal Pain Questionnaire for Musicians (Lamontagne & Bélanger, 2012) and then the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians or MPIIQM (Berque et al., 2014) have been developed investigating epidemiological data, pain prevalence and intensity. These three questionnaires were based on Zaza's PRMDs definition (Zaza et al., 1998). Finally, in order to investigate one of the main issues in terms of mental health, specifically music performance anxiety, the Kenny Music Performance Anxiety Inventory has been developed (Kenny, 2011).

3.2. Physical and postural assessment in musicians

3.2.1. Without the instrument

Assessments of musicians' body, range of motion or muscles (strength and/or activation) have been widely performed in previous years. Schemann et al. (2018) in their systematic review focused on examination techniques used with upper string players, which seems to be quite representative from the common literature found on this specific topic.

Firstly, a complete physical examination has been developed, including several items such as mobility, muscles and nerves function, anthropometrics elements or pain provocation tests (Ackermann & Driscoll, 2010) and partially applied on a large number of orchestra musicians (Driscoll & Ackermann, 2012), observing differences in anthropometrics items (e.g.: greater left hand span in lower strings), range of motion (e.g.: left supination greater in upper strings) or strength (e.g.: grip strength higher in brass players).

Some of the items, included in the assessment written by Ackermann & Driscoll (2010), have been distinctly assessed in other epidemiological studies, such as:

- Height, weight and BMI (Ballenberger et al., 2018)
- Hypermobility (Ballenberger et al., 2018; Vinci et al., 2015; Paarup et al., 2012) and joint mobility (Tawde et al., 2016, Paarup et al., 2012; Steinmetz et al., 2012)
- Muscle motor control (Ballenberger et al., 2018; Silva et al., 2018; Steinmetz et al., 2016; Steinmetz et al., 2010; unpublished work)
- Muscle strength (Ballenberger et al., 2018; Paarup et al., 2012)
- Pain provocation tests (Ballenberger et al., 2018; Steinmetz et al., 2012).

Generally speaking, authors have often highlighted the frequency of impairments in musicians compared to non-musicians (Ballenberger et al., 2018; Steinmetz et al., 2012; Steinmetz et al., 2010), specifically the ones in pain (Silva et al., 2018; Steinmetz et al., 2016). However, limits as low sample size or the issues concerning both sensitivity and specificity of the performed clinical examination (Paarup et al., 2012) should be taken into consideration.

3.2.2. While playing

Research laboratories offer a wide range of possibilities to assess movements in musicians. Many authors have sought to better understand whole body posture while playing, as well as very fine movements. In order to increase our knowledge about the very specific instrumental gestures, several techniques have been used, such as (non-exhaustive):

- 3D motion analysis:
    - In cellists, in order to describe shoulder and torso movements and range of motion while playing (Hopper et al., 2017)
    - In upper string players, to assess how sitting and standing affected movements (Spahn et al., 2014) or to better characterise musicians' motor strategies and kinematics (Wolf et al., 2019; Ancillao et al., 2017; Shan & Visentin, 2003)
    - In clarinettists, to describe the ancillary movements that musicians perform while playing and which seem to have no direct influence on the sound production (Nüsseck et al., 2018)
- Electromyography:
    - In brass players, to assess the potential benefits of better supporting brass instruments, known as quite heavy (Price & Watson, 2018)

- In wind players in general, to understand better how standing and sitting position could influence the recruitment of abdominal muscles while blowing in a musical instrument (Price et al., 2014; Ackermann et al., 2014; Cossette et al., 2008)
- In upper string players, to measure upper trapezius recruitment and the effect of pain on muscle recruitment (McCrary et al., 2016b; Berque & Gray, 2002) or to compare two different chairs and their influence on Lumbar Erector Spinae (Russo et al., 2019)
- In different types of instrumentalists, to investigate how they are recruiting their muscles to perform the movements needed to play (e.g.: cellists, Rickert et al., 2013; violinists and violists, Cattarello et al., 2017; pianists, Baeyens et al., 2020).

Moreover, stabilometry has also been used to assess sitting or standing postures and balance in musicians (Olhendorf et al., 2018; Spahn et al., 2014). In wind players, respiratory function has also been assessed to investigate how posture could influence the chest and abdominal expansion (Ackermann et al., 2014) or to relate respiratory mechanics with sound production (Cossette et al., 2010; 2008; 2000).

Finally, global posture while playing (or without instrument) has also been assessed by rating pictures and videos of musicians practicing their instrument or not, sitting and standing. Valenzuela-Gomez et al. (2019) used the Rapid Entire Body Assessment (REBA) to analyse guitarists posture while Chan et al. (2013a) have sought to evaluate whether experienced raters could detect alterations in musicians' posture by examining photographs. They pointed out that these experts were able to recognise changes (the outcomes being "better than chance") but that one of their main limits was "the lack of a gold standard for the ideal playing posture against which to compare the participant's post-intervention and pre-intervention photographs" (Chan et al., 2013a). Additionally, Blanco-Piñeiro et al. (2015) have developed the Postural Observation Instrument (POI), based on the following definition of physiological posture: "should approximate as closely as possible the correct posture without any instrument" (Lahme, 2010 in Blanco-Piñeiro et al., 2015). The tool rates the overall spine posture as well as several specific items such as location of the axis of gravity, position of pelvis, shoulders or head in all planes. Based on assessments from experts in posture, who rated the musicians' videos and photographs, the authors have pointed out several impairments that were more important while playing than posing (that is to say standing still and not playing their instrument) (Blanco-Piñeiro et al., 2015). Unfortunately, experts were asked to rate "the musician's *neutral* or *average* position while performing, that is, ignoring transient excursions in the course of performance" (Blanco-Piñeiro et al., 2015) and it has not allowed raters to evaluate how much the musicians were moving while playing and varying their postures. It would be important to take into account how much musicians are moving while playing and to distinguish between dynamic and rigid players to investigate further a potential relationship between maintained awkward postures and PRMDs, rather than transient impaired ones.

4. Prevention of playing-related musculoskeletal disorders and their predisposing risk factors

4.1. Educational programs and interventions

Several authors have developed and set up courses related to musicians' health education. Most of them were tailored for music students (Baadjou et al., 2018; Arnason et al., 2018; Martin Lopez & Farias Martinez, 2013; Barton & Feinberg, 2008), and this makes perfect sense since the period of their studies is the ideal time to acquire good and healthy habits for life. Table 2.4 below summarises some of the key studies that have shaped educational courses.

Table 2.4: Examples of health educational programmes in music students

Authors	Country	Sample	Protocol	Outcomes
Baadjou et al., 2018	Netherlands	Music students (EG = 84, CG = 86)	Multicentre RCT with 2-year follow-up. PRESTO-Play (EG): 11 classes/one year (total: 18 hours) on body posture while playing, perf-related psychosocial aspects, etc. PRESTO-Fit (CG): education about PA and instruction to walk 10k steps/day. Measure: self-report questionnaire (DASH, SF-36, PRMDs question)	No significant difference has been observed between the bio-psycho-social prevention course compared to general PA promotion.
Arnason et al., 2018	Iceland	Music students (EG = 13, CG =10)	Monocentre RCT. Course: weekly on 9 months (pre-test before course, post-test after). Content: function of MSK system, PRMDs risk factors, emphasis on PA, Measure: self-report questionnaire (health-promoting habits, body awareness, PRMDs, etc.)	Sign increase in warm-up habits for EG. Body awareness: - Practice: sign. - Performance: not sign. - Daily living activities: sign. PRMDs: not sign.
Martin Lopez & Farias Martinez, 2013	Spain	Music students (EG = 90, CG = 56)	Monocentre RCT. Course: 6 months (pre-test before, post-test after, follow-up + 6 months) on posture, human body, self-applied exercises (warm-up, self-massage, stretching, etc.) and personalised instructions in private lessons. Measure: self-report questionnaire (practice habits, PRMDs description and location, etc.)	Increase in body awareness (91%) and decrease injury frequency (78%) but not sign. compared to the control group.
Barton & Feinberg, 2008	USA	Music students (n = 26)	Pre-test, course 8-weeks + post-test, follow-up: +6 weeks. Content: health promotion and injury prevention (no precise content). Measure: self-report questionnaire (health and injury prevention measures)	Self-report questionnaire: higher score between pre-course and follow-up scores (sign.).

Clark & Williamon, 2011	UK	Music students (EG = 13, CG = 9)	Pre-test (self-report questionnaire and live performance), 9-week mental skills training program, post-test in the two following weeks (identical to the pre-test), focus groups 8 months after Content: key mental skills for performance preparation such as goal-setting, relaxation strategies, imagery and mental rehearsal. Measure: self-report questionnaire (anxiety, self-confidence and efficacy, music and mental skills, self-regulated learning), performance assessment, participant feedback	Self-report questionnaire: significant outcomes for musical skills, self-regulated learning, self-efficacy and mental imagery Collected suggestions from the participants to improve the program.

EG: exercise group
CG: control group
RCT: randomised control trial
PA: physical activity
DASH: Disability of Arm, Shoulder and Hand questionnaire
Sign.: significant

Hildebrandt & Nübling (2004) implemented an interesting weekly course with music teachers with a focus on musicians' sensory and psychomotor systems. Teachers have noticed significant positive alterations in many aspects of their teaching style, for example regarding breathing, playing movements and posture or coping with problems that could arise while teaching. The most interesting outcome of this study is that students from the experimental groups reported beneficial changes in terms of playing posture and movements as well as verbal instructions and explanations from their teachers.

Another pioneering study focused on the usefulness of a physical therapy triage service onsite in orchestras to manage musicians' potential injuries, provide advice and orientate them to healthcare practitioners (Chan et al., 2013b). The authors have pointed out that more than 90% of the screened injuries were preventable (according to the therapists) and that about 80% of the assessed musicians considered this service as "useful or very useful".

Physiotherapists and other healthcare professionals definitely have a important role to play in helping musicians through many different ways in preventing their performance-related injuries.

4.2. Exercises programs and interventions

Different interventional programmes have been developed in previous years to improve musicians' health and performance, as well as prevent further PRMDs. Usually, these programmes have been set up with orchestra musicians in mind (Lundborg & Grooten, 2018; Roos & Roy, 2018; Chan et al., 2014a; Chan et al., 2014b) but also for music students (Roos & Roy, 2018; Kava et al., 2010). Table 2.5 below summarises findings from studies with orchestra musicians.

Table 2.5: Examples of exercise programmes in orchestra musicians

Authors	Country	Population	Protocol	Outcomes
Lundborg & Grooten, 2018	Sweden	Orchestra string players (n=24)	Exercise programme: 2/week, 11 weeks. ø randomisation, ø CG. Program: warm-up, resistance training: upper limb (UL), lower limb (LL) and then whole body exercises. Measures: physical tests, self-reported questionnaires (mobility, pain, performance).	Sign. increase in isometric strength for UL and neck as well as back extensors. No sign. improvements in mobility, performance during play and PRMDs.
Roos & Roy, 2018	Canada	Music students and orchestra musicians (EG=15, CG= 15)	Monocentre RCT. Programme: 11-week home exercise programme + 3 supervised sessions, content: warm-up, recruitment, strength and endurance exercises (based on Chan et al., 2013c), cool-down. Measures: MPIIQM, NMQ	Self-reported compliance: 89% for 14 participants (out of 15). Sign. lower scores in MPIIQM intensity and interference for EG. NMQ: no significant interaction.
Andersen et al., 2017	Denmark	Orchestra musicians (EG=12, CG= 11)	Monocentre RCT. Programme: specific strength training (SST) on neck and shoulders vs general fitness training (GFT) on legs only. For both groups: 3 20-minutes sessions for 9 weeks. Measures: strength test, BMI, self-reported questionnaire (subjective physical conditioning, pain, etc.)	Sign. decrease in pain for SST (no significant for GFT). Sign. increase in aerobic capacity, self-reported muscle strength and aerobic fitness for GFT.
Chan et al., 2014a	Australia	Orchestra musicians (n=50)	Programme: 12-weeks exercises intervention with a DVD, at least 2 sessions/week of 40 minutes. Measures: self-reported questionnaire (questions about PRMDs, exertion, several performance factors, etc.).	PRMDs sign. decreased (intensity and frequency). DVD format well received, several benefits on subjective parameters observed.
Chan et al., 2014b	Australia	Orchestra musicians (EG=30, CG=23)	Programme: 10-weeks intervention, endurance and strength exercises, test after the program (T1) and at 6 months (T2) Measures: self-reported questionnaire (questions about PRMDs, exertion, several performance factors, etc.).	Sign decrease in PRMDs frequency and severity at T1, in perceived exertion at T1 and T2 during private practice (not during concerts/rehearsals).

Warm-up has also been specifically investigated by comparing three different types in expert violinists (McCrary et al., 2016a). Outcomes showed no change in muscle activation but significant differences in rated perceived exertion while playing.

Improving motor control is also a very promising way to prevent injury in musicians and enhance their performance. Ackermann et al. (2002) have unsuccessfully tried to improve scapular motor control in upper string players by taping their scapula in a retracted position, as musicians felt uncomfortable in this constraint. Based on these outcomes, unpublished work has sought to evaluate how task-specific exercises around the scapular region could improve muscle activation while playing in upper string players (Rousseau et al., 2019, PAMA symposium). Several exercises have been taught to upper string players in order to recruit their scapula stabilisers, the *trapezius* and *serratus anterior*. Immediate potential effects of these different motor control training have been monitored by surface electromyography and by collecting subjective sensations while performing the exercises and while playing the violin (before and after having learned and performed the exercise). The task-specific exercises were found as being useful to recruit the targeted muscles and both bilateral task-specific and Scapular Orientation Exercise (inspired from Mottram et al., 2009) were considered by participants (not significantly) as being the most useful exercises to perceive their muscles activation while performing the exercises and while playing. However, the exercises showed no significant effect on muscle recruitment while playing but this may have several explanations such as the length of exercises practice which was too short to modify movements from long-term experienced instrumentalists.

4.3. Ergonomics tools

Assessing and modifying instrumentalist ergonomics could potentially help musicians to decrease physical loads (Storm, 2006). Unfortunately, according to a recent systematic review (Chi et al., 2020), studies on this specific topic are scarce and quite limited in terms of data analysis and interpretation. This notwithstanding, the review reported that the set-up of violin and the use of a shoulder rest may alter muscle activity. Kok et al. (2019) pointed out that a higher shoulder rest was associated with a significantly higher violin fixation force, increased activity in the left deltoid and decreased musicians' subjective comfort while playing their instrument. Price & Watson (2018) have sought to evaluate the effect of using an ergonomic support specifically developed for brass instrumentalists, the ErgoBrass®. If not all muscles were altered, a lot of them have seen their activation reduced from 10 to 35% while playing with the support. Different carrying systems were also investigated in saxophonists as they could use various types such as neck-strap, shoulder-strap or Saxholder, which was considered on a small sample of musicians (n=14) as potentially being the most physiological support (Piatek et al., 2018). Finally, Young & Winges (2017) investigated what changes could occur by varying the thumb-rest height on the clarinet. They brought to light that the thumb was not only a "static anchor" but played a way more complex role as alterations were noticeable in the EMG of different thumb muscles depending on different notes.

CHAPTER 3:

DEVELOPMENT OF A MODEL ABOUT PREDISPOSING INJURY RISK FACTORS IN MUSICIANS

Paper published:
Rousseau, C., Barton, G., Garden, P., & Baltzopoulos, V. (2021) Development of an injury prevention model for playing-related musculoskeletal disorders in orchestra musicians based on predisposing risk factors. International Journal of Industrial Ergonomics, 81, 103026.

1. ABSTRACT

Introduction: Playing-related musculoskeletal disorders (PRMDs) have been defined at the end of the last century and often investigated since then. Playing an instrument could lead to various injuries and several musicians report problems during their career but there is currently no detailed model with all the main predisposing risk factors. The aim of this study was to build a comprehensive model of injury prevention and risk factors in musicians by combining the main ones reported in the literature with findings from interviewing musicians and experts.

Methods: The initial model has been based on literature. This model identified nine categories of risk factors and 50 related sub-categories. Then, interviews were conducted with Royal Liverpool Philharmonic Orchestra musicians (n=15) and experts in musicians' health (n=9). The final version has been adapted to take into consideration the views of musicians and experts.

Results: Eighty percent of the RLPO instrumentalists experienced at least once PRMDs in their career. As main work-related stressors, postural and workload issues were mentioned most frequently. Experts, who agreed broadly with the initial model, added interesting items that should be taken into account in assessing musicians' health and helped to clarify some of the sub-categories.

Discussion: A comprehensive model has been developed based on current literature, and suggestions by musicians and experts in musician and general population health. This theoretical framework provides perspectives in terms of assessment, treatment and prevention in musicians, whether they are currently suffering from PRMDs or not.

Keywords: Playing-related musculoskeletal disorders – injury risk factors – music performance – musician health and wellbeing

2. INTRODUCTION

Playing an instrument at an elite level as a professional musician is a very demanding occupation and almost every musician has experience of musculoskeletal complaints. Playing music is the result of hours of practice, requires extremely repetitive movements in a non-physiological posture, entailing musculoskeletal strain. In recent years, the musician appears to be now described as an athlete (Stanhope, 2016; Baadjou et al., 2015) and compared with manual workers (Storm, 2006).

Although pain among musicians has been investigated for many years, playing-related musculoskeletal disorders (PRMDs) have been defined in 1998 as "pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to" (Zaza et al., 1998). This definition has been based on the views of musicians and healthcare professionals, and musicians have distinguished everyday aches and PRMDs. This definition is now used often to investigate PRMDs (Silva et al., 2015; Wood, 2014; Ackermann et al., 2012) but some authors do use other definitions, that lead to difficulties in conducting systematic reviews.

Reviews rated the lifetime pain prevalence among musicians between 29 and 90% (Silva et al., 2015). Representative percentage of pain prevalence among musicians is difficult to summarise for because of the great variability of elements taken into account such as population, PRMD definition (Zaza's operational one or other definitions), survey types (questionnaire, phone or face-to-face interview), pain reporting, etc. Nevertheless, Silva et al. have estimated that between 25.8 and 84.4% have suffered from PRMDs affecting their playing capacity (Silva et al., 2015). Concerning instrument differences, upper string players are the most affected (Baadjou et al., 2018; Wu, 2007), but brass and woodwind players are not exempted (Ackermann et al., 2012).

In the Royal Liverpool Philharmonic Orchestra (RLPO), the administrative management team has operated a Musicians' Performance and Wellbeing Programme. This programme helps their musicians grow as artists and address many issues: hearing health, musculoskeletal disorders, performance enhancement and career development and wider physical and mental health and wellbeing.

This type of programme is still very exceptional in orchestras around the world but there is a strong increasing interest towards the need of preventive and remedial care to help musicians (Zaza et al., 1998; Chan et al., 2013b).

Even if raising interests in musicians' health have led to improved knowledge, systematic reviews have not shown any relationship between risk factors and injuries because of the studies' variety and lack of consistent methodology.

The aim of this study is to build a theoretical comprehensive model of risk factors that could lead to injuries in musicians by combining existing literature knowledge with current opinion of experts and orchestra musicians so that it can be used effectively for injury prevention in musicians.

3. METHODS

This study comprised three phases:

- Developing an initial model of PRMDs risk factors based on the current literature

- Conducting interviews with musicians' health experts and musicians from the RLPO to assess the model
- Building the final model, based on experts' and musicians' opinions.

3.1. Ethics

The study protocol received ethical approval from the Liverpool John Moores University Ethics Committee (19/SPS/011).

3.2. Data triangulation

Data triangulation was designed to improve the study's quality (Flick et al., 2004). This was achieved by combining literature based topics with experts' opinions and musicians' experiences.

3.3. Literature review and initial model

The main aim of the literature review was to develop the basis for a comprehensive model about all known risk factors that could affect musicians' health and could interfere with their playing. The model should involve groups of risk factors and sub-groups, also to be further used as keywords for transcriptions' analysis and simplify the verbatim categorization.
The search was conducted between September and November 2018 but has been updated in March 2019. The initial model has been based on systematic and meta-analysis papers but to be the most comprehensive, also on narrative, case control and cross-sectional studies, essentially on instrumentalists (studies on vocalists have not been included).
Finally, two essential criteria were formulated:

- The model should follow the principles of the bio-psycho-social conception of health (Wijma et al., 2016; Engel, 1977).
- The model should use the principles of the International Classification of Functioning, Disability and Health (WHO, 2002).

3.4. Musicians' interviews

3.4.1. Sample

Fifteen musicians (8 females, 7 males) from the Royal Liverpool Philharmonic Orchestra (RLPO) were interviewed between 20th of February and 6th of March 2019. Instruments are reported in figure 3.1.

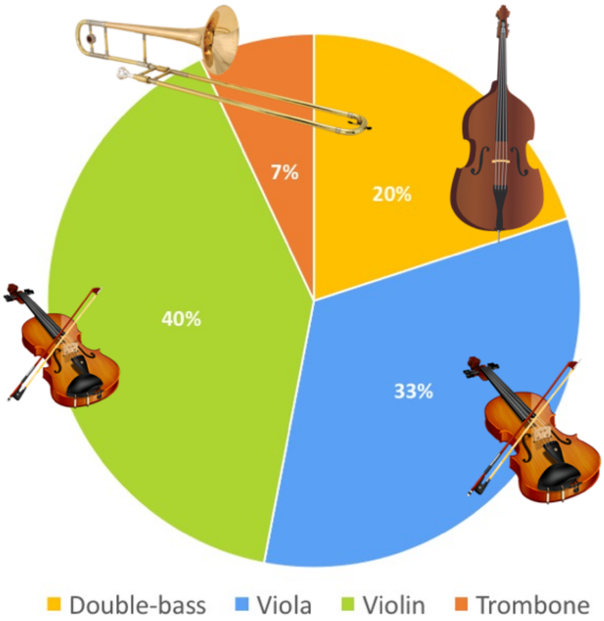


Figure 3.1: Partition of instrument played in the sample (RLPO musicians)

3.4.2. Inclusion criteria

Every volunteer English speaking instrumentalist could participate.

3.4.3. Recruitment

Musicians volunteered to participate after a short presentation and were asked to choose time slots.

3.4.4. Interviews

The interviews were conducted in quiet rooms at the Liverpool Philharmonic as the most convenient location for the musicians and lasted on average 13 minutes (7-19 minutes).

The face-to-face standardised interview included open-ended questions about current health, playing-related musculoskeletal disorders, injury management, physical and psychological stressors (see Appendix A), to investigate their opinion and improve the model. Consent forms were completed by participant before starting.

3.4.5. Equipment

The "Voice Recorder" application has been used on a smartphone (Fairphone 2) to record the participant's answers and immediately transferred and anonymised for transcription.

3.5. Experts' interviews

3.5.1. Sample

Nine experts (5 females, 4 males) from Australia (4), France (3), United Kingdom (1) and United States of America (1) have been interviewed between 20th February and 11th March

2019. Seven are specialized musicians' physiotherapists (with different university levels), one is a psychologist, a psychotherapist and a Professor of Psychology and the last one is an expert musician, trained to coach musicians. Amongst all the experts, three are considered as main researchers in the field of musicians' health and have contributed many published studies to improve knowledge and understanding of playing-related musculoskeletal disorders.

3.5.2. Inclusion criteria

Experts were chosen as experts in musician' health with at least 10-years of experience. As the main goal was to have different ways of thinking and opinions about risk factors represented in the model, not only researcher and healthcare professionals were included. Experts had to be English or French speakers.

3.5.3. Recruitment

Recruitment was done through e-mail. Eleven experts were contacted.

3.5.4. Interviews

Skype (n=8) and face-to-face (n=1) interviews were conducted. Interviews lasted on average 18 minutes (range: 10-30 minutes). The main researcher presented the initial model through a PowerPoint presentation (see Figure 3.2. in Appendix B) and experts were invited to give their opinions on each category or at the end. Consent forms were completed by participants before starting.

3.5.5. Equipment

The same application has been used and records were immediately transferred and anonymised for transcription. Skype has been used for international interviews.

3.6. Verbatim transcription and analysis

The recorded interviews were transcribed by the main researcher. Each transcription was written within three days to ensure that the interview recollection remained fresh. To protect participants' identity, codes were assigned and interviews were transcribed. Only verbal elements have been transcribed, neither non-verbal nor para-verbal ones were taken into account (Flick et al., 2004).

Classification of the verbatim responses is slightly different between musicians' and experts' interviews. The process is based on Creswell (2014) and described in Figure 3.3.

Concerning experts, verbatim responses were classified according to the sub-categories in:

- Agreements
- Disagreements (additions, changes)
- Anecdotes.

Only additions or changes were analysed to improve the initial model. Musicians' verbatim responses have been classified thanks to the initial model but also based on their statements only if items were missing.

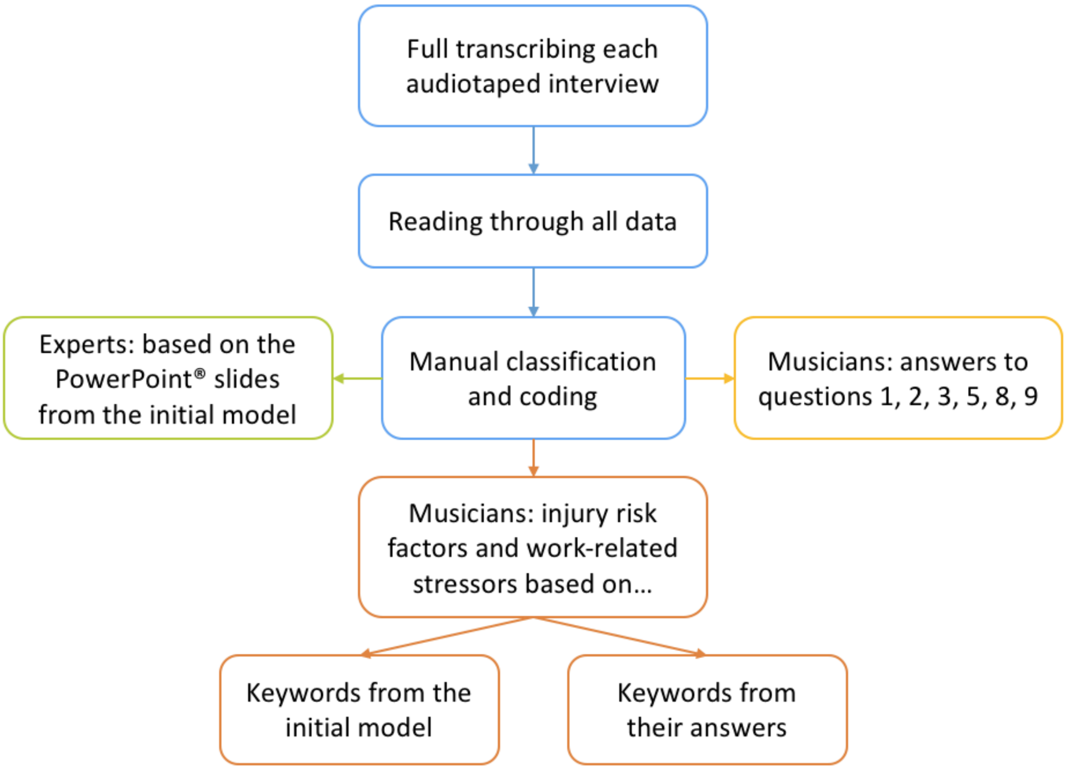


Figure 3.3: Qualitative methodology used for the interview's data treatment (adapted from Creswell, 2014)

3.7. Statistical analysis

Descriptive statistical analysis was conducted to analyse the verbatim responses. Concerning musicians' interviews, some questions were analysed together:

- Questions 1, 2 and 3: health and PRMDs related
- Questions 4, 6 and 7: risk factors, stressors
- Question 5: solutions to manage PRMDs
- Question 8: musicians' needs and perspective for further studies
- Question 9: prevention of PRMDs through teaching.

Expressed percentages represent the number of musicians that mentioned the identified issues.

4. Results

The initial about PRMDs risk factors has been developed based on the literature in musicians (Baadjou et al., 2016; Wu, 2007), but also in the general population. Nine categories have been created to classify each risk factor (Baadjou et al., 2016; Chan & Ackermann, 2014): individual characteristics, posture, biomechanics, workload, injury management, physical conditioning, life habits, environment and psychology. Details of sub-categories are given in Table 3.1 (Appendix C). The notion of "instrument" has deliberately not been included: each instrument will affect in different ways all the listed risk factors and that could explain why some instruments are considered more "risky" to play.

4.1. Experts' interviews

One of the experts has mentioned the importance of clarifying "instrumental musicians" to exclude singers. Another has reported the absence of alternative pedagogy (coaching during professional life), stating that after college, musicians are not followed up in their career. All the elements that experts have added or changed are summarized in Table 3.2 in Appendix D. Each point corresponds to one element mentioned by one expert or more. Classification has been done based on the initial sub-categories.

4.2. Musicians' interviews

Questions 1, 2 and 3: Health and PRMDs

In terms of health (Q1), 87% considered themselves as "OK" or "healthy" and among them three have mentioned problems. One only mentioned problems and another reported to be "not OK". Concerning PRMDs (Q2), 40% of the musicians declared being "aware of them", 60% having experienced them and 20% not knowing about them (but these 20% have experienced them). 80% reported PRMDs during their life and 20% reported only transient aches (Q3).

Questions 4, 6 and 7: Risk factors and stressors

The analysis of the three questions Q4, Q6 and Q7 is summarized in Table 3.3 (see Appendix E). Despite the wide variety of mentioned injury risk factors and stressors, the major issues were:

- Posture-related as holding the instrument (80%), notion of unnatural posture (60%),
- Biomechanics-related as repetitive movements (27%) or sitting position (53%),
- Workload-related as overwork (47%) and length of playing time (80%)
- Environment-related as temperature (40%),
- Psychosocial-related such as stress (53%) and relationship to others (33%).

Question 5: Solution towards pain

Keywords and frequencies about solution to relieve pain are summarized in Table 3.4.

Table 3.4: Answers to the 5th question about solution towards injury/pain

Keywords	Musicians' answers (%)
Medication	13% (2/15)
Alcohol/drugs	7% (1/15)
Self-administered treatments	67% (10/15)
Hot/cold pack	30% (3/10)
Exercises	80% (8/10)
Warm-up	10% (1/10)
Auto-massage	10% (1/10)
Stretching	30% (3/10)
Seek for some help	80% (12/15)
Physiotherapists	100% (12/12)
Sport massage onsite	25% (3/12)
Chiropractor	8% (1/12)
Acupuncture	8% (1/12)
GP	8% (1/12)

Question 8: Required changes

Concerning what the musicians would like to see changed, four groups of risk factors have been mentioned: workload, physical conditioning, environment and injury management.

In terms of workload, 33% of musicians would like to see changes in the management of programmes (to avoid busy periods) and two (13%) mentioned issues in section management (sometimes fewer players than needed). Regarding physical conditioning, two musicians (13%) would like to participate in organised physical activity sessions.

Concerning environment, musicians mentioned better temperature (20%), lighting and music sheets printing (7%) and quieter rooms dedicated to resting (7%). One would like to see more sessions of physiotherapy and massage. Finally, three musicians reported that nothing could be done to improve the mentioned issues.

Question 9: Teaching

Among the 73% musicians who teach, 81% reported to pay attention to PRMDs in their way of teaching and one mentioned their limited knowledge.

The final model has been described in Figure 3.4 below.

Subcategories are more extensively described in Table 3.5 in Appendix F and has been designed as concept map (Figure 3.5 in Appendix G).

Figure 3.4: Final graphical representation of the comprehensive model of PRMDs risk factors in musicians

5. Discussion

5.1. PRMDs and attitudes towards PRMDs

A high life-prevalence of PRMDs has been highlighted: 80% of the musicians reported having suffered from PRMDs during their life. This percentage is quite comparable with literature (Silva et al., 2015; Zaza et al., 1998). However, 87% of the interviewed musicians stated their health as "OK", and this indicates that they seem to consider health and musculoskeletal disorders as separate elements, or even find having PRMDs as "normal". All of the interviewed musicians had some basic awareness of PRMDs and some of them reported not having a lot of knowledge, despite having experienced them. Concerning the chosen approaches to injury, RLPO musicians are more likely to seek help (80%) but several musicians mentioned also self-treatment techniques (particularly active treatments). Each musician who mentioned seeking help they were consulting physiotherapists. From literature and personal experience, this outcome is perhaps quite surprising for someone who is not aware of the injury management programme at the Liverpool Philharmonic. For three years now, musicians can book appointments with physiotherapists, injury prevention screenings and sport massage sessions onsite. This injury management is quite unique but really effective for musicians (Chan & Ackermann, 2014; Milanese, 2000) and could explain why 80% of the interviewed musicians are seeking physiotherapy to help them, a high proportion that is not found in the literature (Wood, 2014).

5.2. Musicians' interview and assessment of the initial model

This study has been designed as exploratory qualitative research. As we currently know a lot of what the musicians feel are the general stressors associated with their work, the main aim was to assess the initial model and have musicians' opinions "quick on the draw" to be certain we were not excluding issues they were facing in their daily life.

Common outcomes found to be in agreement with the literature were the length of playing-time (mentioned by 80% of the RLPO musicians), difficulty of programmes, stress and lack of rest (Ackermann et al., 2012; Rickert et al., 2013; Ackermann & Adams, 2004). According to 40% of the musicians, temperature is also a major issue, despite that it is not often investigated (Wood, 2014; Ackermann et al., 2012; Ackermann & Driscoll, 2010).

Contrary to main findings in the literature, a sudden increase of practice seems to be a minor issue and poor injury management is fortunately not that true anymore with the RLPO (Ackermann et al., 2012). Lack of awareness and knowledge towards PRMDs is not often mentioned in the literature, but this has been described as one major modifiable issue (Baadjou et al., 2018; Hildebrandt & Nübling, 2004). Finally, "poor" or "bad" posture is often described in specialized literature and mentioned in these terms with musicians (Wood, 2014; Ackermann et al., 2012; Ackermann & Driscoll, 2010) but this was not stated in these words by musicians, that reported postural issues in "holding the instrument" and as "unnatural posture". "Poor" or "bad" posture referred to sort of negative judgement of musicians' posture, whereas "ideal" posture has not been described (O'Sullivan et al., 2012). Specific issues relative to the size of the instrument sections have also been highlighted.

5.3. Experts' opinion and changes in the model

Based on experts' opinion, several additions and changes were made. In individual characteristics, non-musculoskeletal disorders, spine curvature and notion of master eye and ear were added. Sitting position has been placed in posture. Motor control has been extended to more joints, body locations such as face (jaws, lips) and breathing. Fatigue has been separated in two different types: physical and mental (Chan et al., 2000). In terms of injury management and workload, experts helped to build a more comprehensive sub-classification. Concerning the environment and working conditions elements, experts added the dust, the chairs arrangement and the lack of space (Ackermann & Adams, 2004). Finally, several changes and additions were made to the psychological elements such as turning anxiety to trait anxiety, pressures to perfectionism, personality traits to negative affectivity (Wu, 2007; Kenny, 2011). Stress has been separated into occupational and general stress (Chan & Ackermann, 2014), fatigue and management of personal life have been added, as well as biomechanics related elements as fear avoidance of movements (Vlaeyen et al., 1995) and beliefs towards pain (Wijma et al., 2016; Britsch, 2005).

5.4. From the initial to the final model

Certain elements have not been changed, even if experts stated against them. For example, instrument has not been added, despite one of the experts' opinion. Literature reports that upper string players seem to be more at risk (Baadjou et al., 2016; Wu, 2007) and playing woodwinds seems to be protective towards PRMDs. This model does not include instrument as a factor but it can be assumed that instrument is an "underlying" factor because this model has to be applied to individuals.

As this model aims to be a comprehensive theoretical framework for further studies, it has been decided to base the model on the literature but, as the studies are often showing poor methodology (Baadjou et al., 2016), we cannot really conclude towards risk factors such as physical activity (PA). That is why warm-up and PA have been kept, despite experts' opinions. Finally, "number of years" has been added in individual characteristics (Baadjou et al., 2016).

5.5. Strengths of the study

The main strength of this study is using data triangulation to develop and assess a theoretical model about risk factors. Indeed, combining literature, musicians' and experts' opinions has been already done by Zaza et al. (1998) to define more precisely the PRMDs and also by Ackermann & Adams (2004) to help with defining risk factors of PRMDs among violinists and violists. In addition, contrary to other studies (Ackermann & Driscoll, 2010; Ackermann & Adams, 2004), musicians have been asked for their opinion without ticking boxes on pre-identified risk factors, and this ensured that answers reflect reality and not pre-defined choices.

Furthermore, this study provides a comprehensive model about PRMDs risk factors, revised by several experts and confirmed by musicians' statements about their life. This model provides perspectives useful for further studies.

5.6. Limitations of the study

The first limitation of the study is the limited sample of interviewed experts and musicians, that is often found in such qualitative research, because of the highly time-consuming transcription and analysis (Creswell, 2014; Pope, 2000). As musicians are from the same orchestra, they will obviously highlight the same kind of issues and these could be slightly different from one orchestra to another. On the other hand, experts are from many countries around the world, which gives many different perspectives of musicians' health and PRMDs risk factors (but remaining "Western" concepts of health). Qualitative research is an art that requires experience and classifying verbatim into keywords is always a difficult exercise (Labbé & Labbé, 2012). Experts' verbatim classification was easier than musicians' thanks to the PowerPoint® slides.

5.7. Perspectives

The next step of this work is to build a comprehensive screening tool based on each identified risk factor in the model, investigated through questionnaire or physical examination.

The secondary implication of this study concerns further interventions that could be conducted with musicians. Solutions suggested by musicians could be investigated through global PA or task-specific exercise interventions, which seems to be more effective (Roos & Roy, 2018; Chan et al., 2014). Lack of knowledge, highlighted by some musicians, could also be improved by specific educational courses, based on this theoretical model and on current evidence (Baadjou et al., 2018; López & Martinez, 2013).

Finally, this model provides further ideas for management teams to improve their attitudes towards injury and programming concerts' calendar.

CHAPTER 4:

ASSESSING RISK FACTORS IN ORCHESTRA MUSICIANS:

A NEW TOOLKIT

First part: Development of a Comprehensive Questionnaire to Assess Predisposing Injury Risk Factors in Musicians

1. Abstract

Introduction: Playing-related musculoskeletal disorders are nowadays more and more investigated. In a previous study, according to the current literature and based on musicians' and experts' opinions, a theoretical model of predisposing risk factors has been developed. The aim of this study was to apply the Injury Risk Factors Questionnaire for Musicians, based on the model, to investigate several injury risk factors in musicians but also to evaluate how this new tool could be useful to efficiently assess predisposing risk factors in musicians.

Methods: The Injury Risk Factors Questionnaire for Musicians (IRFQM) has been developed based on a theoretical model of predisposing risk factors. For every item or group of items, questions for the IRFQM have been based on validated questionnaires developed and described in the literature such as the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM) or the Anxiety Depression Detector (ADD). The IRFQM have been piloted with healthcare experts and musicians, before being then tested with 31 musicians.

Results: The IRFQM has been completed in 19.3 minutes (±7.2) on average (response rate: 42%). Strong differences have been found between musicians in answers concerning common topics, such as tour frequency, rehearsal and concert weekly amount of rehearsal and concert hours or repertoire difficulty. Furthermore, few questions would need a reformulation in future studies as they have often been misunderstood by musicians, such as questions about private practice sessions and physical activity. Musicians themselves helped in rephrasing the concerned questions.

Discussion: The IRFQM covers a wide range of PRMDs risk factors and its strength is to be based on a comprehensive theoretical model. Some questions were difficult to answer for musicians, especially the ones which ask for an average, as private practice playing time or physical activity sessions, but this does not lead to major issues, as the aim of this questionnaire is to screen musicians' current health and well-being, as much as catch noticeable differences in their lives.

2. INTRODUCTION

Pain in musicians has been investigated for many years focusing on the relationship between pain and several anthropometric parameters, biomechanical factors or life habit elements (Chan & Ackermann, 2014). Because of the heterogeneity of methodology of most studies that have investigated musicians' health, there is still a lack of key knowledge about injury risk factors in musicians as most of them took into account only a small number of factors. Several general questionnaires have been used to investigate musicians' health such as the Short QUestionnaire to ASsess Health enhancing physical activity (SQUASH) to investigate physical activity (Baadjou et al., 2015), the Health Promoting Lifestyle Profile II (HPLP II) to investigate several behaviours (Araujo et al., 2017) or several psychological questionnaires (Kenny & Ackermann, 2015). Questionnaires have also been designed specifically for musicians. For example, the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM) is a validated questionnaire that investigates pain intensity and interference in musicians. This pain questionnaire is based on general questionnaires (such as the Nordic Musculoskeletal Questionnaire or the Brief Pain Inventory) but also on the Musculoskeletal Pain Questionnaire for Musicians (Lamontagne & Bélanger, 2012), a non-validated questionnaire designed to also investigate pain in musicians. The MPIIQM has also been inspired by the Musculoskeletal Load and Physical Health Questionnaire for Musicians, designed by Ackermann & Driscoll (2010), which is a non-validated questionnaire that assesses many health-related variables in musicians such as physical activity, pain and problems, sleep quality or alcohol consumption. Finally, music performance anxiety has also been investigated and a special questionnaire has been designed with its psychometric properties validated (Kantor-Martynuska & Kenny et al., 2011).

In a previous study, a theoretical model has been developed to better understand injury risk factors in musicians. The model was intended to be the most comprehensive possible based on the current knowledge found in specialised musician health literature, and also informed by musicians' interviews and opinions of specialised experts (Rousseau et al., 2021). Based on this theoretical model describing predisposing risk factors to injuries, a comprehensive screening tool has been designed to evaluate predisposing injury risk factors in musicians, by assessing every item included in the comprehensive theoretical model through a specific questionnaire and a physical examination (Rousseau et al., 2021). As far as possible, this Injury Risk Factors Questionnaire for Musicians has been built by combining questions from previous validated questionnaires (general or musicians specific questionnaires – if existing). As the length of the questionnaire has been also taken into consideration and to avoid having too many items, some new questions have been created instead of integrating the whole questionnaire, based on the definition of the evaluated construct, as for example the music performance anxiety (Kenny, 2011).

Therefore, this new questionnaire gives the opportunity for healthcare professionals to screen both PRMDs and a wide number of their predisposing risk factors. This can be done by using part of validated questionnaires (contrariwise to what was already described in previous papers) focusing on risk factors such as physical activity (Baadjou et al., 2015) or investigating a large number of them such as the MPIIQM (Berque et al., 2014; Ackermann & Driscoll, 2010).

The aim of this study was to develop a comprehensive questionnaire based on a theoretical model for playing-related musculoskeletal risk factors in musicians.

3. Method

3.1. Sample

The sample consisted of 31 volunteer musicians from the Royal Liverpool Philharmonic Orchestra who volunteered to participate (16 females, 15 males, response rate: 42%), aged from 44.9 (± 10.6) years old on average, with 34.7 years (±10.7) of years of instrument practice on average and 21.1 years of orchestra work (±10.8). Concerning the job status of the musicians, 16% were freelance and 84% employed were full-time by the RLPO. Instruments played by the musicians in the sample examined are described in Figure 4.1. The instrument repartition is quite similar from the usual orchestra instrument repartition, except for brass and percussion where percentages were quite different (about 48% for upper strings, 18% for lower strings, 7% for percussion; 14% for brass; 12% for woodwind).

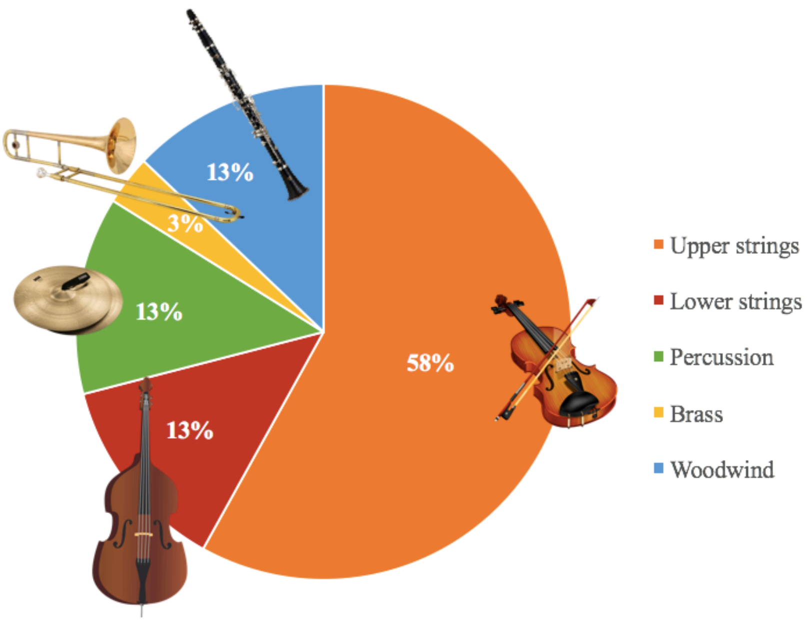


Figure 4.1: Instruments played among the sample of the RLPO musicians

3.2. Inclusion criteria

Every volunteer English speaking instrumentalist of the RLPO could participate as long as they were able to fill an online questionnaire.

3.3. Development of the questionnaire

The questionnaire has been developed in order to cover most injury risk factors in musicians as it has been described in a previous theoretical model, based on literature, musicians' and health experts' opinions (Rousseau et al., 2021). Moreover, each item of the questionnaire has been based on or inspired by existing validated questionnaires (except for the questions about personal life management and recovery routine), by extracting specific questions to provide information about the precise injury risk factors from the model.

3.4. Description of the questionnaire

The IRFQM has been developed based on a comprehensive theoretical model about predisposing injury risk factors in musicians (Rousseau et al., 2021). It includes six sections and every item included in the questionnaire is based on the model risk factors. The content of the different sections of the IRFQM are described below (and the items in Appendix H).

Section A collects epidemiological data (such as age, sex, instrument played, years of playing).

Section B measures the musician's typical workload and work environment, mainly based on elements of the MPIIQM (Berque et al., 2014) but also on several studies that have investigated elements such as sitting posture (Spahn et al., 2014) or repertoire and increase in practice (Kok et al., 2016; Ackermann & Driscoll, 2010).

Section C examines daily physical activity and related work behaviours, such as warm-up, recovery routine with items mainly based on the Global Physical Activity Questionnaire or GPAQ (Bull et al., 2009).

Section D explores playing-related musculoskeletal disorders (PRMDs) through items from the MPIIQM (Berque et al., 2014) that investigates mainly pain prevalence, intensity and interference with daily activities and musical performance. This section also examines the musician's belief towards pain, mainly inspired from the Pain Beliefs Questionnaire (Edwards et al., 1992) and the way the musician and orchestra team are managing injuries (Chan et al., 2013b).

Section E considers several psychological, mental health and well-being elements such as anxiety, depression, perfectionism or stress. These items are mainly based on the Anxiety and Depression Detector (ADD) (Kenny & Ackermann, 2015; Means-Christensen et al., 2006), the Health Promoting Lifestyle Profile II (HPLP II) (Araujo et al., 2017; Walker et al., 1987) and the

Multidimensional Inventory of Perfectionism in Sport (MIPS) (Araujo et al., 2017; Stoeber et al., 1998).

Section F investigates several life habits such as alcohol, tobacco or drugs consumption, sleep habits, nutrition, hobbies, etc. Questions are inspired by WHO questionnaires (WHO, 2011; WHO, 2001), Chalder Fatigue Scale (CFS) (Araujo et al., 2017; Cella & Chalder, 2010), Pittsburgh Sleep Quality Index (PSQI) (Araujo et al., 2017; Buysse et al., 1989) and the HPLP II (Araujo et al., 2017, Walker et al., 1987).

The length of the questionnaire was different for each musician: some parts of the questionnaire were not filled, depending on their previous answers: pain was investigated in musicians who had pain during the last week or month and physical activity was further investigated after a first "yes/no" question concerning global physical activity in the last twelve months.

3.5. Pilot study

Once the questionnaire was fully designed, the online version was developed and sent to two musicians and one physiotherapist via Online Surveys (JISC, UK). All were asked to fill the questionnaire (the physiotherapist was a musician himself) and then, they were asked to report how much time they needed to fill it and if they felt that this was too long.

Then, they were asked to fill in the questionnaire a second time and to rate for each questions:

- The comprehensiveness on a 11-Likert Scale,
- The relevance of every item according to Lawshe (1975) as "essential", "useful but not essential" or "not useful".

No question has been rated as not useful. The majority of all questions has been rated as essential by the three examiners.

Concerning the comprehensiveness, few changes have been made:

- In questions 59 and 60 (about elements that could increase or decrease pain), the number of answers to be selected was missing and this was corrected,
- "Indicate if no special nutrition regime" has been added to question 88.

Question 40 was considered as unclear by one of the musicians (as this question requires the respondent to remember previous answers) but was required to fit with the online questionnaire's requirements.

3.6. Protocol

The questionnaire was competed as part of a whole study to develop tools assessing injury risk factors (this questionnaire and a physical assessment). The questionnaire was completed three

days before the physical examination appointments that were scheduled between 23rd of May and 14th of June 2019, because this was a typical period of work for the orchestra with a normal number of concerts and scheduled rehearsals.
After analysis of the whole questionnaire, a few musicians from the RLPO were asked to help the main researcher improve and reformulate some questions that could have been misunderstood.

3.7. Missing items

As every question has been developed as mandatory in the Google Form version, no items were missing.

3.8. Ethics

The study protocol received ethical approval from the Liverpool John Moores University Ethics Committee (19/SPS/011).

4. RESULTS

4.1. Response time

The amount of time required to complete the whole questionnaire was 19.3 minutes (±7.2).
One musician did not fill neither the pain nor the physical activity part and took 31 minutes to complete the questionnaire (75 questions). Twenty-one musicians (66%) had no pain during the last month or week, have filled 79 questions and took on average 18.1 minutes (±7). Finally, nine musicians have filled the whole questionnaire (88 questions) and took on average 19.7 minutes (±6.2).

4.2. Same orchestra – different answers

Even if all musicians from the sample are employed by the same orchestra, major differences were found in the answers concerning workload items.
Firstly, concerning rehearsal workload, musicians have estimated that they were playing on average 21.3 hours (±6.3) per week, but answers ranged from 12 to 30 hours per week. Concerning concert workload, they have estimated on average 5.8 hours (±1.6) of concert per week and answers ranged from 4 to 10 hours per week.
Finally, questions 17 and 18 were about workload and if musicians thought it was uniform or not. Among the sample, 8 musicians have evaluated their workload as uniform and 20

musicians as fluctuating. Among these 20 musicians, 8 have estimated that their current workload was in a peak period, 10 in a quieter period and 2 in between.
Concerning the repertoire's difficulty, musicians have rated their repertoire as 2.9 (±0.8) on 5-Likert scale (from 1 for really difficult, to 5 for really easy,) but answers ranged from 1 to 4.
Finally, concerning touring, musicians have estimated the number of tour requirements per years on a 6-point Likert scale as 2.6 (±0.6), between rarely and sometimes, and answers ranged from 2 (rarely) to 4 (often).

4.3. Modified questions for better clarity helping to provide more representative answers

Some questions have been difficult to answer for musicians. As the questionnaire was completed before a physical examination appointment, questions with surprising answers have been discussed with the musician to improve the questionnaire.
The first difficulty has been noticed with questions 12, 13 and 14, where the musicians were asked to estimate the number of their private practice sessions, the length and the amount of time they would take a break between practice sessions. Many of them have answered practicing for only one session but have also answered a number different from 0 about the time they would rest between private practice sessions: some have estimated to rest for a couple of minutes during the session, some had misunderstood the concept of private practice sessions.
The second difficulty concerned questions 30 to 35, regarding vigorous and moderate physical activity and hours of practice. Lack of full answer has often been noticed: musicians have sometimes forgotten to provide what kind of physical activity they were performing. Potentially, in next studies using this questionnaire, these questions could be re-written as separate items to provide more reliable information.
Finally, some questions about pain and beliefs have been sometimes misinterpreted. For example, question 56 "Do you play through pain" has been understood by musicians as "if it was needed, will you play through pain" even if they had any pain before while playing.

4.4. Questionnaire changes

Four musicians have helped to amend the questionnaire for better understanding of a few questions. Question 12, 13 and 14 have been slightly changed, by adding a short description about what "practice sessions" means: "*Practice sessions are considered as time allowed to practice your instrument in one go, with no breaks (even short ones such as five or ten minutes), at home or wherever you practice, not including on stage at the orchestra.*" Question 56 has been turned from “Do you play through pain?” to “If you ever feel pain while playing, would you play through it?”.

5. DISCUSSION

5.1. Aim of the questionnaire

This questionnaire has been based on a comprehensive theoretical model of injury risk factors in musicians (Rousseau et al., 2021). This model has been developed according to the relevant literature, but it was also based on musicians' interviews and changed according to advice from experts in musicians' health. The current literature, and particularly the current systematic reviews (Baadjou et al., 2016; Wu, 2007), report a lack of knowledge concerning the relationship between potential risk factors and musculoskeletal pain in musicians. For example, lack of physical activity, absence of warm-up or alcohol consumption have not been highlighted so far as clear risk factors in PRMD development. The main aim of this questionnaire is to encompass all the possible injury risk factors in musicians to allow healthcare professionals (general practitioners, physiotherapists, surgeons, etc.) to screen musicians all over the world with the same tool and help build a stronger model of relationship between several risk factors and PRMDs in musicians.

5.2. Strength of the questionnaire

The IRFQM has been well received by musicians. They reported having completed it with honesty, trying to provide answers closest to reality. Some of them have also reported that it was really difficult to respond to questions asking for “on average” answers, as number of playing hours, time spent with elevated arms, hours spent in physical exercise, etc.

Even if the questionnaire appears to be quite long with its six sections and 88 questions, it could be completed within around 20 minutes, which is completely reasonable for such a tool that investigates a large amount of information.

The main strength of this questionnaire is screening for a large number of risk factors in musicians, including all the potential risk factors known to be implicated in PRMD development that do not need a physical examination (such as motor control or anthropometrics). Moreover, this questionnaire has been based on a comprehensive model about predisposing risk factors in musicians (Rousseau et al., 2021) and underpinned by previous research. Further work should focus on investigating face validity (on which the participants' comments already provided some evidence) as well as assessing concurrent and predictive validity, and test re-test reliability.

5.3. Limitations of the questionnaire

One of the main limitations of this questionnaire is that most of the items are asking for average estimations (of workload, for example) that cannot be averaged easily in the professional life of musicians, such as the rehearsal or concert playing hours or more, the private practice length of sessions or the number of breaks, that will vary from one week to another. Nevertheless, this questionnaire has been thought to screen actual musicians' risk factors. What is needed from musicians is to fill their current average of playing hours, even if it will probably change in the future, to highlight the relationship between sudden increase and PRMDs for example, or number of concert hours rather than rehearsal hours, or lack of breaks during private practice, and so on.

Moreover, the questionnaire has been developed by extracting questions from previously validated questionnaires and by creating others inspired from literature and existing tools. Therefore, the main limitations of this study is that this questionnaire has not been psychometrically validated (that is to say to determine whether the questionnaire measured exactly what it is designed to measure).

6. CONCLUSION

The Injury Risk Factors Questionnaire for Musicians has been developed based on a comprehensive model about predisposing injury risk factors in musicians and its main aim is to screen almost every item of this model to allow healthcare practitioners worldwide to assess musicians' health and achieve better outcomes when evaluating PRMD risk factors and their relationship with musculoskeletal pain and health.

Second part: Playing-Related Musculoskeletal Disorders, Work and Life Habits, Health and Well-Being in Professional Orchestra Musicians in the UK

1. ABSTRACT

Introduction: Playing-related musculoskeletal disorders (PRMDs) have been described by the end of the 20th century and are a lot more investigated these past years. Predisposing risk factors are multiple and a deep comprehension of these factors is still needed to prevent further injuries in professional musicians and help them to enhance their performance. The aim of this study is to investigate several predisposing risk factors in the Royal Liverpool Philharmonic Orchestra and to draw some relationship between some factors and PRMDs.
Method: The Injury Risk Factors Questionnaire for Musicians has been filled by 31 musicians from the Royal Liverpool Philharmonic Orchestra (response rate: 42%). Analysis of the answers and percentages among the sample have been drawn. Then, relationships between factors and presence of PRMDs have been investigated.
Results: Among the sample, about 70% have suffered from PRMDs during their life and 30% during the last month or week. By analysing musicians' answers, several relationships between PRMDs and risk factors have been highlighted such as anxiety, music performance anxiety, recovery routine, position while playing, difficulty of repertoire and behaviours towards pain.
Discussion: Pain prevalence among the sample is comparable to the current literature outcomes. Furthermore, even the sample size of musicians is quite low, significant relationships between risk factors in daily life have been found. The questionnaire seems to be useful to investigate risk factors in musicians and it should be used frequently to improve our knowledge about relationships between identified risk factors and pain in musicians.

2. INTRODUCTION

Playing-related musculoskeletal disorders (PRMDs) in musicians have been described for the first time at the end of the 20th century as "pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to" (Zaza et al., 1998). This definition has been developed to facilitate work and research due to increased awareness and interest in musicians' health and musculoskeletal disorders related to musical performance. Recent reviews estimate the prevalence of PRMDs between 25% and 85% affecting their capacity to play their instrument as they intended (Silva et al., 2015). Epidemiological studies report that upper string players are the most affected (Baadjou et al., 2016; Wu, 2007) but brass and woodwind players are also affected (Ackermann et al., 2012). Predisposing risk factors for PRMDs appear to be numerous and wide ranging. Individual characteristics such as sex, age and anthropometrics are often discussed (Baadjou et al., 2016; Wu, 2007), as well as posture (Blanco-Pineiro et al., 2017; Chan & Ackermann, 2014) and biomechanics impairments (Steinmetz et al., 2010). Furthermore, workload (number of hours playing, lack of rest, etc.) (Baadjou et al., 2016; Wu, 2007), life habits (sleep, nutrition and hydration, alcohol and tobacco consumption, hobbies, etc.) (Chan & Ackermann, 2014) and physical conditioning are often mentioned as related to PRMDs. Environmental elements such as temperature, noise and light could also indirectly lead to musculoskeletal pain (Harper et al., 2002). Culture of injury management (Chan et al., 2013b) and psycho-social elements (anxiety, social support, depression, etc.) (Chan & Ackermann, 2014; Wu, 2007) are also frequently discussed in current literature.

To examine further these various PRMDs risk factors, a questionnaire has been developed based on a theoretical model which described them in the most extensive way possible (Rousseau et al., 2021). Indeed, to the best of our knowledge, several preventive interventions have been developed and tested in orchestras to help musicians avoiding potential injuries by reducing the number and importance of predisposing risk factors (such as setting up a physiotherapy triage service on the lunch time to provide early injury management, while lack of it has been described as being an injury risk factors (Chan et al., 2013b). Unfortunately, so far, it seems that injury risk factors in musicians need further research to be better described and listed (Baadjou et al., 2016; Wu, 2007) in order to be best identified and prevented in individual musicians. Indeed, developing a comprehensive questionnaire to screen risk factors leading to PRMDs in musicians will potentially help researchers to collect stronger data about potential relationships between these risk factors and pain and understand musicians' health better. This will also provide useful tools for healthcare professionals to help them in better identifying musicians at risk as well as improving their diagnosis and rehabilitation skills. It will also provide them resources to tailor prevention interventions.

Therefore, the aims of this study are:

- to report several health and well-being elements such as playing-related musculoskeletal disorders, anxiety, depression, as well as general health behaviour, work and life habits among the Royal Liverpool Philharmonic Orchestra (RLPO)
- to investigate the potential relationship between physical and psychological health, work and life habits with playing-related musculoskeletal disorders.

3. METHOD

3.1. Sample and protocol

The sample and the questionnaire protocol were described in Chapter 4 – Part 1.

3.2. Statistical analysis

Descriptive statistical analysis was performed using Excel® and inferential statistics analysis (Spearman correlations) was performed using SPSS® (version 25.0.0.1). Data normality has been evaluated using the Kolmogorov-Smirnov tests. Degree of significance has been set to 0.05. Moreover, to correlate risk factors and pain, a "pain score" was calculated by summing all obtained scores to the four first questions of the MPIIQM (related to the prevalence of pain: whole life, past year, month or week). This sum gave a pain score between 0 ("no" to all questions, meaning that the musician had never experienced any PRMDs during his/her whole life) and 4 ("yes" to every question, meaning that the musician experienced PRMDs during the last week, and subsequently during the last 4 weeks, 12 months and at least one in his/her life).

4. RESULTS

4.1. Work schedule and habits

Workload per week has been reported in Table 4.2 below.

Table 4.1: Types of workload and number of hours per week

Types of workload	*Rehearsal*	*Concert*	*Private practice*	*Teaching*	*Extra-orchestra*
Hours per week	21.3 (±6.3)	5.8 (±1.6)	6.6 (±4,5)	1.8 (±2.4)	2.2 (±2.4)

Among the sample, private practice sessions number was about 1.3 (±0.5) and their length about 60 minutes (±31.5). Twelve musicians reported not having rest between or during their private practice sessions. For those who are resting during their private practice sessions, they are resting on average 22.3 minutes (±31.9).

Questions 17 and 18 investigated how musicians considered their workload to be uniform or not. Among the sample, 8 musicians have evaluated their workload as uniform and 20 musicians as fluctuating. Among these 20 musicians, 8 musicians have estimated concerning their current workload to be in a peak period, 10 in a quieter period and 2 between both.

Concerning the repertoire's difficulty, musicians have rated their repertoire as 2.9 (±0.8) on 5-point Likert scale, from really difficult (1) to really easy (5) and concerning touring, musicians have estimated the number of tour per years on a 6-point Likert scale as 2.6 (±0.6), between rarely and sometimes.

Questions 21 and 22 have investigated the position while playing and musicians have reported playing mainly sitting during concert and rehearsal (around 1.4 ±0.8 on a 5-point Likert scale) and more standing during private practice (around 2.9 ±1.5).

Concerning position in the stand, 71% of the musicians are playing equally both sides, 16% mainly on the right and 13% mainly on the left. Among the sample, 93% are happy with this position. Finally, concerning playing in the pit or on stage, 93% of the musicians play on stage, the others are playing equally on both pit and stage.

4.2. Physical activity

Musicians have reported by rating it on a 6-point Likert scale (0: never to 5: always):

- having a warm-up routine at 3.5 (±1.5)
- havin a recovery routine at 1.8 (±0.9).

They reported spending about 6.5 hours (±3.5) in a sitting or reclining position on a typical day. Among the sample, 71% of the musicians have reported walking or cycling to work, for about 186 minutes (±179, from 45 to 840 minutes) per week.

Concerning global physical activity, 97% of the musicians have reported participating in regular physical activity during the last year. Among them, 52% reported a regular vigorous activity, for about 134 minutes (± 49, from 75 to 270 minutes) per week and 79% reported a moderate activity, for about 197 minutes (±146, from 30 to 450 minutes) per week.

4.3. PRMDs, behaviours and beliefs towards pain

- <u>Outcomes from the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM)</u>

In terms of PRMDs, 68% of the RLPO musicians from the sample had suffered from pain at some point during their lifetime, 52% during the past year, 32% during the past month and 29% during the past week.

Concerning the 32% of musicians who suffered from pain related to music during the last month or last week, painful body locations are described in Figure 4.2 below.

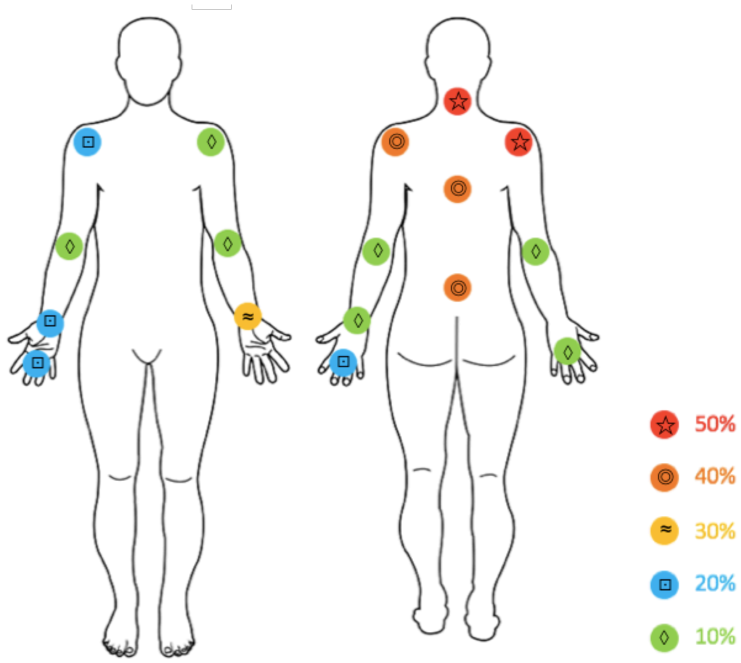


Figure 4.2: Painful body locations (question 41) among the sample of RLPO musicians

Concerning location that hurts the most, were mentioned: neck, right and left shoulders, low back, right elbow and right fingers.

Pain intensity has been described in Table 4.2.

Table 4.2: Pain intensity in participants reporting PRMDs in the last month or week

Items	*Maximum*	*Minimum*	*On average*	*Right now*
Pain intensity last month or week (scale 0-10)	6.7 (±1.9)	3.0 (±2.6)	5.1 (±2.4)	4.4 (±3.2)

Pain interference with daily life and playing their instrument has been described in Table 4.3.

Table 4.3: Pain interference in participants reporting PRMDs in the last month or week

Topics	*Mood*	*Enjoyment of life*	*Usual technique*	*Playing the instrument*	*Playing as well as wished*
Pain interference last month or week (scale 0-10)	5.0 (±3.2)	5.2 (±3.1)	4.9 (±2.4)	4.5 (±2.8)	4.7 (±3.2)

Among the sample, 13% have reported having medical conditions that may impact their play and 13% other have missed working days because of injuries.

- Behaviours and beliefs towards pain

On a 6-point Likert scale (1: never to 6: always), musicians answered they were likely to report injury to the orchestra hierarchy at 2.8 (±1.4) and they found this helpful at 3.8 (±1.6). They have reported they were playing through pain at 3.5 (±1.1).

Concerning the beliefs towards pain, musicians have rated that playing through pain was normal at 2.8 (±1.0) on a 6-point Likert scale, that is to say between rarely and sometimes. They have also reported their belief that pain was a damage of the body tissues at 3.3 (±1.1), between sometimes and often.

Musicians have been asked what could reduce or increase pain while playing. Their answers are described in the Figures 4.3 and 4.4.

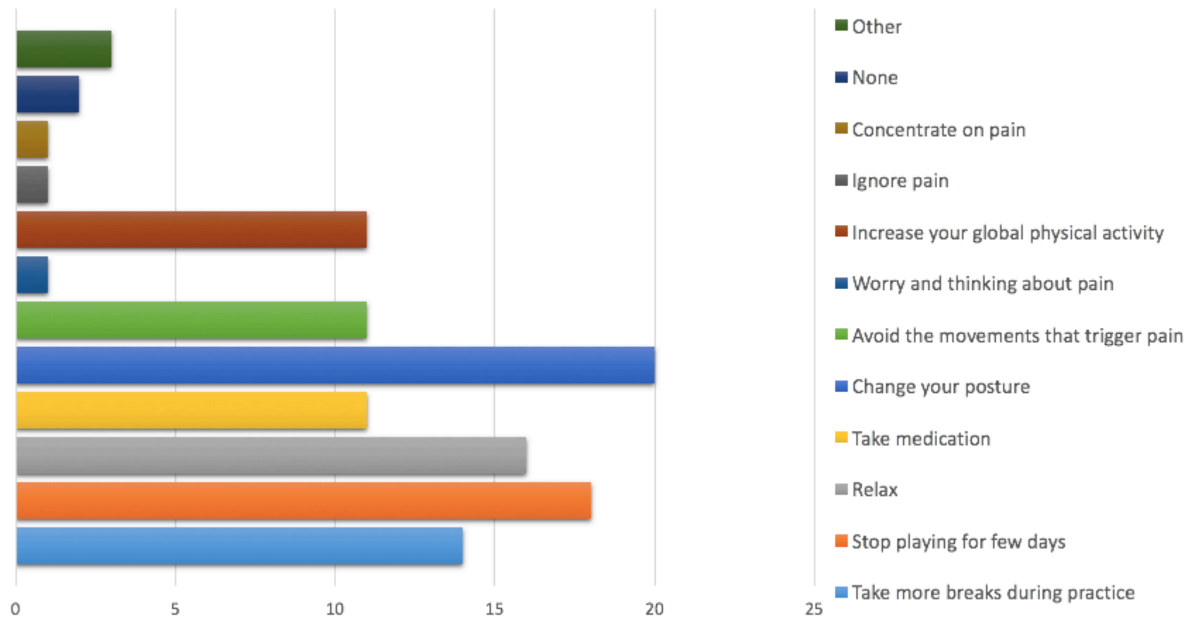


Figure 4.3: Elements that could reduce pain according to musicians' answers in percentage (Q61)

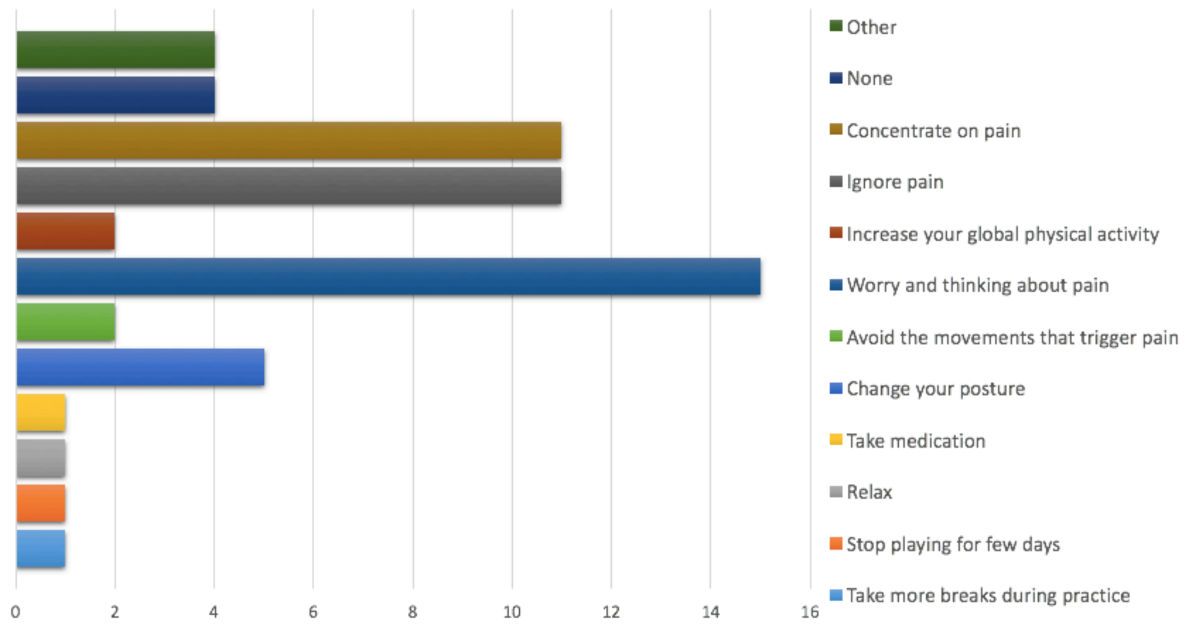


Figure 4.4: Elements that could increase pain according to musicians' answers in percentage (Q62)

4.4. Psychological and pyschosocial elements

In their responses to the Anxiety and Depression Detector, 45% reported having had a spell or an attack when all of a sudden they felt frightened, anxious, or very uneasy; 62% stated having been bothered by nerves or feeling anxious or on the edge; 26% mentioned being anxious or uncomfortable around other people as a problem for them and 32% declared having had at least one week or more when you lost interest in most things like work, hobbies, and other things you usually enjoyed. Three musicians answered positively to the four items and four musicians to three different items.

Musicians have rated on a 6-point Likert scale (1, no difficulty to 6, major difficulties) their ability to manage their personal life at 2.5 (±1.2).

Concerning perfectionism, on a 6-point Likert scale, musicians have rated their drive to strive for performance at 4.3 (±1.1), to put themselves under pressure at 4.6 (±1.2), to be disappointed when performance was not perfect at 4.5 (±1.0) and to accept things they can't change at 2.4 (±0.8). Musicians have rated on a 4-point Likert scale their meditation or relaxation practice at 1.5 (±0.7). Concerning music performance anxiety (MPA), 97% of the sample have reported having suffered from MPA during their life and 36% during the past month.

4.5. Life habits

In terms of sleep, musicians have reported sleeping around 7 hours (±0.9) per night. On a 4-Liket Scale, they have rated having problems with tiredness at 2.3 (±0.7), needing to rest more at 2.4 (±0.6) and not getting enough sleep at 2.3 (±0.7). Their sleep quality has been estimated at 2.6 (±0.6).

Concerning hydration and nutrition, musicians have reported drinking about 1.6 litres (±0.7) of water per day and on a 4-point Likert scale, musicians have rated eating at least 3 vegetables a day at 3.6 (±0.6), between often and routinely, and limiting their use of sugars at 2.6 (±0.9), between sometimes and often.

Concerning tobacco consumption, one musician has reported smoking daily. In terms of alcohol, musicians' consumption is described in Figure 4.5.

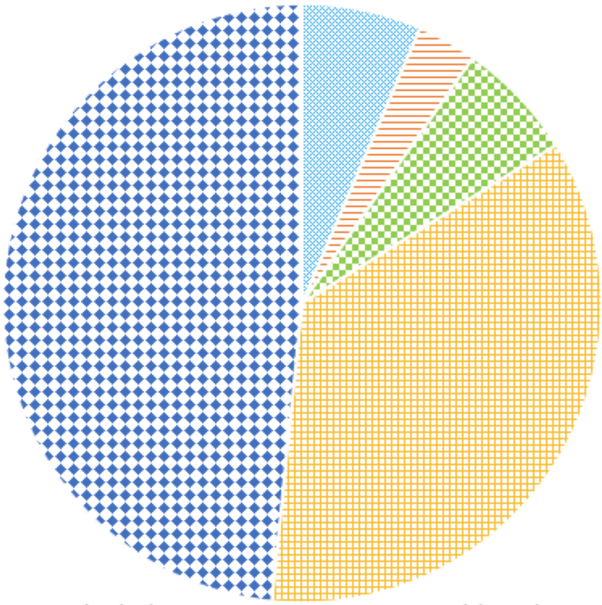


Figure 4.5: Frequency of alcohol consumption among the sample

Finally, musicians have reported spending around 10.5 (±16.0) hours using their arms and hands in extra-work activities and 1.5 (±2.5) hours with elevated arms.

4.6. Relationship between pain and work/life habits

Several relationships have been calculated between work, life habits and pain to investigate the possible risk factors leading to pain in musicians.

Table 4.4 below shows the outcomes of Spearman correlations on different variables and the significance of the relationships between these different variables and pain score.

Table 4.4: Spearman correlation scores between several variable and overall pain (MPIIQM score) among the sample

Variables	**Correlation** *(Spearman's rho)*	**Significance**	**Confidence intervals**
Psychological elements			
ADD score	0.390	0.030*	[0.31 – 0.660]
Perfectionism score	0.135	0.470	[-0.241; 0.475]
Stress score	0.05	0.979	[-0.360; 0.368]
MPA lifetime	-0.233	0.208	[-0.550 – 0.143]
MPA last month	0.410	0.022*	[0.054 – 0.673]
Work and performance related			
Total hours (with PP[1])	-0.040	0.830	[-0.398; 0.328]

Total hours (without PP[1])	-0.178	0.337	[-0.509; 0.198]
Workload uniformity	-0.098	0.601	[-0.446; 0.276]
Total hours of PP[1]	0.254	0.168	[-0.121; 0.566]
Breaks	-0.131	0.491	[-0.478; 0.251]
Years of instrument practice	0.281	0.126	[-0.092; 0.585]
Years of orchestra	0.338	0.063	[-0.030; 0.625]
Job status	-0.036	0.849	[-0.394; 0.333]
Position during performance	-0.357	0.048*	[-0.638; 0.007]
Position during PP[1]	-0.155	0.406	[-0.491; 0.222]
Repertoire	-0.436	0.014*	[-0.691; -0.086]
Life habits			
Sleep score	0.020	0.915	[-0.346; 0.381]
Sleep hours	-0.276	0.133	[-0.582; 0.098]
Nutrition score	0.213	0.249	[-0.163; 0.536]
Water consumption	0.125	0.517	[-0.263; 0.479]
Tobacco consumption	-0.130	0.485	[-0.472; 0.245]
Alcohol consumption	0.351	0.053	[-0.015; 0.634]
Drug consumption	0.192	0.300	[-0.184; 0.520]
Physical conditioning			
Moderate PA[2]	-0.231	0.227	[-0.559; 0.159]
Minutes of moderate PA[2]	0.89	0.700	[-0.368; 0.512]
Vigorous PA[2]	0.162	0.401	[-0.228; 0.507]
Minutes of vigorous PA[2]	-0.324	0.239	[-0.725; 0.241]
Warm-up	0.108	0.562	[-0.266; 0.454]
Recovery routine	0.385	0.032*	[0.025; 0.657]
Belief and behaviours towards pain			
Report pain to hierarchy	0.194	0.296	[-0.183; 0.521]
Orchestra's help	-0.107	0.567	[-0.453; 0.267]
Playing through pain	0.514	0.003**	[0.185; 0.740]
Pain normal while playing	0.324	0.075	[-0.045; 0.616]
Pain and body tissues	0.356	0.050*	[-0.010; 0.637]

[1]PP: private practice

[2]PA: physical activity

*: significant $p<0.05$

**: significant $p<0.01$

4.7. Other analysis

Instrumentalists who can play both whilst sitting and standing (excluding cellists, double-bassists and percussionists) are predominantly playing whilst sitting during concerts and rehearsals but are rather practicing whilst standing ($t=7{,}110$, $p<0.001$).

5. DISCUSSION

In terms of playing-related musculoskeletal disorders, we observed in the sample a lifetime prevalence of 68%. This outcome is quite comparable with the current literature (Sousa et al., 2017), even if this percentage seems to be a bit lower than what is commonly found in orchestra musicians which is often around 80%, which could be partly explained by the preventive programme the RLPO has implemented these past years (Ackermann et al., 2012; Abeu-Ramos et al., 2007). In terms of point prevalence, around 30% of the sample are currently suffering from PRMDs, which is also quite comparable with frequent findings (Silva et al., 2015). As well as percentages, main body locations concerned by PRMDs are the neck, the back and the shoulders and this finding is also in accordance with epidemiological studies (Ackermann et al., 2012).

The main findings of this study concern the relationship between PRMDs and several risk factors that have been highlighted in a previous model as possible predisposing risk factors to develop PRMDs in musicians. Despite a low sample size (which should have been at least 326, based on the number of orchestra freelance or permanent contracted musicians in the UK – 2,145 musicians – ABO, 2019), some significant relationships have been found. Figure 4.6 summarises the significant correlations that have been found between screened risk factors and pain score, based on the nine categories mentioned in the theoretical model (Rousseau et al., 2021) on which the whole question based.

* $p<0.05$ ** $p<0.01$

Figure 4.6: Graphical representations of the correlations between several risk factors and pain score based on the model nine categories (from Rousseau et al., 2021)

First, in accordance with what can be read in literature, anxiety and more specifically music performance anxiety (which occurred during the last month) have been found significantly related to higher MPIIQM score (Kenny & Ackermann, 2015).

Concerning work and performance, we found that body posture while playing during concert and rehearsal was significantly related to PRMDs. This could mean that musicians who are spending more time seated during concert and rehearsal are at higher risk of developing PRMDs than musicians who play their instrument whilst standing. Conversely, the cause effect relationship can be reversed: injured musicians may prefer to sit down while playing. Nevertheless, this finding has not been confirmed by the posture during private practice. Future prospective research would be useful to identify in which direction works the cause-effect relationship. In orchestras, percussionists are the main players who are playing whilst standing, but PRMDs have also high percentage in this specific population (Sousa et al., 2017; Ackermann et al., 2012; Abeu-Ramos et al., 2007) that is why the explanation of this relationship cannot be only instrument related. Furthermore, players that can play in both postures significantly rather practice whilst standing at home ($p<0.001$), potentially because of the different positive aspects of standing postures such as wider ranges of motion (Spahn et al., 2014), better muscle activation or chest expansion (Ackermann et al., 2014; Price et al., 2014).

Moreover, in terms of workload, a potential relationship has been found between difficulty of the repertoire and severity of PRMDs. This correlation can be understood in two different ways: musicians who are finding the repertoire really difficult have to strive to achieve performance and therefore, this could develop PRMDs. But, it could also be understood as indicating that musicians who have PRMDs are feeling like the repertoire is getting more and more difficult, according to their symptoms which could interfere with their ability to play their instrument at the level they are accustomed to (Zaza et al., 1998). Finally, although number of playing hours has been highlighted as a potential risk factors in several papers (Wu, 2007), no correlation has been found in the studied sample.
In terms of life habits and physical activity, no significant relationship has been found except concerning recovery routine. The more musicians are affected by PRMDs, the more they have recovery routine after the play. This correlation should be investigated using prospective methods to understand if it is thought in a preventive way or more to relieve existing pain, developed during the previous play.

Finally, belief and behaviours towards pain are also closely related to PRMDs. A strong relationship has been found, unsurprisingly, between answers to the question “do you play through pain?” and the MPIIQM score. Moreover, musicians with a high PRMDs score are significantly more likely to think that pain is mainly the result of damage to the body tissues. They also seem to be thinking that pain is normal while playing although this result was not significant. The results are highly related to the answers musicians gave to question 59 and 60 about what could increase or reduce their pain. Among the sample, about 20% think that stopping for few days could reduce their chronic pain, and around 15% reported lare that taking more breaks during practice could be useful. Furthermore, about 10% are likely to avoid the movements that trigger pain to avoid pain. This behaviour will modify posture and music technique, not always in the best possible way, and this could involve avoidance of movements and kinesiophobia.

These outcomes are also quite comparable with musicians' behaviours found in the literature as Britsch (2005) have found that, among 250 music students, 35% were considering as "acceptable" to play through pain.

The main limitations of this study concern the absence of validation of the questionnaire and the low sample size whereas the main strengths of this study are related to the questionnaire itself for the following reasons. Firstly, this questionnaire has been based on a comprehensive model developed to describe and understand more predisposing risk factors in musicians, based on literature, musicians' opinion and experts' advice. This makes the tool more relevant to help health practitioners in the screening of their musician clients or patients.

Nevertheless, this screening tool has been developed using several validated questionnaires such as the MPIIQM (Berque et al., 2014), World Health Organisation (WHO) questionnaires (about tobacco and alcohol consumption, about physical activity) or the Anxiety and Depression Detector (Means-Christensen et al., 2006). This tends to provide confidence but at the same time caution is advised, as these items were taken out of their original validated context and this can have unintended consequences.

Moreover, this study was an exploratory one, and we had to make methodological and statistical choices in order to investigate the greatest number of risk factors. Given the high number of correlations and the absence of *post-hoc* corrections, this may lead to some spurious correlations that may be significant by chance. The above discussion of these relationships considered any potential theoretically illogical correlations given these limitations.

Finally, the sample includes a range of instrumentalist and so the questionnaire is not specifically orientated towards one specific instrument population, therefore can only provide generic results about orchestra musicians without focusing on upper string players only, for example, as it is often the case with other applications in the literature.

6. CONCLUSION

In this study, we found that anxiety and more specifically music performance anxiety, but also difficulty of the repertoire, frequency of recovery routine, posture while playing but also behaviours and beliefs towards pain were significantly related to pain. This information is useful for prevention but also provides perspectives and further directions to investigate more orchestra musicians to increase our knowledge about risk factors and build better prevention frameworks and systems.

Third part: Assessing Anthropometrics and Muscle Function in Orchestra Musicians

1. Abstract

Introduction: Playing a music instrument leads to several postural loads that could strongly interfere with the body functioning. Musicians have to be regularly screened to highlight musculoskeletal disorders (or future ones) to prevent or treat playing-related musculoskeletal disorders (PRMDs). Physical assessments have been developed and already tested on musicians, but some items, as further investigation of hand and low back motor control, were missing. The aim of this study is to develop and test with a small sample of musicians a comprehensive assessment based on a model that describes theoretically all risk factors in musicians to develop PRMDs.

Method: A physical assessment has been developed based on a comprehensive model for predisposing risk factors in musicians and on the several assessments that already exist for musicians. Individual characteristics, motor control, mobility and strength have been investigated in 31 musicians from the Royal Liverpool Philharmonic Orchestra.

Results: Thirty-one musicians from the Royal Liverpool Philharmonic Orchestra have been assessed and this has lasted about 45 minutes. The physical assessment shows many differences between group of instruments and also between both sides in same group of instrumentalists.

Discussion: This physical assessment shows many strengths such as his feasibility for physiotherapists as first session, his ability to screen differences between musicians or between both upper limbs in same musicians as well as his capacity to highlight motor control disorders that could be reduced through exercises and training to support the play, reduce injuries rates and enhance performance.

Conclusion: This assessment is highly practicable for healthcare practitioners who aim to treat musicians. It has been based on a comprehensive model about risk factors, on existing assessments for musicians and on the best clinical tests we currently have to screen disorders.

2. Introduction

Musculoskeletal loads related to music performance and the relationship with musculoskeletal pain or impairments have been discussed extensively over recent years. Because of the repetitiveness of musical performance, musicians are more frequently now compared to athletes or manual workers or even called “small-muscles athletes” (Wilson in Dawson et al., 2011).

In a large sample of orchestra musicians, Driscoll et al. (2012) have shown that anthropometric measurements could significantly differ from one musician to another, reflecting the instrument they play daily: higher grip strength for brass players, greater left supination for violinists and violists and wider hand span for lower string players.

In terms of motor control, scapular dyskinesia, neck and lumbar stabilisation impairments were further studied and discussed in current literature, showing high level of motor control impairments in musicians such as lower cervical core strength (Tawde et al., 2016), scapular stabilisation defects (Tawde et al., 2016; Steinmetz et al., 2010) or lack of low back motor control (Steinmetz et al., 2010), and particularly in musicians with prolonged symptoms (Silva et al., 2018).

Even on some neurological aspects, a musician's brain differs from a non-musician. In fact, musicians present differences such as larger hand motor area, primary auditory area or corpus callosum (connection between hemispheres) as well as a less marked asymmetry of hemispheres' size (Dawson et al., 2011).

A recent systematic review on postural quality in musicians concluded that protocols in most studies were too widely different to draw any consistent comparison. Moreover, even if anthropometrics, muscle function, motor control and many other musculoskeletal elements have been occasionally studied in musicians, few papers itemised comprehensive physical assessments specifically developed for musicians. One of them has been described by Ackermann & Driscoll (2010), designed to last about one hour and assessing numerous physical parameters such as muscle strength, endurance and control, anthropometrics and mobility, neural tension and several pain provocation tests. Nevertheless, despite its comprehensive nature, this physical examination omitted several motor control tests or assessing lumbar or scapular stabilisation, and the tests were not combined with a postural analysis while playing or without holding the instrument. Detecting such deviations is important because they have consequences on musicians' health.

The aim of this paper was to develop a physical assessment specifically designed to address musculoskeletal health issues frequently found in musicians. The two key requirements were to maximise comprehensiveness while reducing the duration of the assessment. This physical examination was intended to be completed together with a specific questionnaire investigating risk factors in musicians, the Injury Risk Factors Questionnaire for Musicians (IRFQM, see Chapter 4 – Parts 1 and 2) as well as with a postural analysis (see Chapter 4 – Part 4).

This screening tool has been conceptually based on an existing theoretical model (Rousseau et al., 2021) which includes the main predisposing risk factors in musicians related to individual characteristics in terms of anthropometrics, biomechanics elements such as motor control impairments, hypermobility, hypo-mobility, posture and ergonomics.

3. METHOD

3.1. Sample and inclusion criteria

The sample and inclusion criteria have been thoroughly described in Chapter 4 – Part 1.

3.2. Description of the physical assessment

Included items

The whole physical examination is fully described in Appendix J.

In sections A, B and C, the physical examination investigates anthropometrics, medical history of the participant (potential further contraindication to several items of the physical examination) and ergonomics tools used while playing.

In section D, the physical examination explores the musician's motor control of shoulder blades (distance acromion-wall and scapular dyskinesia tests) (McClure et al., 2009; Struyf et al., 2009), lumbar spine (Luomajoki et al., 2007, 2008) and hand (Godwin et al., 2014; Schreuders et al., 2007).

In section E, muscle strength and endurance has been shortly examined through hand grip (Ackermann & Driscoll, 2010), plank test (Tong et al., 2013) and Deep Neck Flexors (DNF) endurance test (Domenech et al., 2011).

Finally, in section F, mobility has been investigated through ranges of motion (shoulder, elbow, wrist, neck, spine) and Beighton Scale for hypermobility (Cleland et al., 2011; Ackermann & Driscoll, 2010). This part of physical examination has been strongly based on Ackermann & Driscoll's assessment (Ackermann & Driscoll, 2010). Despite the fact ranges of motion assessment of wrists, elbows and neck has been described as optional in Appendix, all of these ranges of motion have been measured in the sample (neck: flexion/extension, rotations, lateral bending; wrist: flexion/extension, lateral bending; elbow: flexion/extension).

In section G, pain is more specifically assessed through trigger points on the upper trapezius, mentioned several times in musicians' novel art (Kenny & Ackermann, 2015; Rickert et al., 2012; Ackermann & Driscoll, 2010) but also by questioning the participant and examining several joints (shoulder, elbow, wrist and finger pain).

Items not included

The lips, jaws and face have not been investigated because the focus of the physical examination has been on instrumental posture, spine and limbs examination. Face examination requires specific knowledge and should be the main subject of a separate examination to further investigate any risk factors concerning this body location.

Fatigue has not been included in the model: we know from Chan et al. (2000) that fatigue is really difficult to investigate in expert musicians, as they are used to play for long durations in concerts, rehearsals or even private practice. Exploring fatigue in this study would have asked from musicians to play for hours.

Finally, strength measurements have not been included (except hand grip strength) contrary to Ackermann & Driscoll's (2010) physical examination. The main reason is that lack of strength (to be discriminated from muscle activation or motor control) has not been mentioned as an important injury risk factor in musicians (Chan & Ackermann, 2014). Indeed, playing a music instrument requires more precision and stabilisation rather than increased muscle strength.

Validity and reliability of the physical assessment

All the assessment tests were based on existing and previously described ones, none has been developed specifically for this physical assessment. For almost all tests (except very few of them, for example, hand tests such as the Thomas sign), validity and reliability has been thoroughly discussed in previous work (all references are available in Appendix J). Although, intra-reliability was not assessed, all the assessments were conducted by a physiotherapist with three years of experience, including in the administration of these tests (or similar one).

3.3. Protocol

Once the musicians' time slot was chosen, after having consented, the physical examination took place in a quiet room at the Liverpool Philharmonic. This physical assessment examination lasted between 35 and 45 minutes.

3.4. Ethics

The study protocol received ethical approval from the Liverpool John Moores University Ethics Committee (19/SPS/011).

3.5. Statistical analysis

Descriptive analysis of the outcomes has been done using Excel®. As all data were not normally distributed (Shapiro-Wilk test), Mann-Whitney tests and Spearman correlations have been calculated for all inferential analysis using SPSS® (version 25.0.0.1). Degree of significance has been accepted at 0.05.

4. Results

The outcomes of the physical assessment are described in Table K.1 in Appendix K for males and Table L.1 in Appendix L for females. The physical assessment has been well received by musicians and has lasted around 40 minutes, so this examination is feasible for typical sessions conducted by physiotherapists.

4.1. Gender differences

In terms of gender, the Mann-Whitney test showed significant differences, summarised in the Table 4.5.

Table 4.5: Gender differences in anthropometrics

Gender difference	**Items**		**Mann-Whitney test**
Greater in males	Height		U = 231.5, p < 0.001
	Weight		U = 190.0, p < 0.01
	Lower arm	Left	U = 203.5, p < 0.01
		Right	U = 207.5, p < 0.01
	Upper arm	Left	U = 202.5, p < 0.01
		Right	U = 187.0, p < 0.01
	Hand span	Left	U = 221.5, p < 0.001
		Right	U = 209.5, p < 0.001
	Hand length	Left	U = 229.0, p < 0.001
		Right	U = 228.0, p < 0.001
	Right supination		U = 63.0, p < 0.05
	Right pronation		U = 69.5, p < 0.05
Greater in females	Left wrist flexion		U = 69.5, p < 0.05
	Left wrist extension		U = 65.0, p < 0.05
	Beighton score		U = 62.0, p < 0.05

4.2. Instrument differences

Between instrumentalists, significant differences have been found between upper and lower string players in terms of distance between acromion and wall (left shoulder was more protracted for upper strings and right shoulder for lower strings):

- When shoulders were relaxed, on the right side (U = 64.5, p < 0.05)
- When shoulders were retracted, on the right (U = 67.5, p < 0.01) and left sides (U = 60.5, p < 0.05).

4.3. Physical tests and pain

The MPIIQM score has been calculated by summing all obtained scores to the four first questions of the MPIIQM (related to the prevalence of pain: whole life, past year, month or week). This sum gave a pain score between 0 (“no” to all questions) and 4 (“yes” to every question). Correlations between assessment items and pain have been calculated. Only few elements have shown significant correlations with the MPIIQM score:

- Apley 2 with right hand behind the back and low back pain ($\rho = 0.398$, $p < 0.05$)
- Right scapular dyskinesia in abduction ($\rho = 0.483$, $p < 0.01$) and flexion ($\rho = 0.474$, $p < 0.01$) evaluated via the Scapular Dyskinesia Test (McClure et al., 2009);
- Luomajoki’s tests (Luomajoki et al., 2007):
    - Rocking backwards ($\rho = 0.438$, $p < 0.05$) and elevation of the knee in prone position ($\rho = 0.396$, $p < 0.05$) were significantly correlated with MPIIQM score;
    - Total score has been calculated by summing all the Luomajoki’s tests and shows significant correlations with MPIIQM score ($\rho = 0.590$, $p < 0.001$), with left shoulder ($\rho = 0.407$, $p < 0.05$) and thoracic pains ($\rho = 0.422$, $p < 0.05$).

In terms of pain, significant correlations between pain around the right shoulder and cervical left ($\rho = 0.534$, $p < 0.01$) and right rotation ($\rho = 0.447$, $p < 0.05$) have been found.

4.4. Correlations between physical tests

Table 4.6 summarises the significant correlations that have been found between different pairs of physical tests.

Table 4.6: Correlations between physical tests among the sample

Tests		Significance
Modified Apley with left hand behind the head	Apley 1 with left hand behind the head	($\rho = 0.442$, $p < 0.05$)
	Apley 1 with right hand behind the head	($\rho = 0.427$, $p < 0.05$)
	Apley 2 with left hand behind the back	($\rho = 0.471$, $p < 0.05$)
	Left ulnar deviation	($\rho = 0.372$, $p < 0.05$)
	Right cervical lateral bending	($\rho = 0.420$, $p < 0.05$)
	Right cervical rotation	($\rho = 0.450$, $p < 0.05$)
Modified Apley with right hand behind the head	Apley 2 with left hand behind the back	($\rho = 0.503$, $p < 0.01$)
	Left wrist extension	($\rho = 0.501$, $p < 0.01$)
Apley 1 with left hand behind the head	Left supination	($\rho = 0.457$, $p < 0.01$)
	Left ulnar deviation	($\rho = 0.444$, $p < 0.05$)
	Left cervical lateral bending	($\rho = 0.426$, $p < 0.05$)
	Right cervical lateral bending	($\rho = 0.615$, $p < 0.001$)
	Right cervical rotation	($\rho = 0.499$, $p < 0.01$)
Apley 2 with left hand behind the back	Left supination	($\rho = 0.537$, $p < 0.01$)

Apley 1 with right hand behind the head	Right wrist extension	($\rho = 0.447$, $p < 0.05$)
	Right cervical lateral bending	($\rho = 0.450$, $p < 0.05$)
	Right cervical rotation	($\rho = 0.499$, $p < 0.01$)
Apley 2 with right hand behind the back	Right supination	($\rho = 0.616$, $p < 0.01$)
	Right pronation	($\rho = 0.443$, $p < 0.05$)
	Cervical extension	($\rho = 0.365$, $p < 0.05$)
	Right cervical rotation	($\rho = 0.455$, $p < 0.05$)

5. DISCUSSION

5.1. A new tool to screen musicians' musculoskeletal health

This new physical assessment has been developed based on a comprehensive theoretical model about predisposing risk factors to develop PRMDs in musicians (Rousseau et al., 2021). Each item in the model that could not be evaluated through a questionnaire has been investigated through a physical test.

This new tool has focused on motor control, because this has been highlighted to be one of the most relevant areas to investigate in injured musicians based on the theoretical model developed and on experts' advice and opinion. For example, to investigate low back motor control, Luomajoki's tests have been included and found to be significantly correlated with PRMDs. These could help physiotherapists to investigate low back issues in musicians and to teach them exercises which could support their play and enhance their performance. Scapular dyskinesia has also been further investigated, for the same reasons, precisely among upper string players (Tawde et al., 2016; Steinmetz et al., 2010), as well as deep neck flexors endurance (Tawde et al., 2016). This assessment has been based as much as possible on tests that have been already used for musicians (Tawde et al., 2016; Godwin et al., 2014; Ackermann & Driscoll, 2010) but also tests have been chosen for their relevance, their clinical validity and reliability.

This physical assessment showed differences among instrumentalists as well as between males and females, even if the sample size was very small. For example, significant differences have been found in the distance between the acromion and wall between upper and lower string players. Several differences such as height, weight, upper limb sizes or hypermobility scores have been observed as well between both genders. This shows that the physical assessment could allow examiners to screen differences between individuals. Furthermore, some significant differences between both sides in groups of instrumentalists have also been highlighted, such as distance of acromion and wall between left and right side for upper string players (higher on the left side) and lower string players (higher on the right side) or independence of the common finger flexors that is more found on the left hand rather than on the right one in upper string players. These differences seem to be related to the instrument postural load: in upper string players, the left hand has to finger along the instrument neck, that could explain a higher independence of hand and forearm muscles (Godwin et al., 2014). Concerning distance between wall and acromion, due to the posture, we often observe higher distance for the left shoulder than the right one in upper string players who have to maintain the violin between the shoulder and the chin (Shan & Visentin, 2003), and higher for the right shoulder in lower string players, who have to bow with the right hand and finger along the instrument neck with the left fingers, which requires to keep the right shoulder much behind the left one (and sometimes also a torsion of the spine) (Rickert et al., 2012).

Interestingly in this study, significant correlations have been found between pain and several physical tests, such as Luomajoki's test, Apley's with right hand behind the back or Scapular Dyskinesia Test in abduction on the right side. Nonetheless, these correlations should be considered in the light of the controversial debate about assessing scapular dyskinesia and the relationship between dyskinesia and pain (Littlewood & Cools, 2017; Hickey et al., 2017).

Considering Luomajoki's test, further research is needed as this result is quite surprising. Higher score in Luomajoki's tests means better motor control around the low back and it seems to be related with pain in our population (particularly with left shoulder and thoracic pains). A better motor control around the back could maybe, in some musicians, compensate for pain, lack of mobility or control around the shoulder blades and thoracic spine. This is a hypothesis that needs to be further developed and investigated.

Moreover, positive significant correlations between physical tests have been found as well and more specifically between modified Apley's tests and original ones. With further investigation, modified Apley's could be performed instead and screen patients in a shorter time.

5.2. Strengths of the assessment

First of all, this assessment lasts about 40 minutes, which is short compared to the physical assessment previously described by Ackermann & Driscoll (2010), lasting about one hour.

Furthermore, this assessment is focused and specific and conceptually based on a comprehensive model about predisposing risk factors to develop PRMDs in musicians. Every test is related to one item of the model, and that is why a lot of strength tests have been excluded from the physical examination, contrary to other assessments (Ackermann & Driscoll, 2010).

Finally, almost all the tests have been chosen based on their validity and reliability in the current literature and most of them have already been used in musicians (Tawde et al., 2016; Godwin et al., 2014; Ackermann & Driscoll, 2010).

5.3. Limitations and suggestions for improvements

The main limitation of this study is the small size of the sample. This assessment should be performed again with a larger number of participants to allow drawing conclusions about any significant differences between musicians, according to their postural load, and also highlight differences between musicians with and without PRMDs.

Moreover, some tests have been used even without strong information of their validation such as the Thomas sign, which is supposed to show lack of strength in the intrinsic muscles, and should be more investigated in future research. Also, trigger points have previously been used in musicians, that is why we have chosen to include this test in the physical examination, despite the controversial consideration to use it as part of an assessment (and as well as a treatment) (da Silva et al., 2020; Shah et al., 2016).

One of the model items has not been tested: the physical fatigue. This item was complex to test in the allowed period of time and Chan et al. (2000) have shown that expert musicians are able to play for long periods without reaching sufficient levels of fatigue. One viable approach could be to perform the assessment straight after the musician plays for several hours without resting.

Suggested improvements include the addition of several tests such as the lateral scapular slide test (used in Ackermann & Driscoll, 2010) and the cranio-cervical function test (Jull et al., 2008) (which has been added to the whole examination in Appendix J but not widely performed with the investigated sample; highlighted in grey) but particularly more tests to investigate the hand motor control, movements and strength, as the ones we used have not been thoroughly validated and investigated, especially in musicians (Schreuders et al., 2007). Finally, exploring fatigue in this study would have been very interesting but very difficult to practically organise. Musicians would have been asked to come after their performances (often very late in the evening) and it would not have been possible to control the played repertoire, leading to different fatigue levels and to consequent bias.

6. CONCLUSION

This physical assessment has been developed based on a comprehensive model for predisposing risk factors to develop PRMDs in musicians and has assessed every item of this model through tests such as anthropometrics measurements, motor control tests or mobility rating. This model is useful to screen differences in individuals, between instrumentalists or between both upper limbs in the same group of instruments, that seem to be in accordance with the postural load of their playing performances.

Fourth part: Assessing posture while playing in musicians – A systematic review and proposal for a new tool: the Postural Analysis Tool for Musicians

1. ABSTRACT

Introduction: Playing a musical instrument at an elite level can potentially lead to musculoskeletal disorders. Postural loads are different among musicians considering the instrument they play: violin and flute require an important elevation from both upper limb, asymmetrical postures are very common and instruments' weight can be significant. The aim of this systematic review was to explore how musicians' posture are investigated, and potentially if there is an association between postural impairments and pain.

Methods: A systematic search was performed in several databases, combined with manual search in the journal *Medical Problems of Performing Artists*. Study inclusion, data extraction and quality assessment were performed independently by two reviewers.

Results: Twenty seven relevant studies were included in this review (21 cross-sectional, 1 observational, 3 longitudinal studies) covering musicians with the full range of playing experience (professionals, students, teachers, amateurs). The main considered methods to investigate postures are visual assessment and three dimensional analysis using videography.

Discussion: This review provides a critical synthesis of the different methods used to investigate and monitor posture in musicians and provides information in order to build protocols which will allow to draw comparison with previous papers. Further research is still needed to explore the relationship between posture and playing-related musculoskeletal disorders.

2. INTRODUCTION

Playing music at a professional level can often lead to musculoskeletal disorders. Playing-related musculoskeletal disorders (PRMDs) have been defined as "pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to" (Zaza et al., 1998). Systematic reviews have reported pain prevalence in musicians as ranging between 29 and 90% (depending on the recall period, playing-related pain or symptoms' definitions, choice of the investigated population, etc.) (Silva et al., 2015). These PRMDs are considered as multifactorial health issues and several risk factors are commonly reported such as number of playing hours, sex, repetitive movements, posture, mental health issues or sudden increase in playing load (Rousseau et al., 2021; Baadjou et al., 2016; Kok et al., 2016; Kenny et al., 2015).

In the current literature, posture and particularly postural impairments, are frequently considered as one of the main injury risk factors in musicians, as the practice of music instruments requires repetitive movements potentially in an awkward posture, often asymmetrical (violin, trumpet, bassoon, etc.), that could lead to important musculoskeletal strains (Blanco-Pineiro et al., 2017; Chan & Ackermann, 2014; Ranelli et al., 2011; Watson, 2009). For example, maintaining both arms in elevation for a very long duration has been described to lead to neck and shoulder pain among upper string players and brass players (trumpet, trombone, etc.), compared to woodwind (oboe, clarinet, etc.) and lower string players (Nyman et al., 2007). By considering differences between musical instruments, Ramella et al. (2014) have pointed out how playing an asymmetrical instrument, associated with the impact of practice years, increases the risk of adopting "non-optimal" postures. Moreover, standing and different sitting postures have been investigated and compared by analysing different elements such as abdominal muscles recruitment or spirometry parameters in woodwind players (Ackermann et al., 2014; Price & Watson, 2014), while body movements were compared among violinists, depending on if they were orientated on the right or on the left of the music stand (Spahn et al., 2014). Baadjou et al. (2017) have investigated how sitting posture could influence muscle activity or sound quality in clarinettists. Their outcomes highlighted that decrease in muscle activity could be induced by increasing stability and considering sound quality, participants felt it was altering depending on their sitting posture, whilst music experts found no consistent relationships between posture and sound.

Nonetheless, analysing musicians' posture is not an easy or straightforward task. Different methods have been used to evaluate and rate posture in musicians (Valenzuela-Gomez et al., 2019; Blanco-Piñeiro et al., 2015; Chan et al., 2013), such as describing postural alterations before and after an intervention on photographs (Chan et al., 2013) or analysing with the Rapid Entire Body Assessment (REBA) (Valenzuela-Gomez et al., 2019). In 2015, Blanco-Pineiro et al. have developed an instrument to systematically investigate posture in music students: the Postural Observation Instrument (POI).

According to musicians' health experts and past research, posture emerges as an important risk factor that should be considered in musicians' health assessment the treatment and prevention of PRMDs. Nonetheless, studies present heterogeneous methods that are difficult to compare and despite the fact that although a recent non-systematic bibliographic review highlights the potential relevance of posture as influence on both performance and musculoskeletal health (Fernandez-Paz et al., 2020), the existence of a relationship between posture and pain remains controversial. As a major example, a systematic review of systematic reviews has highlighted the absence of clear evidence concerning the relationship between low back pain and physical causes in the general population (Swain et al., 2020). Moreover, it has also been shown that no consensus exists between physiotherapists about what could be the "best spinal posture" (O'Sullivan et al., 2012). Therefore, a comprehensive review of the literature was justified to examine how posture is related to PRMDs.

The main objective of this study is to determine how posture while playing has been investigated in instrumentalist musicians so far and the implications for practice. The secondary aim is to examine the relationship between posture and playing-related musculoskeletal disorders.

3. METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement (Moher et al., 2009). In order to minimise potential bias, the AMSTAR-2 tool (A Measurement Tool to Assess Systematic Reviews, 2nd Version) was used as a backdrop for this work (Shea et al., 2017). This review was prospectively registered on PROSPERO (CRD42021290730).

3.1. Search strategy

A search for relevant publications was performed electronically between September 2021 and October 2021 in the following databases: Cochrane Register of Clinical Trials, PubMed, Science Direct, PEDro, CINAHL and LILACS. Grey literature, including thesis and conference abstracts, was investigated using Open Grey and Kinedoc. A search of ongoing studies was also performed using Clinicaltrials.gov. Search keywords included the following combination of free text terms and Medical Subject Heading (MeSH) terms: "((*Posture*) OR (*postural*) AND (*musician OR instrumentalist)* AND (*measurement* OR *analysis* OR *assessment*))". In addition, reference lists of included studies were manually screened for further eligibility. Finally, a manual search of the journal *Medical Problems of Performing Artists* was also performed from year 2000.

3.2. Eligibility criteria

Studies were included if they fulfilled the following eligibility criteria:

- The study population included male and female instrumentalists, of age ≥ 16 years old;
- The study specifies the musicians' status: professional musician, music student or music teacher;
- The study presented posture-related data relative to the musculoskeletal system;
- The study included postural analysis while playing in musicians;
- The study had an observational (cross-sectional, cohort, case-control and case series) or interventional design (randomized controlled studies);
- The study was written in French or English.

No restriction was applied regarding the type of instrument and repertoire nor the level of musical experience.

Publications were not included if:

- The study included mixed artistic populations (painters, dancers, etc.);
- The study included non-instrumentalist singers;
- The study protocol included only measurements on the instrument and not on the individuals playing;
- The study protocol relied solely on a self-reported questionnaire;
- The study does not investigate the relationship between the musculoskeletal parameters which were assessed and PRMDs.

Table 4.7 summarises the inclusion criteria of the review using the PICOS acronym.

Table 4.7: Review objectives, inclusion and exclusion criteria according to the PICOS components

	Inclusion	Non-inclusion
Objective	Main: To determine how posture while playing has been investigated in instrumentalist musicians so far. Secondary: To determine if posture influences the development of playing-related musculoskeletal disorders (PRMDs) among instrumentalist musicians. *Research question: How posture while playing has been investigated in instrumentalist musicians?* *Secondary research question: Is there an association between playing posture and the development of PRMDs in instrumentalist musicians?*	
P	• Age ≥ 16 years old; • Male and female instrumentalists; • Professional musician, music student, music teacher, amateur musician, etc.	• Studies including mixed artistic populations (e.g.: dancers, painters); • Studies including singers.

	N.B.: No restriction was applied regarding the type of instrument or repertoire nor the level of experience.	
I	• The study investigated MSD in relation to playing posture as a risk factor; • The study included biomechanical measurements and/or clinical examination measurements; • The study specified the type of instrument; • The study specified the playing duration required during the testing; • The study was written in English or French.	• Studies focusing only on the instrument parameters or position.
C	No restriction (presence of a control group is not required).	
O	• Studies whose primary outcome was the analysis of musicians' posture while playing N.B.: No restriction was applied concerning the tools (used to conduct the measurements nor the timeline of the measurements.	• Studies which focused on PRMDs that are not described as related to the musculoskeletal system (i.e. neurological disorders such as focal dystonia); • Post-operative follow-up measures.
S	• Observational studies: Cross-sectional, cohort (with a prospective or retrospective inclusion pattern), case control and case series • Interventional studies: Randomized Controlled Trials (RCTs) • Grey literature	• Studies relying solely on a self-reported questionnaire for analysing posture; • Reviews.

3.3. Study selection

After duplicate removal, the title and abstract of all studies were independently screened by two independent reviewers (LT and CR) applying the aforementioned eligibility criteria. All articles presenting non-inclusion criteria were eliminated. If the authors did not describe the PICOTS criteria in the abstract, the article was kept and analysed during the next stage. Subsequently, full text articles of all records eligible for inclusion were independently reviewed by the two same reviewers. Any discrepancies between the two independent reviewers were resolved through discussion until consensus was reached.

3.4. Data extraction

Data were extracted by two independent raters (LT and CR) using two previously developed tables. The first table considered studies' general characteristics:

- Title, authors' name, date of publication;
- Study design and setting;
- Sample description: size, gender, age, instrument played, music status;
- Method used to investigate posture;

The second one focused on studies' outcomes:

- Performed task by the participants;

- Type of variables;
- Marker's position (if suitable);
- Form of the results.

3.5. Quality assessment

Methodological quality of the selected studies was assessed by two independent reviewers (LT and CR), using both the Newcastle Ottawa Scale (NOS) (Wells et al., 2013) for both cross-sectional and cohort studies and the Quality Assessment Tool for Before-After (Pre-Post) Studies With No Control Group (National Heart Lung and Blood Institute et al., 2014) for uncontrolled trial of intervention.

3.6. Statistical analysis

The inter-rater agreement between the two reviewers for the quality assessment process using the aforementioned scales will be calculated using Cohen's kappa (κ) coefficient and percent agreement by using Excel® and SPSS® (version 25.0.0.1).
Following Landis and Koch's interpretation, the agreement is considered as:

- "almost perfect" if $\kappa>0.81$,
- "substantial" if $0.61<\kappa<0.80$,
- "moderate" if $0.41<\kappa<0.60$,
- "fair" if $0.21<\kappa<0.40$,
- "poor" if $\kappa<0.20$.

However, the interpretation of the kappa coefficient has important limitations. These paradoxes are mainly due to two phenomena: the influence of prevalence and bias (Cicchetti & Feinstein, 1990). This sometimes results in a discordance between the degree of agreement and the kappa value (e.g a high agreement with a low kappa value). Thus, these authors recommend reporting the proportion for both positive (P_{pos}) and negative (P_{neg}) agreements in addition to the overall kappa value as they allow a better understanding and contextualisation of the kappa coefficient.

4. RESULTS

4.1. *Study selection*

The initial literature search strategy provided 1972 potentially relevant publications. After duplicate removal and title and abstract screening, 59 full-text articles were assessed for eligibility. Inter-rater agreement for this first inclusion phase was 81.29%, discrepancies were resolved by discussion until consensus was reached. Nineteen reports were finally included in the present review. Forty articles were excluded due to the participants' age (n=5), no postural analysis performed (n=15) or not performed while playing (n=5), survey-based studies (n=3), the absence of full text (n=9) , one review and three duplicate protocols. Inter-rater agreement for this second phase was 92.43%, discrepancies were resolved by discussion until consensus was reached. Reference checking of included studies and a manual search in Medical Problems of Performing Artists identified 9 additional papiers. Finally, 27 studies published between 1989 and 2020 were included in this review. The PRISMA flowchart (see Figure 4.7) summarizes the whole inclusion process.

4.2. Studies' and samples' characteristics

Three types of studies were included in this systematic review: case studies (n=2), cross-sectional studies (n=21), uncontrolled trial of intervention (n=1) and cohort studies (n=3) (see Table 2).

Instruments played among the 27 included studies were various: 4 studies included multi-instrumental samples while 23 studies focused on specific instruments or group of instruments (such as upper string players counting violinists and violists). Figure 4.8 summarises the repartition of the instruments played in the review, which has been detailed as well in Table 4.8.

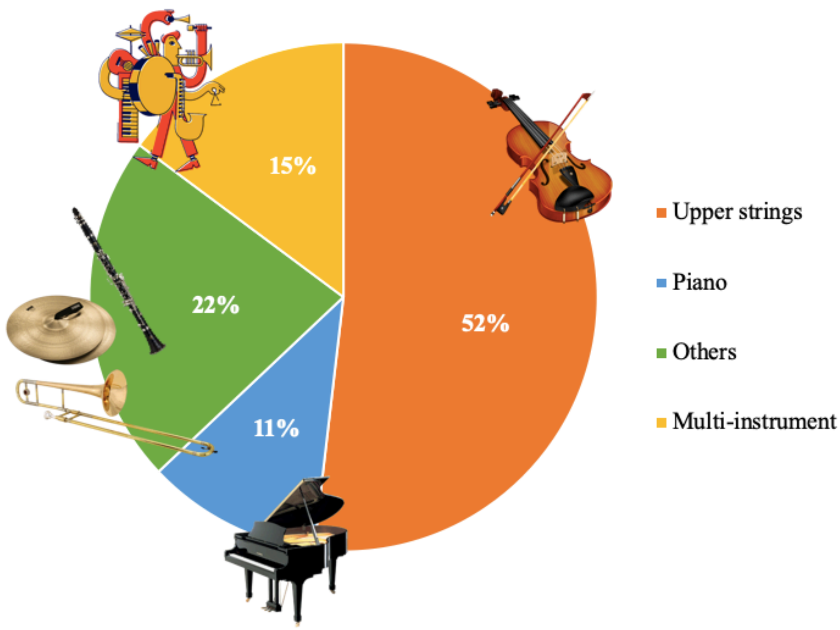


Figure 4.8: Graphical representations of the music instruments played in the included samples

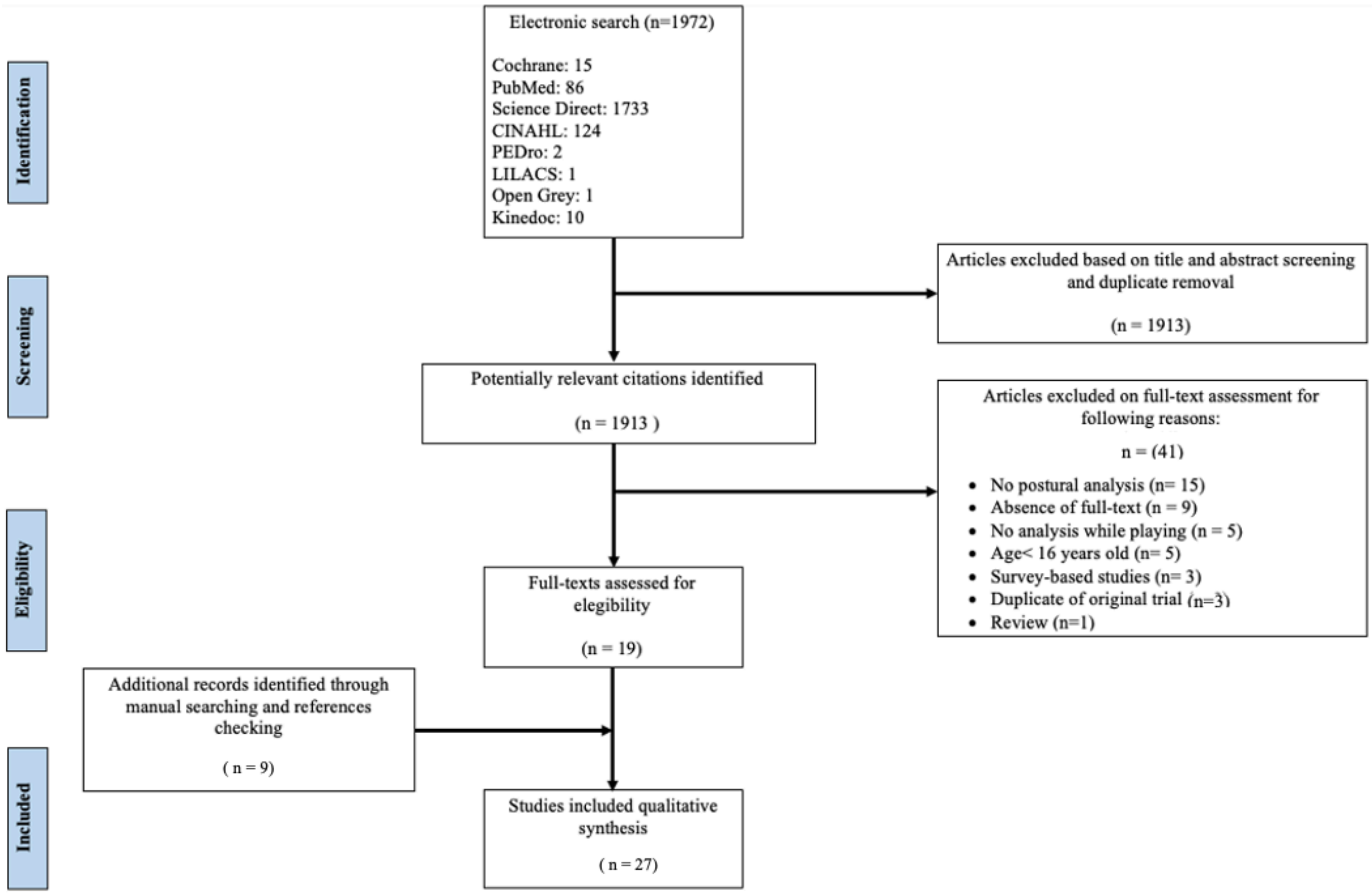


Figure 4.7: Inclusion flow-chart

From these 27 studies, 530 musicians were included. In terms of musical status, studies included different populations: professional musicians (in a large extent, orchestra musicians), music students and amateurs. Among the 27 studies, 10 included sample from diverse backgrounds, 6 only professional musicians, 10 only students and one study included only music teachers. Details are listed in Table 4.8.

4.3. Studies' quality assessment

4.3.1. Risk of bias assessment

4.3.1.1. Cross-sectional and cohort studies

Figure 4.9 illustrates the risk of bias assessment for the twenty cross sectional and three cohort included studies using the Newcastle Ottawa scale (NOS) (Wells et al., 2013). Out of the three key domains, studies were judged as particularly poor in the comparability domain with all of the included studies scoring zero stars. This was mainly due to the lack of consideration of confounding factors.

4.3.1.2. Case reports

Concerning the two case reports, to this day there is no scale recommended by the Cochrane Handbook for systematic reviews of intervention to assess their methodological quality. This is why the authors decided not to assess the quality of these case studies.

4.3.1.3. Uncontrolled study of intervention

The Quality Assessment Tool for Before-After (Pre-Post) Studies With No Control Group developed by the National Herat, Blood and Lung Institute (NHLBI) was used (National Heart Lung and Blood Institute, 2014) to assess the quality of one study (Chan et al., 2013). While this tool is not standardized its study-specific design allows it to assess the major flaws in study methods. Key point for this evaluation is the absence of eligibility criteria that result in a selection bias.

Table 4.8: Details of included studies – Characteristics, samples and methods

No.	Title	Authors	Year of publication	Study design	Study setting	Sample size	Instrument/ status	Method used
1	Interobserver Reliability of General Practice Physiotherapists in Rating Aspects of the Movement Patterns of Skilled Violinists	Ackermann et al.	2004	Cross-sectional study (Reliability study)	Australia	N = 30 musicians + 12 PT %M/F = not stated Mean age= not stated	Violin Professional, undergraduate and postgraduate students	Questionnaire (visual assessment)
2	Three-dimensional motion capture applied to violin playing: A study on feasibility and characterization of the motor strategy	Ancillao et al.	2017	Case study	Italy	N = 1 Male Age = 30	Violin Professional	3D motion capture
3	Analysis of the Frequency of Postural Flaws During Violin Performance	Kruta de Araujo et al	2009	Cross-sectional study	Brazil	N = 4 Mean age = not stated (16-19)	Violin Students	Videography 2D motion analysis
4	Playing the Clarinet: Influence of Body Posture on Muscle Activity and Sound Quality	Baadjou et al.	2017	Cross-sectional study	Netherlands	N = 20 45% M/ 55 % F Mean age = 29.2 (18-60)	Clarinet Professionals and students	Goniometric analysis 2D motion capture
5	Postural kinematics of trumpet playing	Bejjani & Halpern	1989	Cross-sectional study	United-States	N = 16 100% M/ 0% F Mean age = 40 (±14)	Trumpet Professionals	Photography 2D motion capture
6	Common postural defects among music students	Blanco-Piñeiro et al.	2015	Cross-sectional study	Spain	N = 100 Mean age = 23.9 (18-30) 60% M/ 40% F	Brass and woodwind, strings, piano, percussion, bagpipes Students	Videography and visual assessment of the videos
7	Comparison of chairs based on HDsEMG of back muscles, biomechanical and comfort indices, for violin and viola players: A short-term study	Cattarello et al.	2018	Cross-sectional study	Italy	N = 21 62% M/ 38% F Mean age= 25 (15-53)	Violin and viola Students and professors	Goniometric analysis

8	Can experienced observers detect postural changes in professional musicians after interventions?	Chan et al.	2013	Uncontrolled trial of intervention	Australia	N = 57 37% M/ 63% F Mean age (exercise group) = 43 (SD 10.1) // mean age (alexander group) = 44 (SD 11.8)	Violin, viola, cello, double bass, flute, clarinet, oboe, bassoon, timpani Professional	Photography and visual assessment of the photos
9	Three-dimensional analysis of the cranio-cervico-mandibular complex during piano performance	Clemente et al.	2014	Cross-sectional study	Portugal	N = 17 %M/%F not stated	Classical piano and jazz piano Students	Accelerometry 3D motion analysis
10	Postural Sway of Percussionists: A Preliminary Investigation	Coker et al.	2004	Cohort study	United-States	N = 14 86% M/14% F Mean age = 20.4	Percussion instruments Students	Stabilometry
11	Musculoskeletal Discomfort of Music Teachers: An Eight-year Perspective and Psychosocial Work Factors	Fjellman-Wiklund et al.	1998	Cohort study	Sweden	N = 6 5% H/50% F Mean age (F) = 37 (SD 5) /Mean age (M) = 45 (SD 11,3)	Violin Music teachers	Micro-switch sensors
12	Torso and Bowing Arm Three-Dimensional Joint Kinematics of Elite Cellists: Clinical and Pedagogical Implications for Practice.	Hopper et al.	2017	Cross-sectional study	Australia	N = 31 45% H/ 55% F Mean age = 20.3 (tertiary-level students), 31.7 (freelance professionals), 37.6 (orchestra professionals)	Cello Professional, tertiary-level students	Videography 3D motion analysis
13	Analysis and Fem Simulation Methodology of Dynamic Behavior of Human Rotator Cuff in Repetitive Routines: Musician Case Study	Islan et al.	2018	Case study	Spain	N = 1 Female, 24 years old	Violin Professional	RULA (Rapid Upper Limb Assessment) analysis + FEM (Fine Element Method) analysis
14	Voice Parameter Changes in Professional Musician-Singers Singing with and without an Instrument: The Effect of Body Posture	Longo et al.	2020	Cross-sectional study	Italy	N = 17 % M/F = not stated Mean age = 27.7 (± 9.4)	Piano and guitar Professional musician-singers	Visual assessment

15	Comparison between the musician-specific seating position of high string bow players and their habitual seating position – a video raster stereographic study of the dorsal upper body posture	Ohlendorf et al.	2018	Cross-sectional study	Germany	N = 13 38% M/ 62% F Mean age = 43.6 ± 9.9	Violin/viola Professional orchestra musicians	Video raster stereography 3D motion analysis 3DMA with VRS or VRS + 3DMA
16	Influence of ergonomic layout of musician chairs on posture and seat pressure in musicians of different playing levels	Ohlendorf et al.	2018	Cross-sectional study	Germany	N = 47 49% M/ 47% F Mean age = 32.4 ± 13.2	Clarinet, trumpet, saxophone, violin, guitar and concert flute. Professionals, amateurs and students	Video raster stereography + stabilometry
17	Comparison of Electromyographic Activity and Range of Neck Motion in Violin Students with and without Neck Pain During Playing	Park et al.	2018	Cross-sectional study	Korea	N = 18 100% females Mean age (pain group) = 17.88 ± 0.33 / mean age (CG) = 17.11 ± 0.33	Violin Students	Ultrasound 3D motion analysis
18	Influence of Different Instrument Carrying Systems on the Kinematics of the Spine of Saxophonists	Piatek et al.	2018	Cross-sectional study	Germany	N= 14 50% M/50% F Mean age = 25.86 ± 4.52 (18-38)	Saxophone Amateur and students	Ultrasound 3D motion analysis
19	Tuning of the Violin–Performer Interface: An Experimental Study about the effects of Shoulder Rest Variations on Playing Kinematics	Rabufetti et al.	2007	Cross-sectional study	Italy	N = 15 47% M/53% F Mean age= 40.9 ± 10.2 (23-59)	Violin Professionals and students	Optoelectronic motion capture
20	Hand Span and Digital Motion on the Keyboard: Concerns of Overuse Syndrome in Musicians	Sakai et al.	2006	Cross-sectional study	United-States	N = 10 40% M/6% F Mean age = 29 (24-39)	Piano Professionals, semi-professionnals and amateurs	Videography 3D motion analysis
21	A Quantitative Three-dimensional Analysis of Arm Kinematics in Violin Performance	Shan & Visentin	2003	Cross-sectional study	Canada	N = 11 Age and gender not stated	Violin (teachers, professional musicians and students)	Videography 3D motion analysis

22	Comparing violinists' body movements while standing, sitting, and in sitting orientations to the right or left of a music stand	Spahn et al.	2014	Cross-sectional study	Germany	N = 19 16% M/84% F Mean age = 23.6 ± 2.8	Violin Students and (semi)professional orchestra.	Posturography + videography
23	Analyzing working conditions for classical guitarists: design guidelines for new support and guitar positioning	Valenzuela-Gomez et al.	2020	Cross-sectional study	Mexico	N = 9 89% M/11% F Mean age = 19.6 (18-21)	Classical guitar Students	Visual assessment (REBA)+ 3DMA using 3DSSPP (3D Static Strength Prediction Program)
24	Distinct digit kinematics by professional and amateur pianists	Winges et al.	2015	Cross-sectional study	United States	N = 10 40% M/60% F Mean age = 33 ± 10 (19-54)	Piano Professionals and amateurs	3D motion capture data device
25	Effect of the Alexander Technique on Muscle Activation, Movement Kinematics, and Performance Quality in Collegiate Violinists and Violists: A Pilot Feasibility Study	Wolf et al.	2017	Cohort study	United-States	N = 8 %M/F not stated Mean age = not stated (18-20)	Violin/viola University orchestra students	3D motion capture magnetic sensors
26	Marker-Based Method for Analyzing the Three-Dimensional Upper Body Kinematics of Violinists and Violists	Wolf et al.	2019	Cross-sectional study	Germany	N=12 %17% M, 83% F Mean age = not stated (18-20)	Violin/viola Music college students and orchestra musicians	Videography 3D motion analysis
27	Evaluation of Three-Dimensional Motion Analysis of the Upper Right Limb Movements in the Bowing Arm of Violinists Through a Digital Photogrammetric Method	Yagisan et al.	2009	Cross-sectional study	Turkey	N = 9 100% males Mean age = 22.4 (±2.9)	Violin Students	Photogrammetry

Legend:

3D: three-dimensional
2D: two-dimensional
CG: control group
MA: motion analysis

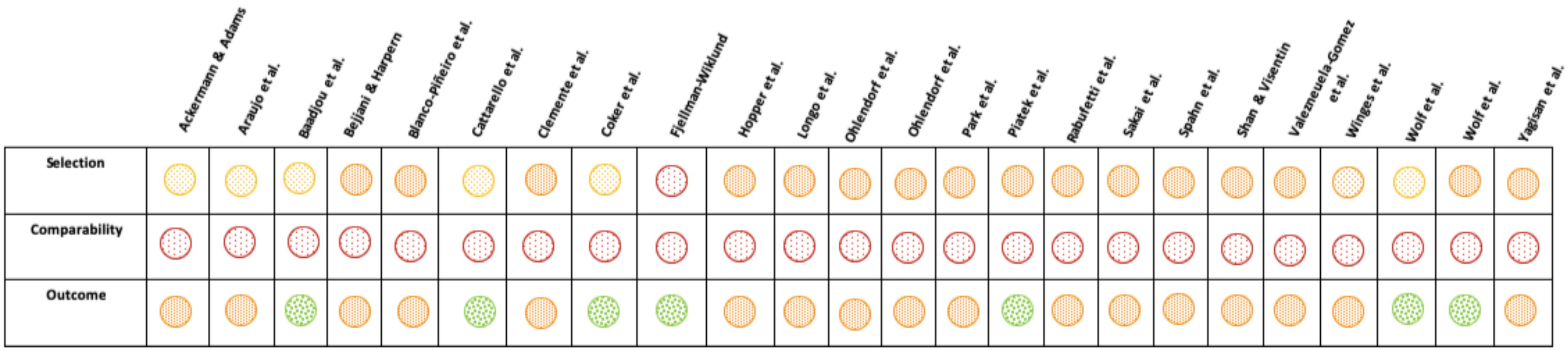
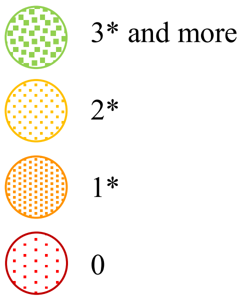


Figure 4.9: Quality assessment in cohort and cross-sectional studies

Legend:



4.3.2. Inter-rater agreement

4.3.2.1. Cross-sectional and cohort studies

For all cross sectional (n=20) and cohorts (n=3) articles included in this review, Cohen's kappa was 0.82 (cf Table 2) suggesting an almost perfect level of agreement between the two independent reviewers. However, for two of the comparability domain, Cohen's kappa value appears to be zero (cf Table 2), suggesting poor inter-rater agreement. As explained earlier in the material and method section, this situation refers to the paradox we are confronted with when interpreting the Kappa alone, namely that this parameter is strongly influenced by the prevalence of the data measured. This is reflected in the very high P_{neg} value, highlighting the strong consistency between the two raters and not a poor level of agreement as we would have concluded if we had stopped at the interpretation proposed by Landis and Koch. Cohen's kappa, level of agreement as well as P_{pos} and P_{neg} calculations are illustrated in Table 4.9.

Table 4.9: Level of inter-rater agreement for the assessment of cross-sectional and cohort studies

	Cohen's Kappa	**Level of Agreement**	**P_o**	**P_{pos}**	**P_{neg}**
Selection	0.98	Almost Perfect	0.99	0.99	0.99
Comparability	0	Poor	1	0	1
Outcome	0.48	Moderate	0.77	0.65	0.83
Overall	0.82	Almost Perfect	0.93	0.88	0.95

Legend:
P_o = Observed proportion of agreement,
P_{pos} = Observed proportion of positive agreement,
P_{neg} = Observed proportion of negative agreement

4.3.2.2. Uncontrolled study of intervention

The two raters demonstrated a perfect agreement as they were in accordance for all of the twelve items of the NIH tool.

4.4. Posture analysis

Concerning methods used for postural assessment, a large heterogeneity has been observed. Three dimensional analysis using videography (n=9) and visual assessment (n= 4) remain the most used methods for postural analysis. Two studies employed ultrasound (Park et al., 2012; Piatek et al., 2018), two other records resorted to goniometry (Baadjou et al., 2018; Cattarello et al., 2018). Amongst the other methods we found photogrammetry (Yagisan et al., 2009), accelerometery (Clemente et al., 2014), optoelectronic motion capture (Rabufetti et al., 2007) and the use of micro-switch sensors (Fjellman-Wiklund et al., 1998; Wolf et al., 2018). The last column of Table 4.8 summarises all the different postural assessment methods described among the 27 included studies. Different variables were investigated such range of kinematics parameters (such as velocity, acceleration, jerk) or postural impairments assessed by external raters. For each study, these variables were listed and the protocols (including musical tasks) were briefly described in Table 4.9. Moreover, Table 4.10 summarises also the considered body landmarks to evaluate posture using external devices or not.

4.5. Considerations about physiological posture

Among the 27 included studies, some authors reported several considerations about physiological posture. As an example, Blanco-Piñeiro et al. (2015) defined physiological posture while playing an instrument as “a posture with three fundamental characteristics: 1) maintenance of the spine, and of the head-trunk unit, along the “axis of gravity”, i.e. the vertical axis through the relevant centre of gravity (that of the head, trunk and arms if sitting; that of the whole body if standing); 2) total freedom of the arms to play the instrument; and 3) well-planted legs with joints unhindered and free to move”. They mentioned that playing a musical instrument should combine “maximum physiological and biomechanical efficiency” and “minimum expenditure of energy”. Nonetheless, they took into account how much playing specific instrument could lead to adopt different posture, such as double bass or the violin. Other authors reported elements about posture such as Ackermann and Adams (2004) who asked experts to evaluate “uprightness and” apparent muscle tension, or Cattarello et al. (2018) who stated that backrests were recommended for office workers to “promote “good” spinal posture”, as well as Longo et al. (2020) who state that “good postural alignment is necessary to achieve excellent voice performances”. They defined the ideal position to sing as “erected, with the

Table 4.9: Variables, protocols, landmarks used and form of the results of included studies

Authors, year	**Task**	**Type of variables**	**Used landmarks *(if suitable)***	**Form of the results**
Ackermann et al., 2004	Violinists were asked to play selected musical excerpts and were videotaped using 2 different cameras simultaneously. Videotapes shown to PT for movement pattern rating using an adapted version of a VAS.	- ROM (°) for shoulder, elbow and wrist; - Perceived injury risk for shoulder, elbow, wrist, hand, finger and thumb.	N.A.	Intraclass Correlation Coefficient (ICC) values
Ancillao et al., 2017	The violinist was asked to perform a legato bowing task (10 bowings). Video streams coming from 6 cameras allowed a reconstruction of markers trajectories to identify the biomechanical strategy of the upper limb and bow positioning	- ROM (°) for shoulder, elbow, wrist, neck, bow - Velocity (°/s) for shoulder, elbow, wrist, bow - Acceleration (°/s^2) for shoulder, elbow, wrist, bow - Jerk (°/s^3) for shoulder, elbow, wrist, bow	- 3 markers on the head, - Left and right acromioclavicular joint, - Right sternoclavicular joint, - C7, T8, L1 - Sacrum vertebrae, - Right and left elbow, wrist, hand, - Left four fingers (excluding thumb)	Mean values and coefficient of variation (CV)
Araujo et al., 2009	Musicians were videotaped while playing in a seated position (videotaping duration: 20 min). The captured images provided joint angle measurements.	- Wrist flexion while using the middle third (°) - Wrist flexion while using inferior third (°) - Lateral R/L deviation of the head - Shoulder abduction during playing of the four strings of the violin (°)	- Right acromion - Glabella - Humerus lateral epicondyle - Radius and ulnar styloid process - Wrist joint - Forearm - Third and fifth metacarpal heads	Descriptive analysis

Baadjou et al., 2017	60 seconds of the adagio in the clarinet concerto of Mozart in A major (KV.622) played 10 times in two different postural conditions: habitual and experimental sitting postures. Measurement at four moments: start of playing, at selected notes at approximately 20 and 40 s into the piece, and at the end of the piece. Total of experiment: 2 hours.	- High thoracic angle - Low thoracic angle - Pelvic tilt angle	- Lateral femur condyle, - Greater trochanter - Anterior superior iliac spine, - Posterior superior iliac spine, - L2, T7, C7 (spinous process level)	Mean + 95% CI
Bejjani & Halpern, 1999	Each trumpetist was asked to perform two different tasks, standing while being videotaped by two cameras: a trumpet exercise, with an equal distribution of notes, and a piece of his own repertoire. Photographs were taken simultaneously as the trumpeter hit specific notes which allowed angle calculation.	- Vectorial sum of body segment angles in neutral standing posture and three-notes relating playing posture - Neck length - Leg length - Spine length	- Inion, - Base of head, - Base of neck, - Apex of thoracic kyphosis and lumbar lordosis - Sacral prominence - Popliteal fossa - Heel.	Mean + standard deviation (SD) Estimated regression coefficient + standard errors + F-ratios
Blanco-Piñeiro et al., 2015	Each student was videotaped (rear + lateral viewpoints in standing and seating positions) while playing a self-chosen piece for 2 minutes. Photographs of each participant in static standing and seated positions (without instrument) were taken. The photographs were then given to four individually trained experts for postural evaluation	- Overall posture (rigid/slumped/physiological) - Location of the axis of gravity (in a sagittal plane (forward-shifted, backward-shifted, physio) - Location of the axis of gravity in a frontal plane (right-shifted, left-shifted, physiological) - Pelvic attitude (forward-tilted, backward-tilted, physiological) - Dorsal curvature (excessive, insufficient, physiological) - Alignment of the head in sagittal planes (forward, backward, physiological) - Alignment of the head in frontal planes (tilted sideways, physiological) - Frontal plane of the shoulders (forward, backward, physiological) - Transverse plane of the shoulders (shrugging, physiological) - Lateral tilt of the shoulders (tilted, physiological) - Legs and feet (misplaced, physiological)	N.A.	Descriptive analysis

Cattarello et al., 2018	Two pieces of medium difficulty for 5 minutes in five different conditions (25 minutes of play in total). Pelvic tilt and spine angles in the sagittal plane were evaluated using a palpation meter while lumbar lordosis and thoracic kyphosis spine angles were evaluated using a flexicurve.	- Pelvic tilt standing (S), Standing with the instrument (Sv) in ° - Sagittal spine angles (kyphosis and lordosis angles) standing (S) and standing with the instrument (Sv) in ° - Trunk-thigh angle in sitting in °	- PSIS and ASIS - C7, T1, T12, L1, L5, S1 - Six additional points for the kyphosis curve - Six additional points for the lumbar curve.	p-values + 95% CI
Chan et al., 2013	Musicians were asked to play their instrument before and after a 10-weeks intervention program (exercise or Alexander Technique) and photographed. Posture was recorded by anterior and lateral photographs pre and post-intervention. Experienced evaluators had to determine which picture was the better posture using those two sets of photographs	- Probability of selecting the true post-intervention photo as having improved posture (%) - Response according to the judges and intervention (%) (in favor/against/no differences)	Circular retro-reflective markers: - Facial, spinal, pelvic and lower limb standard landmarks - Elbow's lateral epidondyle - Radial styloid process - Base of the fifth metacarpal	Descriptive analysis
Clemente et al., 2014	Assessment of the head and cervical posture of piano players during musical performance while wearing glasses including an accelerometer (playing duration = 3 min).	- Head orientation (°) - Global acceleration (g) - F/B and R/L tilt (°)	N.A.	Mean values
Coker et al., 2004	For both pre- and post-test, musicians were asked to play different percussive exercises under eight different conditions (simple quiet upright bipedal stance followed by seven fundamental percussive exercises in an upright bipedal stance) while standing on a center of pression measuring platform.	- COP displacement in the sagittal and frontal planes for each of the eight conditions. (inches) - Gain Scores for the Center of Pressure Displacement (inches)	N.A.	Mean + SD
Fjellman-Wiklund et al., 1998	Musicians were first assessed by a PT in order to identify any obstacle to full arm elevation. Subjects were then recorded by an arm-position analyser during a whole working day.	- Upper arm angle - Upper-arm elevations	N.A.	Mean values

Hopper et al., 2017	Musicians' movements (torso, upper arm and forearm) while playing a C-major scale under two volume conditions were recorded. A 3D motion capture device was used to create a customized biomechanical model that allowed upper arm kinematics calculation.	- Torso: flexion/extension (°), lateral flexion (L/R) (°), rotation (L/R) (°) - Shoulder: flexion/extension (°), abduction/ adduction (°), rotation (I/E) (°) - Elbow: flexion/extension (°), pronation/supination (°)	- 5 markers on the torso: acromion, C7 and T10 (spinous processes) - Sterno-clavicular notch and xiphoid process 3 makers on the upper arm and forearm (not listed)	Mean values
Islan et al., 2018	A RULA analysis was first performed evaluating the different positions of the musician's upper arm during her routine. Subsequently, the use of Finite Element Model (FEM) allowed a simulation of the glenohumeral joint and rotator cuff behavior.	- Position of the right and left arm (°) - Location of the first joint fault - Response of joints to the fatigue	N.A.	Descriptive analysis
Longo et al., 2020	Musicians were asked to sing different vowels while playing or not. Voice and body posture under those two conditions was then visually assessed by an expert osteopath using a modified version of an Italian validated method	- Head/neck (Straight/ Flexion/ Hyperextended/anteposition/retroposition/ rotated/sloping) - Jaw (open/close/central/lateralized) - Shoulders (neutral position/ intrarotated/ extrarotated/lifted up/lifted down) - Back (straight/flexion/hyperextended/ rotated)	N.A.	Descriptive analysis
Ohlendorf et al., 2018a	Musicians were asked to play on six different chairs with and without their instrument while their upper body (video raster stereography) and the seat pressure (load distribution) were analyzed. 3 scans were taken within 2 min which allowed body posture analysis	Spinal parameters - Trunk length D (mm) - Trunk length S (mm) - Sagittal trunk decline (°) - Frontal trunk decline (°) - Axis decline (°) - Thoracic bending angle (°) - Lumbar bending angle (°) - Standard lateral deviation (mm) - Maximal lateral deviation (mm) - Standard deviation rotation (°) - Maximal rotation (°) - Kyphosis angle (°)	6 self-adhesive markers : - C7 - Inferior scapular angles - Pelvis dimples - Rima ani.	Mean + SD and p-values

		- Lordosis angle (°) Pelvis parameters: pelvis distance (mm), height (°), height_2 (mm), torsion (°), rotation (°). Shoulder parameters: scapular distance (mm), height (mm), rotation (°), right and left angles (°).		
Park et al., 2012	Musicians were asked to play a specific piece from Kreutzer's *42 Études* (No. 2) using their instrument while their muscle activity and neck ROM were recorded.	- Neck flexion and extension (°) - Neck right and left rotation (°) - Neck right and left axial rotation (°) - Right and left lateral bending (°)	N.A.	mean ± SD,
Piatek et al., 2018	Musicians were asked to play their instrument with and without different saxophone-carrying systems. A 3D ultrasound device allowed posture measurements in the sagittal, coronal and transverse plane with and without the carrying items.	Sagittal plane: - Head posture to ankle distance [mm], - Head posture angle [°], - Bow head forward angle [°], - Chin to saxophone distance [mm] Coronal plane: - Shoulder obliquity [mm] - Pelvic obliquity [mm], - Lateral flexion of the head [°] Transverse plane: - Head to shoulder rotation [°] - Shoulder to pelvis rotation [°]	- External occipital protuberance, - External auditory canals, - Chin, - Acromion - Anterior points of the iliac spine - Posterior points of the iliac spine, - Apexes of the iliac cres - Ankles	mean + 95%CI
Rabufetti et al., 2007	Musicians were asked to play a three- octave ascending and descending scale in the G key while using their instrument in three conditions: no shoulder rest, shoulder rest all-up and all-down. An optoelectronic device allowed the evaluation of kinematic patterns of the right upper limb.	- Head leftward rotation angle (°) - Head rightward bending angle (°) - Chin rightward deviation (mm) - Left acromion elevation (mm) - Left shoulder flexion angle (°) - Left shoulder rotation angle (°) - Left wrist radial deviation (°)	21 passive reflective markers (Not listed)	Mean values
Sakai et al., 2006	Musicians were separated in two groups (small and large hand span) and were asked to play a chord and an octave using their instrument while their hand movements were being recorded. Video-based passive marker detection	- Maximum and minimum abduction angle of the thumb (°) - Maximum and minimum abduction angle of the little finger (°)	26 markers on the dorsal side of the middle finger, small finger, thumb, dorsal hand, and forearm.	Mean + SD

	system measured abduction angle of both the thumbs and the small fingers.	- Thumb and little finger ROM (°)		
Shan & Visentin, 2003	Musicians were asked to play a two-octave G- major scale in first position using one note per bow while being recorded. A VICON system allowed a 3D motion analysis of the upper-body kinematics.	- Joint moments for the right shoulder, elbow and wrist (Nmm) - Range of load of the shoulder, elbow and wrist.	30 reflective markers (not listed)	Mean + SD
Spahn et al., 2014	Musicians were asked to play their instrument while being videotaped, sitting on a force platform and in four different conditions (standing, sitting, sitting oriented to the right of the music stand, and sitting oriented to the left of the stand). The posturographic device allowed: weight distribution analysis, 3D motion capture of the back and bowing arm in the 4 set-ups.	- Comparison sitting position to the right or left of the stand (°): right and left head angles, neck lordosis, thoracic kyphosis, elbow angle. - Comparison between sitting and standing position (°): shoulder angle, thoracic kyphosis, lumbar lordosis, hip angle, elbow angle. - Body weight distribution (% of total body weight).	9 markers - Right and left protuberantia occipitalis externa - Acromion - C4 (neck lordosis), T6 (thoracic kyphosis), L3 (lumbar lordosis) - Sacrum - 7 cm next to the right and left posterior superior iliac spine	Mean + SD
Valenzuela-Gomez et al., 2020	Musicians were asked to play their instrument with three different support devices (guitar cushion, rigid lap support and footstool). Body posture was assessed in two phases: first using REBA and then a 3D software (3D Static Strength Prediction Program).	- Hip flexion (°) - Trunk flexion (°) - Trunk axial rotation (°) - Low back compression (N)	Not stated	Mean + SD
Winges et al., 2015	Musicians were asked to play 14 different excerpts while wearing a right-handed glove with open fingertips which provides joint angles data. Authors then proceeded to a movement kinematics analysis using magnetic sensors for motion tracking	- MCP, PIP and Abduction/adduction angles for each of the four fingers - MCP, IP joint angles and rotation angle (ROT) for the thumb - Joint velocity profiles of a professional and amateur pianist during INDEX finger strikes - Joint velocity profiles of a professional and amateur pianist during RING finger strikes.	Not stated	Mean (± SE) and SD (± SE)

		- Peak joint velocity by preceding digit strike.		
Wolf et al., 2017	Subjects were divided into two groups (AT intervention group and control group). Magnetic sensors permitted head and shoulder motion tracking as musicians played a scale and a Kreutzer *étude*. Descriptive measures of ample entropy and average mutual information (AMI) were then performed.	- Sample Entropy - AMI	6 magnetic sensors: - Occipital lobe - C6 - Left arm, forearm, hand (just above wrist) and humeral head.	Mean + SD
Wolf et al., 2019	Subjects were asked to play their instrument while being videotaped. A 10-camera Qualysis system allowed a 3D motion analysis of the upper-body kinematics.	Angle and ranges of motion for the spine, shoulder, elbow, wrist, scapulothoracic joint on G and D-strings.	31 single markers (pelvis, thorax, spine, head, both scapulae, upper arms, forearms, hands), 2 pre-built and 4 custom-made clusters for thorax, upper arms, right forearm and both scapulae.	Mean, maximum and minimum angles, range of motion + SD
Yagisan et al., 2009	Participants were photographed while playing a standard violin with a standard bow performing the basic bow drives. Three measurement points were used for the E, A and G strings. Digital photogrammetric methods then allowed upper-arm kinematics analysis.	- Average angle of the elbow (°) on E, A and G string - Average angle of the wrist (°) on E, A and G string - Arm direction (%) on E, A and G string - Forearm direction (%) on E, A and G string - Hand direction (%) on E, A and G string	6 markers: - Acromion - Lateral epicondyle - Olecranon - Ulnar styloid - Hamate - Fifth metacarpal head	Mean + SD

Legend:
AMI: average mutual information
AT: Alexander Technique
SE: Standard error
SD: standard deviation
ROM: range of motion
VAS: visual analogic scale

axes of the neck, jaw, shoulders, back, and pelvis aligned on the sagittal, axial, and transversal body axes" based on previous research (Longo et al., 2020). Moreover, Spahn et al. (2014) reported that musicians should have a standing symmetric posture understood as an equal distribution of the weight over both lower limbs. Finally, one study reported considerations about the potential mobility of the instrumentalists while playing: Ackermann and Adams (2004) asked the raters to evaluate the postural mobility of musicians between static and dynamic on a visual analogue scale. On the contrary, Blanco-Piñeiro et al. (2015) asked their assessors to ignore "transient excursions in the course of performance" and to rate musicians' posture as average position, that is to say, not considering how much the instrumentalists were mobile while playing.

4.6. Potential relationship between posture and PRMDs

Studying the link between possible postural impairments and PRMDs was a secondary objective. Only one study investigated this possible relationship: Park et al. (2012) studied how neck ranges of motion while playing could potentially be associated with neck pain in violinists. The authors reported that lateral bending and rotation to the left side while playing the violin were significantly greater in the group of musicians with neck pain compared to the control group. This result provides a brief but limited insight regarding the possible relation between posture while playing and PRMDs.

5. DISCUSSION

5.1. Main findings of this review

This systematic review determined out how posture while playing has been analysed in musicians from different backgrounds and with different levels of expertise for 30 years. Among all the identified methods, visual assessment (using both videos or pictures) and three-dimensional analysis using video cameras were the most reported ways to record posture while playing. Considering the visual assessments, the Postural Observation Instrument (or POI) developed and tested by Blanco-Piñeiro et al. (2015, 2018) seems to be the most comprehensive including overall posture as well as specific body locations (often reported as painful ones in musicians – Silva et al., 2015; Kok et al., 2015) such as shoulders, neck, spine, etc. Nonetheless, this tool considers musicians' posture as "average positions" and asks the experts who have rated the different postures to ignore transient movements while playing. Unfortunately, this does not allow to compare musicians with fixed postures and musicians with changing ones. Considering the investigated body locations and the body landmarks used to assess posture, the area of interest focuses mainly on the spine and upper limbs' positions while playing a music instrument. Indeed, repetitive movements and asymmetrical postures required to play instrument such as the cello (Hopper et al., 2017) or the violin (Ancillao et al., 2017; Shan & Visentin, 2003) affect mainly the spine and the upper limbs compared to the lower ones.

Surprisingly, while posture has been investigated in all the included studies (as it was one of the main requirements for inclusion), what is considered as "physiological" posture is not often thoroughly or specifically described in the different papers. The absence of strong evidence for ideal posture and the debate about potential relationships between postural impairments and pain (Swain et al., 2020) could explain the difficulty of precisely stating what is identified as physiological when considering musicians' posture.

5.2. Comparison with previous reviews

Authors have investigated posture in musicians, its potential association with pain and which methods were employed to evaluate it both without instrument and while playing (Fernandez-Paz et al., 2019; Blanco-Piñeiro et al., 2017). One of these reviews has not followed a systematic research strategy, data extraction and assessment (Fernandez-Paz et al., 2019). The second one has not evaluated the quality of the primary included studies (Blanco-Piñeiro et al., 2017). In addition to these distinctions, the current review may differ also considering several other elements. First of all, our review did not include self-reported questionnaire to analyse posture, as the authors considered this method was not appropriate enough to assess posture in the best way possible. This review also excluded musicians who were singers only, as that made them too difficult to be compared to instrumentalists. Furthermore, only posture while playing was considered in this work, excluding all postural considerations without the instrument or other musculoskeletal assessments, which were included in the other reviews (Fernandez-Paz et al., 2019; Blanco-Piñeiro et al., 2017).

Finally, Fernandez-Paz et al. (2019) mentioned in their abstract that posture appears to be one relevant risk factors influencing both musculoskeletal health and performance, without stating precisely if they were considering general posture or posture while playing a music instrument. This statement has not been shared with this review's general findings (even if one primary study mentioned association between postural impairments and neck pain in violinists – Park et al., 2012). Indeed, it seems that this association has been based on self-reported measures or musculoskeletal assessments which provide some information but probably not enough to associate positively postural impairments and pain development.

5.3. Strengths and limitations of this review

This review provides a large synthesis of how musicians' postures while playing are currently investigated, excluding self-reported measures. This could potentially help researchers to choose one method or the other to investigate and monitor posture while playing, in order to allow potential comparisons with previous findings in literature. Moreover, in contrast to the reviews (systematic or not) which mentioned posture in musicians and in which primary studies were not assessed, in our review the included studies' quality has been evaluated with the Newcastle Ottawa Scale (Wells et al., 2013). This provides additional information regarding the methodological quality of some studies to inspire further research.

The relationship between posture (and more specifically postural impairments) and PRMDs is often assumed in research about musicians' injuries. This systematic review highlight the lack of clear evidence to state that an association exist between "bad" posture and PRMDs' development.

Finally, the considered research strategy had included studies in French and English only and some studies using interesting methods in other languages could exist. Finally, concerning the use of visual assessment, tools reliability (and particularly interrater reliability) may be questionable in the included studies. This element provides perspectives for further research as well.

5.4. Perspectives and proposal of a new tool

As pointed out in this review, visually analysing musicians' posture is not a simple or straightforward task. Moreover, it is not the most reliable way to investigate posture, compared for example to three-dimensional analysis. Nonetheless, posture in musicians is mainly assessed by musicians themselves, music teachers with their students and healthcare professionals with their patients and three-dimensional analysis cannot be the only way to study posture as it is obviously unaffordable for most people and not available widely in workplace settings.

The Postural Observation Instrument in Blanco-Piñeiro et al. (2015) study seems to be simultaneously very comprehensive and quite time-efficient to be applied in different contexts, from physiotherapy assessment to music teaching. Even if the reliability process has not been thoroughly described in the original paper, this instrument seems to be reliable between experts. Nonetheless, it appears to us that one of its major drawback is to rate postural components as fixed, considering "average" positions and not mobility while playing, in contrast to

Ackermann & Adams (2004) who included this measurement to their tool. Further research should focus on investigating how much musicians are moving while playing and how these movements could be easily assessed. This systematic review provided the necessary background to develop a new instrument to assess posture in musicians: the Postural Analysis Tool for Musicians (PATM), by including to a modified version of the Postural Observation Instrument (Blanco-Piñeiro et al., 2015), the analysis of how musicians are mobile while playing. Moreover, and in contrast to Ackermann & Adams (2004) who used visual analogue scales to assess most items, the choice has been made to favour a 3-point scale to assess mobility while playing, in order to increase both its inter- and intra-reliability. The whole tool and the protocol developed to validate it has been detailed in Appendix M.

6. CONCLUSION

Further research is still need to understand better the potential relationship that is often assumed between postural impairments or technical flaws while playing a music instrument and the development of playing-related musculoskeletal disorders.

In the future and in order to be used by a great number of musicians and healthcare practitioners, a tool investigating musicians' posture while playing and particularly how much they are moving while playing, should be developed and tested.

Fifth part: Chairs' height and sitting position in cellists: a pilot study

Before the Covid-19 pandemic, this study was conceived as part of the initial PhD plan to include as many cellists as possible. As only one participant was tested before the pandemic disrupted the research process, this section will describe a case study.

1. Abstract

Introduction: Sitting position is considered as a potential risk factor which could lead to injuries in musicians, as most of them are playing seated for hours during rehearsals, concerts but also at home, while practicing. Cellists, who play a large instrument, have rarely the possibility to adjust their chair's height, contrary to most of the double bassists. The aim of this study is to investigate the effect of sitting on an adjustable stool compared to the usual orchestra chair on both spine posture and performance.

Methods: One cellist has been asked to play several music excerpts on a usual chair and an adjustable stool as well as to rate the perceived exertion and performance parameters. Excerpts have been recorded and an external examiner has been asked to rate them. Moreover, spine posture and hip movements have been analysed using a 3D motion capture system.

Results: The cellist has increased the height of the chair from 2 cm compared to the usual chair, rated perceived exertion 1 point less and stated that all performance parameters were positively impacted. The performance was rated as lightly better on the usual chair. Postural parameters indicated a lower hip flexion on the adjustable stool and most of the spine parameters (particularly lateral bending and rotation) decreased on the stool.

Discussion: This study was aimed to include more participants. In the future, the protocol should include a longer period of familiarisation with the new chair's height. It could also integrate the measurement of spine muscle activation and musicians themselves could evaluate their own performances.

2. Introduction

Sitting position has often been described as a problem in musicians and one of the main injury risk factors (Spahn et al., 2014; Price et al., 2014). Orchestra musicians are playing seated for hours during rehearsals and concerts. Nevertheless, breaks in rehearsals and entr'actes allow musicians to stand up and move for a while. Among the main factors affecting posture, poor chairs (Ackermann & Adams, 2004), length of time while sitting (Chan & Ackermann, 2014) and orientation towards the music sheet (Spahn et al., 2014) are the most important. By interviewing musicians, sitting for a long time is one of the most frequently mentioned injury risk factors (Rousseau et al., 2021). Moreover, sitting position while performing has been investigated and has being correlated with PRMDs scores in orchestra musicians (see Chapter 4 – Part 2).

Playing sitting down is a particularly crucial issue for cellists as the cello is one of the few instruments that does not allow to be played upright. Cellists maintain the instrument between their thighs, the right hand and fingers orientate the bow while the left fingers are pressing the strings along the cello's neck. Some studies have reported that cellists had similar or higher risk to develop injuries than other string players, and that 16% of orchestra cellists had right shoulder pain (Rickert et al., 2012). In Ackermann et al. (2012), the main body locations where lower string players, including cellists, reported pain are upper back (13.2%), lower back (16.2%) and right shoulder (11.8%). Right upper limb seems to be much more affected than the left (25.0% vs 11.8%) (Ackermann et al., 2012). In orchestras, cellists are often sitting on common chairs, that are not adjustable, unlike double bassists' stools or chairs. Cello has been previously described as one of the instruments that requires an asymmetrical position while playing (Hopper et al. 2017; Rickert et al., 2013). Hopper et al. (2017) have investigated cellists' overall posture while playing and have highlighted several biomechanical elements such as sustained left rotation that may explain why upper and lower back are frequently reported as pain locations (Ackermann et al., 2012).

In previous studies, some cellists have mentioned that sitting position could even affect the function of their left and right shoulders, and the importance of securely planting feet on the floor (Rickert et al., 2015). Chair height could help with managing spinal posture, the distance between the musician's body and the cello and this should be done to facilitate the musicians' comfort. To the best of our knowledge, sitting position and chair's height have never been investigated in cellists as impacting posture and muscle activation, as well as performance and comfort while playing.

The aim of this study was to investigate sitting position and how chair height could affect spinal posture, perceived exertion and even the performance itself. This would have been achieved by investigating all of these elements in two different conditions:

- On the usual chairs (non-adjustable) they are usually sitting on at the orchestra and
- On an adjustable chair, with which they would be able to choose subjectively a comfortable height

3. Methods

3.1. Inclusion criteria and ethics

The participants should be professional orchestra cellists, aged above 18 years and able to speak English fluently. The study protocol received ethical approval from the Liverpool John Moores University Research Ethics Committee (19/SPS/062).

3.2. *Standardised play*

Cellists would have been asked to play in a random order 45-seconds excerpts (McCrary et al., 2016) from different standardised pieces:

- Ein Heldenleben, Op.40, Richard Strauss: provides the analysis of forte/fortissimo and high notes across all four strings (bars 1-24, crotchet = 104 bpm);
- Symphony No.8, Scherzo, Ludwig Van Beethoven: provides the analysis of short notes across the four string (bars 43-64, crotchet = 116 bpm);
- Marriage of Figaro, Ouverture, Mozart: provides the analysis of short and fast notes (bars 1-33, minim = 144 bpm);
- Three octaves C-major scale up and down, 40 bpm, with "quiet bow": provides the analysis of progressive movements along the neck as well as high control of the bow to produce a quiet and slow sound.

These excerpts have been chosen with the help of a professional cellist to be well-known pieces (that every orchestra cellist would play easily) and to cover a wide range of movements, at different *tempi*. All cellists would have been asked to perform the four excerpts twice on the usual chair and twice on the adjustable stool. A metronome would have been used in order to standardise tempo before the play (Baadjou et al., 2017; McCrary et al., 2016).

3.3. Chairs

Figure 4.10 below provides information about the usual chair cellists are currently sitting on while performing at the orchestra. The height of this chair is 46 centimetres. The adjustable stool used for this study would have been a standard piano stool.

Figure 4.10: Usual orchestra chair for cellists (without backrest)

3.4. 3D motion capture procedure

A six-degrees of freedom full body marker set has have been used and 54 retro-reflective markers were tracked by 12 motion capture cameras (120Hz, VICON Motion Systems, Oxford, UK). Participants would have been asked to wear sport or tight clothes to facilitate the placement of markers accurately on anatomical landmarks and the motion analysis. Reflective markers would have been placed on the cellists' body as described in in Appendix N. A head band with six reflective markers would have been used to track head movements.

3.5. Sound record procedure and synchronisation

All standardised pieces and scales were recorded using a Zoom H4N Handy Portable Digital Recorder (Zoom, Tokyo, Japan). Using a controlled device producing both electrical signal, light and sound, 3D motion capture and audio recording have been synchronised.

3.6. Assessment of audio recordings

One external expert has been asked to rate the musical performance. Firstly, he has been asked to point out the fragment in which performance was better (Baadjou et al., 2017). Then he has been asked to rate both performances according to the scale developed by McCrary et al. (2016) in Appendix O. The expert is a professional musician with more than 10 years of experience as teacher (to be used to the procedure of grades) (Baadjou et al., 2017; McCrary et al., 2016; Ackermann et al., 2002). Second excerpts for both conditions have been used to be rated. The expert has been asked to listen to two fragments (same musician, same standard piece) in a randomised order (Baadjou et al., 2017).

3.7. Questionnaires and self-rating scales

The Injury Risk Factors Questionnaire for Musicians would be used to investigate several elements such as individual characteristics, reported disorders, pain or injury and their management, physical activity, workload, life habits, psychological health, etc.

To rate their perceived exertion while playing, musicians would be asked to use the Borg scale (Borg, 1998), which has often been used in musicians to quantify performance exertion (Schemann et al., 2018; McCrary et al., 2016; Chan et al., 2000). Moreover, pre and post-intervention questionnaires have been completed to investigate sitting posture habits and perceived changes after the intervention (see Appendix O).

3.8. Data analysis and process

Only second plays in each condition (usual chair and adjustable stool) will be considered for analysis.

3.8.1. Posture data process

In terms of posture, differences would have been investigated on all movements (i.e.: flexion/extension, lateral bending and rotations) of the spine:

- Angle between pelvis and lumbar spine;
- Angle between pelvis and lower lumbar spine;
- Angle between lower and upper lumbar spine;
- Angle between upper lumbar spine and lower thoracic spine;
- Angle between lower thoracic spine and lumber spine.

Hip angles will also be compared.

Table 4.11 described how the segments were built in Visual 3D to analyse spine and hip angles.

Table 4.11: Segments construction

Segments	**Proximal**	**Distal**	**Note**
Head	Joint center: midSTC7	Lateral: LEAR Medial: REAR	
Thorax/Ab	Lateral: RILCR Medial: LILCR	Lateral: RSHOULDER Medial: LSHOULDER	
Upper thoracic spine	Joint center: C7	Lateral: RT7 Medial: LT7	Depth calculation: distance between C7 and STERNUM
Lower thoracic spine	Lateral: RT7 Medial: LT7	Joint center: T12	
Upper lumbar spine	Joint center: T12	Lateral: RL4 Medial: LL4	
Lower lumbar spine	Joint center: L3	Lateral: RPSIS Medial: LPSIS	
Lumber spine	Joint center: T12	Lateral: RPSIS Medial: LPSIS	
Pelvis			CODA model with calibration targets: RASIS, LASIS, RPSIS, LPSIS
Right Upper Arm	Joint center: RSHOULDER	Lateral: REELBOW Medial: RIELBOW	
Left Upper Arm	Joint center: LSHOULDER	Lateral: LEELBOW Medial: LIELBOW	
Right Lower Arm	Lateral: REELBOW Medial: RIELBOW	Lateral: RRADST Medial: RULNST	
Left Lower Arm	Lateral: LEELBOW Medial: LIELBOW	Lateral: LRADST Medial: LULNST	
Right Hand	Lateral: RRADST Medial: RULNST	Joint center: RHAND	

Left Hand	Lateral: LRADST Medial: LULNST	Joint center: LHAND	
Right Thigh	Joint center: Right Hip	Lateral: RECOND Medial: RICOND	
Left Thigh	Joint center: Left Hip	Lateral: LECOND Medial: LICOND	
Right Shank	Lateral: RECOND Medial: RICOND	Lateral: REMAL Medial: RIMAL	
Left Shank	Lateral: LECOND Medial: LICOND	Lateral: LEMAL Medial: LIMAL	
Right Foot	Lateral: REMAL Medial: RIMAL	Lateral: REFOOT Medial: RIFOOT	
Left Foot	Lateral: LEMAL Medial: LIMAL	Lateral: LEFOOT Medial: LIFOOT	

Three specific landmarks were also created:

- Right hip: using the CODA Pelvis V3D model;
- Left hip: using the CODA Pelvis V3D model;
- MidSTC7: half distance between STERNUM and C7.

Figure 4.11 represents the created skeleton.

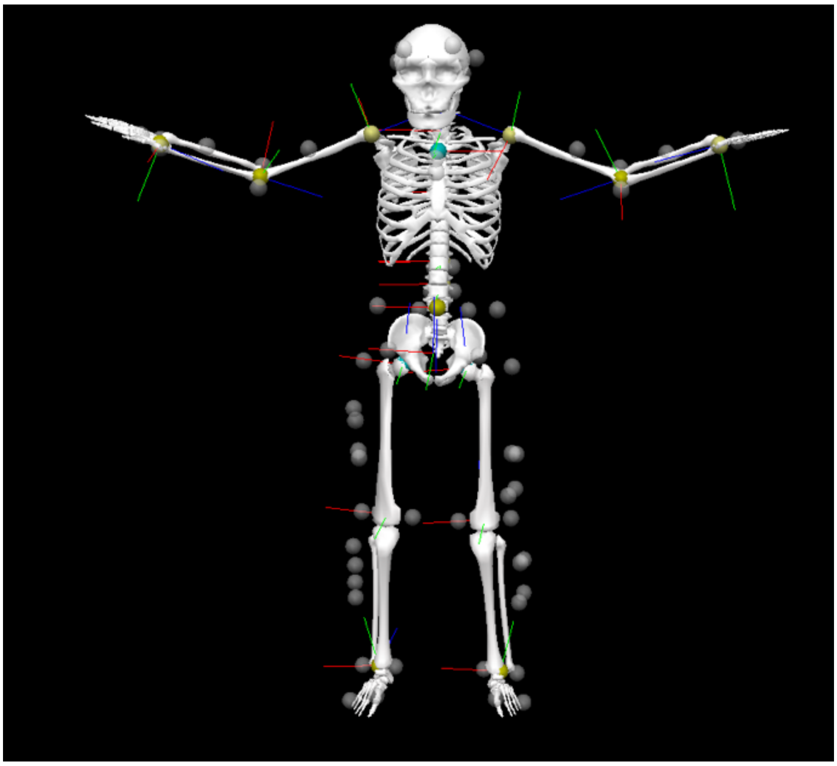


Figure 4.11: Segments model in Visual 3D

Posture data were filtered with a 3rd order Spline filter.

3.8.2. Posture data analysis

Concerning the angles, Table 4.12 below described how the angles were created.

Table 4.12: Angles construction in Visual 3D

Angle	Reference segment	Segment
LLS/pelvis angle	Pelvis angle	Lower lumbar spine
LS/pelvis angle	Pelvis angle	Lumbar spine
ULS/LLS angle	Lower lumbar spine	Upper lumbar spine
LTS/ULS angle	Upper lumbar spine	Lower thoracic spine
LTS/LS angle	Lumbar spine	Lower thoracic spine
Pelvis/R thigh	Pelvis	Right thigh
Pelvis/L thigh	Pelvis	Left thigh

3.8.3. Performance, exertion and qualitative data process

The pre-questionnaire would have been also used to draw musicians' profile regarding their usual practice and existing knowledge or thoughts about sitting position (as a potential preventive behaviour to handle PRMDs). Finally, perceived exertion would have been evaluated by comparing the score obtained by using the Borg scale.

In terms of performance, differences have been evaluated by considering:

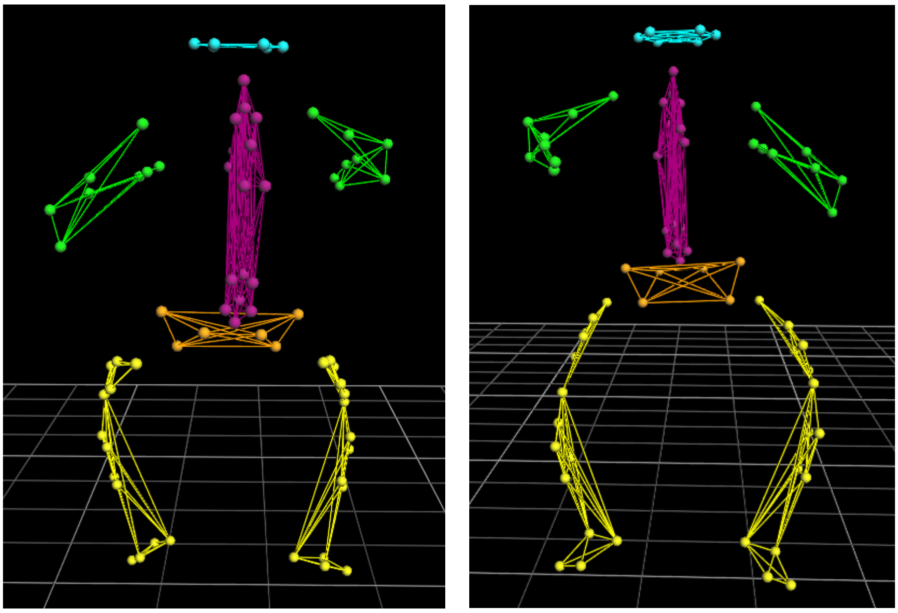
- The musician's subjective feelings assessed with the post-intervention questionnaire;
- The expert's adjudications.

3.8.4. Statistical analysis

All statistical analysis would have been performed using SPSS. All data would have been checked and confirmed to be normally distributed using probability plots. Then, paired Student t test or non-parametric tests would have been performed between the two tested conditions, usual chair (UC) and adjustable stool (AS).

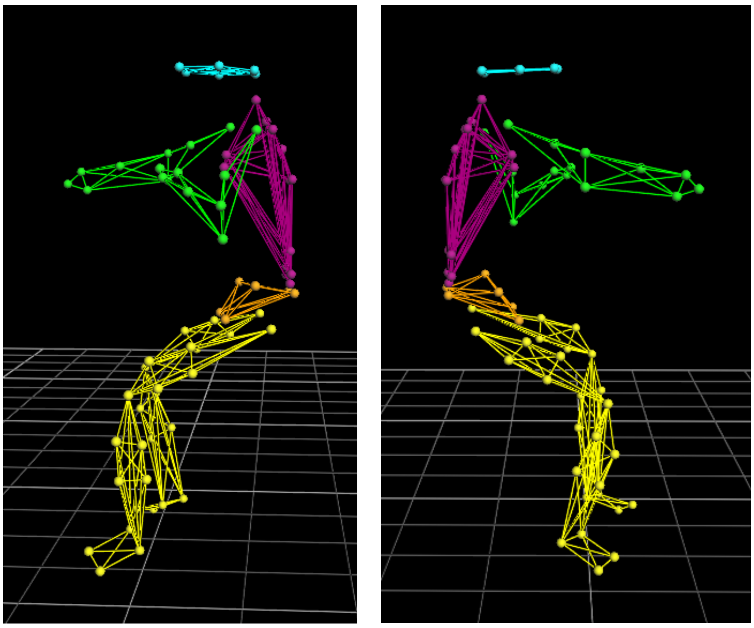
4. Results

The participant included in this pilot study was a professional cellist. Figure 4.12 and 4.13 below shows the participant's position while playing and the considered landmarks on which have been placed the markers.



(1) (2)

Figure 4.12: Cellist playing his instrument on his usual chair, back (1) and front views (2)



(1) (2)

Figure 4.13: Cellist playing on the adjustable stool, left (1) and right views (2)

4.1. Height of the chair

The height of the adjustable stool for the participant was 48 centimetres (+2 cm compared to the usual orchestra chair).

4.2. Perceived exertion

The rated perceived exertion while playing was 12 on the usual chair and 11 on the adjustable stool.

4.3. Performance adjudication

The external examiner rated the 8 recorded excerpts from 1 to 6 on three different items (total score: 18):

- On the usual chair, 17 for Beethoven, Strauss and Mozart's excerpts and 18 for the scale
- On the adjustable stool, 16 for Beethoven, Strauss and Mozart's excerpts and 17 for the scale.

4.4. Pre- and post-intervention questionnaires

Concerning the pre-intervention questionnaire, the participant answered that participation was motivated by finding out what effect different seat height has on performance and to persuade the employer to make adjustable chairs available for cello section. The participant stated that sitting position while playing the cello should be: "Seated on a chair of the correct height that an angle of just over 90° is achieved at the knees. Feet should ideally be able to be placed flat on the floor. Straight but not arched back." The participant reported using as usual chair at home a standard dining chair (IKEA) with a cushion and having had some advice about sitting position by one teacher.

Concerning the post-intervention questionnaire, the participant rated the effect of playing on the adjustable stool (on a Likert-scale from -5 to 5): 2 for overall playing capacity, posture, music sound, confidence and technique, 3 for ease of movement and 3 how likely the participant would be to play all the time with this new height.

4.5. Posture analysis

Range of motion while playing in spine were:

- Flexion (+) and extension (-)
- Left (+) and right (-) lateral bending
- Left (+) and right (-) rotations

Range of motion while playing in the hips was flexion (+).

Table 4.13: Mean angles (± SD)

Angles	**Axis**	**Scale**	**Mozart**	**Beethoven**	**Strauss**

		UC	AS	UC	AS	UC	AS	UC	AS
<u>LLS/pelvis angle</u>	*x*	6.8 (±2.5)	8.7 (±2.5)	6.0 (±1.1)	6.0 (±1.0)	5.9 (±0.9)	7.5 (±1.0)	9.3 (±1.7)	11.2 (±2.0)
	y	7.8 (±1.3)	6.4 (±1.2)	7.4 (±0.6)	5.9 (±1.0)	7.2 (±1.1)	6.9 (±0.7)	8.1 (±1.2)	6.8 (±0.8)
	z	4.1 (±1.3)	3.5 (±0.7)	4.0 (±0.8)	3.0 (±0.6)	3.8 (±0.4)	2.8 (±0.6)	4.1 (±1.1)	3.9 (±0.6)
<u>LS/pelvis angle</u>	*x*	8.4 (±1.7)	11.8 (±2.7)	9.0 (±0.7)	9.0 (±1.0)	9.4 (±0.9)	10.8 (±1.2)	12.3 (±1.8)	14.1 (±1.8)
	y	9.0 (±1.7)	7.5 (±1.7)	8.4 (±0.9)	6.7 (±1.2)	8.2 (±1.5)	7.7 (±1.1)	9.8 (±1.9)	8.1 (±1.3)
	z	-9.0 (±4.4)	-8.4 (±3.0)	-7.4 (±3.7)	-9.0 (±3.4)	-6.7 (±2.6)	-7.9 (±3.6)	-5.4 (±5.7)	-7.2 (±3.8)
<u>ULS/LLS angle</u>	*x*	1.1 (±1.4)	3.1 (±1.2)	3.0 (±1.4)	2.7 (±1.2)	3.4 (±0.9)	3.3 (±1.2)	3.0 (±1.4)	3.0 (±1.4)
	y	-1.8 (±0.4)	-1.9 (±0.4)	-1.7 (±0.3)	-1.7 (±0.2)	-1.8 (±0.2)	-1.7 (±0.2)	-1.7 (±0.6)	-1.8 (±0.4)
	z	3.5 (±0.1)	3.5 (±0.1)	3.5 (±0.1)	3.5 (±0.1)	3.6 (±0.1)	3.5 (±0.1)	3.7 (±0.2)	3.6 (±0.1)
<u>LTS/ULS angle</u>	*x*	14.6 (±2.3)	12.4 (±2.4)	14.3 (±1.1)	13.6 (±1.2)	14.4 (±1.7)	13.4 (±1.5)	9.6 (±2.8)	9.0 (±2.2)
	y	-0.1 (±1.2)	0.1 (±1.3)	-1.0 (±0.9)	-0.3 (±1.3)	-0.7 (±1.0)	-0.8 (±1.1)	0.1 (±1.9)	-0.8 (±1.4)
	z	-3.5 (±1.9)	-3.2 (±1.7)	-3.7 (±1.0)	-2.6 (±1.1)	-2.7 (±1.5)	-2.1 (±1.6)	-2.4 (±2.7)	-2.1 (±2.3)
<u>LTS/LS angle</u>	*x*	14.2 (±2.1)	12.3 (±2.3)	14.4 (±0.7)	13.4 (±1.3)	14.5 (±1.6)	13.6 (±1.4)	9.5 (±2.4)	9.5 (±2.0)
	y	1.2 (±1.7)	0.8 (±1.8)	0.1 (±1.3)	1.0 (±1.5)	0.2 (±1.2)	0.1 (±1.4)	-0.9 (±2.9)	-1.4 (±2.0)
	z	13.0 (±3.4)	12.1 (±3.3)	11.0 (±2.2)	12.7 (±3.3)	11.2 (±1.9)	11.8 (±3.2)	10.2 (±5.1)	12.6 (±3.3)
<u>Pelvis/R Thigh</u>	*x*	79.9 (±0.7)	75.5 (±1.2)	80.7 (±0.8)	75.9 (±1.3)	80.7 (±1.2)	74.8 (±1.4)	81.0 (±0.7)	77.3 (±1.4)
<u>Pelvis/L Thigh</u>	*x*	80.4 (±0.9)	77.3 (±1.2)	81.2 (±0.4)	77.1 (±1.3)	80.9 (±1.0)	78.4 (±1.0)	81.1 (±0.6)	78.1 (±1.1)

<u>Legend:</u>
LS: lumbar spine
LLS: lower lumbar spine
ULS: upper lumbar spine
LTS: lower thoracic spine
x, y, z: cartesian coordinate system axis
R: right
L: left
AS: adjustable stool
UC: usual chair

<u>Table 4.14: Range of motion</u>

<u>**Angles**</u>	<u>**Axis**</u>	<u>**Scale**</u>		<u>**Mozart**</u>		<u>**Beethoven**</u>		<u>**Strauss**</u>	
		UC	AS	UC	AS	UC	AS	UC	AS
<u>LLS/pelvis angle</u>	*x*	11.2	10.3	5.4	4.9	4.9	4.6	8.7	8.2
	y	5.4	6.0	3.4	3.8	4.8	3.5	6.9	3.9
	z	6.5	4.4	5.0	2.4	2.3	4.2	6.3	3.2
<u>LS/pelvis angle</u>	*x*	9.1	9.9	5.9	5.8	4.2	5.2	9.8	10.6
	y	8.8	8.5	6.2	5.6	7.3	5.8	12.1	6.3
	z	55.2	16.2	57.8	16.1	10.5	23.6	44.0	23.9
<u>ULS/LLS angle</u>	*x*	8.5	5.4	9.1	4.9	4.1	6.6	8.4	7.6
	y	5.0	2.0	5.0	1.0	0.9	1.2	4.7	2.2
	z	0.8	0.5	0.8	0.5	0.5	0.5	1.0	0.6
	x	11.8	12.5	11.7	6.4	7.8	7.3	15.5	9.7

LTS/ULS angle	*y*	8.2	7.0	6.5	8.5	4.3	4.4	10.3	5.4
	z	10.6	7.3	5.8	8.3	6.8	7.8	13.6	11.2
LTS/LS angle	*x*	9.2	10.7	3.2	7.4	7.7	6.6	14.2	8.8
	y	9.6	10.0	6.8	7.7	5.5	7.0	16.2	8.9
	z	18.6	16.2	9.4	16.2	10.2	20.6	46.3	23.6
Pelvis/R Thigh	*x*	3.7	5.2	3.3	9.4	6.5	7.1	4.3	9.6
Pelvis/L Thigh	*x*	3.9	5.5	3.1	7.0	3.7	4.4	3.6	7.2

Legend:
LS: lumbar spine
LLS: lower lumbar spine
ULS: upper lumbar spine
LTS: lower thoracic spine
R: right
L: left
AS: adjustable stool
UC: usual chair

5. Dicussion

5.1. Main findings from the case study

The cellist included in this study has adjusted the chair's height by increasing it of two centimetres. This could appear as being quite small but actually, by comparing different angles around the hip and the spine, it seems that this slight change only could alter both mean angles and range of motion. On both sides, means of hip flexion angles decreased sitting on the adjustable stool while range of motion increased, meaning these joints were more mobile while playing compared to the usual chair. Around the lumbar spine, mean angles showed greater flexion, smaller rotation and lateral bending sitting on the adjustable stool for the angle between pelvis and lower lumbar spine, while all of these angles were quite comparable for the angle between lower and upper lumbar spine. In terms of range of motion, flexion and lateral bending were lower for the angle between lower and upper lumbar spine sitting on the adjustable stool while rotation was lower for the angle between lower lumbar spine and pelvis. Finally, if outcomes for the thoraco-lumbar ranges of motion are very unclear and need further investigation as well as a greater sample size to compare cellists all together, averaged flexion was lower for angles between lower thoracic spine on one hand and both upper lumbar spine and whole lumbar spine while sitting on the adjustable stool. Comparable values were found for lateral bending and rotation. All of these outcomes tend to show that choosing the sitting height while playing the cello could potentially reduce several spine angles (except flexion between lower lumbar spine and pelvis), and particularly lumbar and thoraco-lumbar rotation and lateral bending.

Concerning the perceived exertion, the change was very small (as the cellist estimated it on 12 with the usual chair and 11 with the adjustable stool). Nonetheless, the participant rated quite high the impact of this new sitting height on different performance parameters. This subjective ratings are very important to assess the potential usefulness on conducting this same study with a larger group of cellists.

In addition, another element is worthy of attention: by answering the pre-intervention questionnaire, the cellist who participated in this pilot study mentioned hoping that the orchestra management will provide the whole cellists section some adjustable chairs. However, our participant reported practicing at home on a standard dining chair and not using an adjustable one. Maybe it could be a first individual step for cellists to play their instrument on adjustable chairs at home as well, or at least using cushions.

Finally, surprisingly, the external examiner rated all the excerpts played by the cellist as slightly better on the usual chair compared to the adjustable stool. If this outcome was observed in a larger sample, this difference in terms of performance could be symptomatic of a very slight change in terms of playing habits, which could affect experts' performance. It would then be valuable to add to the global protocol a period of time during which cellists could get accustomed to this new chair's setting.

5.2. Expected findings in a larger sample and comparisons to the existing literature

These outcomes provide us a brief insight of what could be found in a larger sample. Indeed, some significant changes in the spine and hip angles might be observed in all directions, which would definitely show the positive influence of letting cellists choose their own height to play their instrument. Effects of different ergonomic chairs have been investigated in previous studies. Russo et al. (2019) have investigated the potential differences in terms of muscle activation around the lumbar spine (i.e.: erector spinae) between orchestra and ergonomic chairs in upper string players. It appeared from their outcomes that the erector spinae activation was significantly reduced while playing on the ergonomic chair, which could have a positive impact on the muscle fatigue when playing for long hours. Unfortunately, if upper string players and cellists perform similar movements, they play their instrument maintaining very different postures which makes them difficult to compare. Hopper et al. (2017) have investigated using three dimensional analysis both upper limb and torso kinematics in cellists. Considering the spine (and even if the authors focused on the upper part of the spine), they reported an important rotation to the left, as observed in our single participant, and significantly increasing by playing louder in their study (Hopper et al., 2017).

5.3. Future research and perspectives

Playing the cello needs an important body adjustment depending on the individual's anthropometric dimensions. In order to increase our knowledge about the potential effect of modifying the players' sitting height, it could be also interesting to investigate what happens in terms of muscle activation, and for example for the erector spinae (Russo et al., 2019). Moreover, to evaluate the performance itself, it could also be interesting to ask the musicians themselves to rate their own play. Finally, it would also be potentially necessary to let the musicians practicing their instrument with the new chair's height, in order for them to get accustomed to the different posture.

6. Conclusion

This case study showed quite promising outcomes, showing that modifying the chair's height in cellists could potentially be useful for them in order to reduce their spine angles and enhance their performance. Further research should apply this protocol to a larger sample, possibly increasing the number of measured parameters (such as muscle activation).

CHAPTER 5:

PAIN BELIEFS IN ORCHESTRA MUSICIANS

(Paper in review for publication in Medical Problems of Performing Artists)

1. ABSTRACT

Introduction: Playing-related musculoskeletal disorders (PRMDs) are common in orchestra musicians. Many risk factors have been highlighted in the literature as predisposing them to develop such injuries. Among the ones that have been investigated in the general population but not in musicians, pain beliefs are one of the psycho-social elements that show correlations with chronic pain. The aim of this study is to investigate pain beliefs in musicians and possible correlations between these beliefs and PRMDs.

Methods: 107 orchestra musicians from France and the United Kingdom have completed two validated online questionnaires: the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM) and the Pain Beliefs Questionnaire (PBQ).

Results: Correlations have been found between psychological beliefs' score and lifetime pain prevalence ($\rho = -0.210$, $p < 0.05$) as well as with one-month pain prevalence ($\rho = -0.199$, $p < 0.05$). Moreover, there were significant correlations between several answers to the PBQ and pain prevalence as well as between age and organic beliefs.

Discussion: Epidemiological prevalence found in orchestra musicians, as well as affected body locations (mainly spine and shoulders) are quite comparable to percentages found in literature. Correlations between psychological beliefs and pain prevalence indicates that musicians with pain are less aware about the influence of psychological factors' influence on pain. This provides information and a framework for healthcare practitioners to adjust their pain education strategy and provides guidelines to build injury prevention programmes with musicians.

2. INTRODUCTION

Being an elite level musician requires an intense and repetitive training. The increased workload of being a professional musician, combined with several risk factors such as individual characteristics and anthropometrics, instrument and posture, gender or playing conditions (Chan & Ackermann, 2014), can often lead to develop instrument-related disorders or pain, sometimes becoming chronic. Moreover, several psycho-social elements have been highlighted in musicians as being highly predisposing to developing musculoskeletal disorders.

The playing-related musculoskeletal disorders have been defined as "pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to" (Zaza et al., 1998). Even if a representative percentage of pain prevalence among musicians is hard to estimate, a systematic review rated the lifetime pain prevalence in musician between 29 and 90% (Silva et al., 2015). Pain has been defined by the International Association for the Study of Pain (IASP) as “an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage.” (Raja et al., 2020) and classified into three categories: nociceptive, neuropathic and nociplastic (Cohen et al., 2021).

Among psycho-social elements, in the general population, a large range of studies have highlighted how much mistaken pain beliefs could partly explain predisposition of individuals to chronic pain (Grøn et al., 2019; Babadag et al., 2015; Sloan et al., 2018). These authors have highlighted how much pain beliefs were different between healthy individuals or reporting chronic pain as well as between populations and diverse social classes, ethnicities, cultures or jobs (Orhan et al., 2018).

Musicians are known to be a very specific population and the importance of their musculoskeletal health is nowadays appreciated more and investigated in detail. In a recent study, chronic pain has been investigated in German orchestra musicians and 66% of the surveyed musicians reported chronic pain (Gasenzer et al., 2017).

Nevertheless, to the best of our knowledge, there is limited information in the literature about what musicians really know about pain and no study has been conducted to investigate specifically pain beliefs in orchestra musicians. More precisely, understanding pain beliefs in musicians could help healthcare professionals to treat and better educate their patients but could also encourage and motivate music teachers and musicians’ health prevention stakeholders to discuss more about what pain really is and how to potentially alleviate it through pain management education.

The aim of this study was to identify pain beliefs in orchestra musicians and how reporting playing-related musculoskeletal disorders could affect these beliefs.

3. METHODS

3.1. Sample

The sample consisted of 107 self-selected musicians from several orchestras in France and in the United Kingdom (58 females, 49 males), aged 43.8 ± 11.3 years on average.

3.2. Inclusion criteria

Every English or French speaking orchestra musician volunteers that could fill in the questionnaire participated in the study.

3.3. Questionnaire

Two validated questionnaires were used in this study:

- The Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM, Appendix Q) (Berque et al., 2014) has been used to screen playing-related musculoskeletal pain or disorders in the sample, as well as the intensity of pain and the influence on personal and professional life,
- The Pain Beliefs Questionnaire (PBQ, Appendix R) (Edwards et al., 1992) assessed two different types of pain beliefs via two scales: questions 1, 2, 3, 5, 6, 8, 10 and 11 have been developed to investigate organic beliefs (considering biomedical aspect of pain causes and management) whereas questions 4, 7, 9 and 12 evaluate psychological beliefs (considering how much pain can be altered by psychosocial elements) (Alaca et al., 2019).

Both questionnaires were combined and distributed via Online Surveys (JISC, UK). The French version of the PBQ has been used (Demoulin et al., 2016). As no validated translation exists, a non-validated French version of the MPIIQM has been used.

Orchestra musicians have been approached through orchestra contacts, social media, acquaintances, etc. French and English surveys were both made public on 6th February 2020 and stayed open online for 2 months until 6th April 2020. Before filling the questionnaire, all participants were asked to read the Participant Information Sheet (approved by the university ethics committee). Then, the questionnaire included an implied consent.

The amount of time needed to fill both questionnaires was about 7 minutes 53 seconds (± 4 minutes 43 seconds).

3.4. Ethics

The study protocol received ethical approval from the Liverpool John Moores University Ethics Committee (20/SPS/007).

3.5. Statistical analysis

Descriptive statistical analysis was performed using Excel® and inferential statistics analysis using SPSS® (version 25.0.0.1). Data normality has been evaluated with the Shapiro-Wilk test. As the data was not normally distributed, Spearman correlation has been calculated for all inferential analysis. Significance level was set at 0.05.

4. Results

4.1. Epidemiological data

Years of instrumental practice, orchestra work, workload and played hours per week are described in Table 5.1.

Table 5.1: Years of practice and work, type of workload and playing hours in the sample

	Years of practice	Years of orchestra	Workload	Playing hours per week in the orchestra	Playing hours per week (outside the orchestra)
Participants (n=107)	34.5 years (± 10.2)	21.3 years (± 11.6)	Full-time: 76.4% Part-time: 23.6%	22.4 (±7.9)	11.3 (±6.5)

Musicians from various orchestras have responded, with a high number of musicians working at the Royal Liverpool Philharmonic Orchestra (UK, n=20), the City of Birmingham Symphony Orchestra (UK, n=8), the Orchestre Philharmonique de Radio France (France, n=19) and the Orchestre National de France (n=11). Instruments played among the sample are described in Figure 5.1.

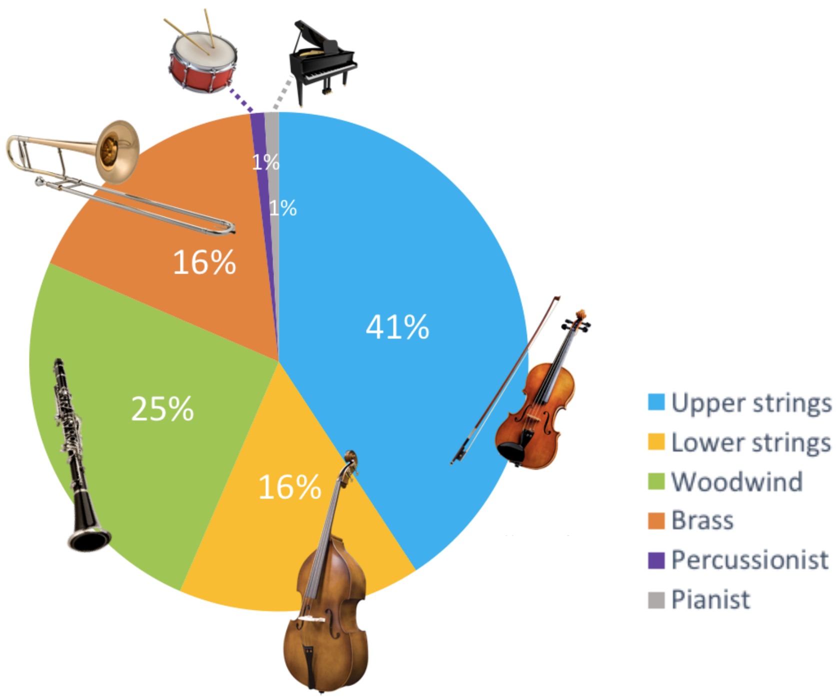


Figure 5.1: Instruments played in the sample

4.2. Playing-related musculoskeletal disorders

Playing-related musculoskeletal disorders have been investigated with the MPIIQM. Among the sample, 77.5% reported having suffered from PRMDs at least once, 53.2% during the last year, 32.7% during the past month and 28% during the past week.
Body locations concerned by pain and problems are described in Figure 5.2.

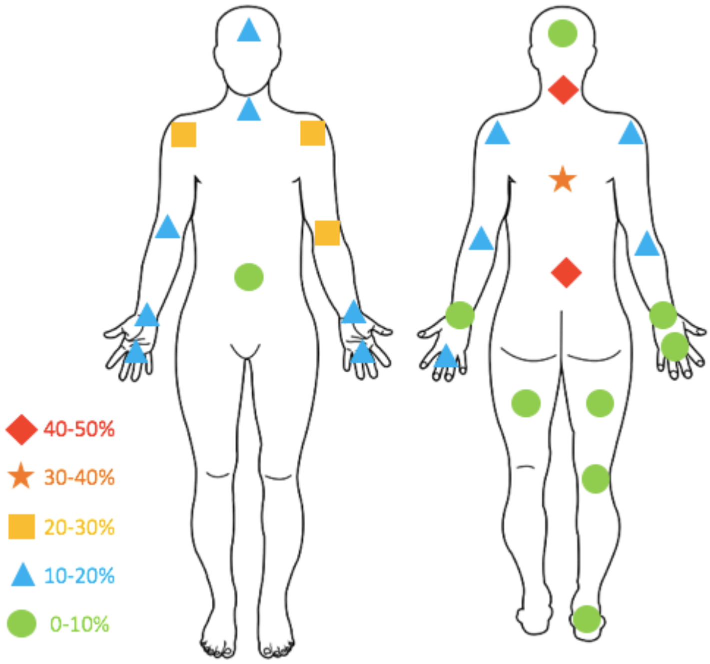


Figure 5.2: Body locations linked to reported pain and problems and frequencies among the sample

Concerning the location that hurts the most, the most often reported were spine (37%), shoulders (26%) and elbows (17%).

Pain intensity has been described in Table 5.2 (Likert Scale 0-10).

Table 5.2: Pain intensity in participants reporting PRMDs in the last month or week

Items	*Maximum*	*Minimum*	*On average*	*Right now*
Pain intensity last week or month	5.8 (±1.7)	2.5 (±2.1)	3.9 (±2.0)	3.1 (±2.2)

Pain interference on daily life and playing their instrument has been described in the Table 5.3 (Likert Scale 0-10).

Table 5.3: Pain interference in participants reporting PRMDs in the last month or week

Topics	*Mood*	*Enjoyment of life*	*Usual technique*	*Playing the instrument*	*Playing as well as wished*
Pain interference last week or month	4.7 (±3.0)	4.7 (±3.1)	3.8 (±2.6)	3.4 (±2.9)	5.1 (±2.9)

4.3. Pain beliefs

The MPIIQM score has been calculated by summing all answers to the questions about PRMDs with 0 for no and 1 for yes. This score is comprised between 0 (meaning that the musician had never experienced any PRMDs during his/her whole life) and 4 (meaning that the musician experienced PRMDs during the last week, and subsequently during the last 4 weeks, 12 months and at least one in his/her life).

Organic and psychological beliefs depending on MPIIQM score are described in Table 5.4.

Table 5.4: Pain scores among the sample depending of their MPIIQM scores

MPIIQM score	0	1	2	3 - 4
Organic beliefs	25.6 (± 7.1)	25.6 (± 6.7)	27.3 (± 7.5)	28.2 (± 5.7)
Psychological beliefs	17.3 (± 4.9)	15.2 (± 4.9)	16.4 (± 5.9)	14.7 (± 4.1)

- Pain beliefs and MPIIQM score

No correlation has been found between MPIIQM score and organic beliefs ($\rho = 0.073$, $p = 0.463$) or psychological beliefs ($\rho = -0.177$, $p = 0.075$). Table 5.5 describes all correlations.

Table 5.5: Correlations between PBQ answers and MPIIQM score

PBQ questions	***MPIIQM score***
1. Pain is the result of damage to the tissues of the body.	$\rho = 0.161$, $p = 0.107$
2. Physical exercise makes pain worse.	$\rho = 0.166$, $p = 0.095$
3. It is impossible to do much for oneself to relieve pain.	$\rho = -0.014$, $p = 0.889$
4. Being anxious makes pain worse.	$\rho = -0.101$, $p = 0.312$
5. Experiencing pain is a sign that something is wrong with the body.	$\rho = 0.143$, $p = 0.151$
6. When relaxed pain is easier to cope with.	$\rho = -0.040$, $p = 0.483$
7. Being in pain prevents you from enjoying hobbies and social activities.	$\rho = -0.069$, $p = 0.491$
8. The amount of pain is related to the amount of damage.	$\rho = 0.007$, $p = 0.945$
9. Thinking about pain makes it worse.**	$\rho = -0.285$, $p < 0.01$
10. It is impossible to control pain on your own.	$\rho = 0.091$, $p = 0.365$
11. Pain is a sign of illness.	$\rho = -0.002$, $p = 0.981$
12. Feeling depressed makes pain seem worse.	$\rho = -0.190$, $p = 0.056$

**significant correlation $p < 0.01$

- Pain beliefs and time prevalence

Correlations have been calculated between organic and psychological scores as well as participants' answers with pain time prevalence.

No correlation has been found between the lifetime PRMDs prevalence and the organic beliefs (ρ = 0.041, p = 0.684) but a significant correlation has been found with the psychological beliefs (ρ = -0.210, $p < 0.05$). No correlation has been found between one-year PRMDs prevalence and organic beliefs (ρ = 0.101, p = 0.312) or psychological beliefs (ρ = -0.072, p = 0.469). No correlation has been found between the one-month PRMDs prevalence and the organic beliefs (ρ = 0.003, p = 0.980) but a significant correlation has been found with the psychological beliefs (ρ = -0.199, $p < 0.05$). No correlation has been found between the one-week PRMDs prevalence score and organic beliefs (ρ = 0.056, p = 0.580) or psychological beliefs (ρ = -0.135, p = 0.184). Table 5.6 describes all correlations.

Table 5.6: Correlations between PBQ answers and time prevalence

PBQ questions	Lifetime prevalence	Past 12 months' prevalence	Past 4 weeks prevalence	Past 7 days' prevalence
1. Pain is the result of damage to the tissues of the body.	ρ = 0.177, p = 0.075	ρ = -0.263, p < 0.01**	ρ = -0.004, p = 0.965	ρ = -0.013, p = 0.900
2. Physical exercise makes pain worse.	ρ = 0.085, p = 0.394	ρ = 0.089, p = 0.374	ρ = 0.184, p = 0.064	ρ = 0.240, p < 0.05*
3. It is impossible to do much for oneself to relieve pain.	ρ = -0.020, p = 0.843	ρ = 0.006, p = 0.953	ρ = -0.026, p = 0.793	ρ = -0.003, p = 0.994
4. Being anxious makes pain worse.	ρ = -0.031, p = 0.756	ρ = -0.020, p = 0.840	ρ = -0.183, p = 0.065	ρ = -0.146, p = 0.150
5. Experiencing pain is a sign that something is wrong with the body.	ρ = 0.213, p < 0.05*	ρ = 0.245, p < 0.05*	ρ = -0.037, p = 0.713	ρ = -0.057, p = 0.567
6. When relaxed pain is easier to cope with.	ρ = -0.064, p = 0.521	ρ = -0.036, p = 0.722	ρ = -0.055, p = 0.586	ρ = -0.091, p = 0.372
7. Being in pain prevents you from enjoying hobbies and social activities.	ρ = -0.157, p = 0.114	ρ = -0.014, p = 0.888	ρ = -0.049, p = 0.622	ρ = -0.021, p = 0.837
8. The amount of pain is related to the amount of damage.	ρ = -0.050, p = 0.618	ρ = 0.062, p = 0.533	ρ = -0.020, p = 0.843	ρ = 0.021, p = 0.834
9. Thinking about pain makes it worse.	ρ = -0.254, p < 0.05*	ρ = -0.192, p = 0.053	ρ = -0.275, p < 0.01**	ρ = -0.236, p < 0.05*
10. It is impossible to control pain on your own.	ρ = 0.041, p = 0.684	ρ = -0.025, p = 0.802	ρ = 0.148, p = 0.138	ρ = 0.184, p = 0.068
11. Pain is a sign of illness.	ρ = -0.087, p = 0.386	ρ = -0.087, p = 0.448	ρ = 0.093, p = 0.354	ρ = 0.116, p = 0.251
12. Feeling depressed makes pain seem worse.	ρ = -0.197, p < 0.05*	ρ = -0.133, p = 0.183	ρ = -0.164, p = 0.099	ρ = -0.120, p = 0.237

*significant correlation $p < 0.05$
**significant correlation $p < 0.01$

- Pain intensity, interference and beliefs

No significant correlation has been found between pain intensity (maximum, minimum, etc.), interference (on playing technique, on mood, on enjoyment of life, etc.) and psychological or organic beliefs.

- Age, gender, MPIIQM score and pain beliefs

Gender shows no correlation with organic ($\rho = 0.053$, $p = 0.596$) or psychological beliefs ($\rho = -0.082$, $p = 0.414$). Concerning age, no correlation has been found with psychological beliefs ($\rho = 0.045$, $p = 0.653$) but a significant correlation has been observed with organic beliefs ($\rho = 0.224$, $p < 0.05$).

Among the 12 questions from the PBQ, only three correlations have been found:

- Between question 8 ("The amount of pain is related to the amount of damage.") and age ($\rho = 0.288$, $p < 0.01$);
- Between question 8 ("The amount of pain is related to the amount of damage.") and being a male ($\rho = 0.242$, $p < 0.05$);
- Between question 10 ("It is impossible to control pain on your own.") and being a male ($\rho = 0.203$ $p < 0.05$).

5. DISCUSSION

5.1. Playing-related musculoskeletal disorders

Among the musicians' sample, we observed a lifetime pain prevalence of 77.5%. This outcome is quite close to percentage often found in literature (around 80%, depending on the investigated instruments and population) (Silva et al., 2015; Ackermann et al., 2012; Abeu-Ramos et al., 2007). In terms of point-prevalence (four weeks or seven days), percentage around 30% has been calculated in the sample. These percentages are also quite comparable with the literature about musicians' health (around 35%) (Silva et al., 2015). In our sample, the main affected body locations are the spine and the shoulders, which is as well in accordance with painful body areas reported in several studies (Silva et al., 2015; Ackermann et al., 2012).

5.2. Pain beliefs

The Pain Beliefs Questionnaire (PBQ) assesses two different types of pain beliefs: organic beliefs and psychological beliefs (Alaca et al., 2019; Edwards et al., 1992). Organic beliefs about pain consider the biomedical aspects of pain, both its causes and management (Baird & Haslam, 2013). In the PBQ, questions about organic beliefs focus on concepts of body damage and illness (Sloan et al., 2008). Psychological pain beliefs explain how much pain could be altered by depression, anxiety, relaxation or attention to pain (Baird & Haslam, 2013).

In musicians who have never reported PRMDs, organic pain beliefs score (25,6) is quite comparable to scores that could be found in pain free population in the literature (26,5) (Baird & Haslam, 2013). On the contrary, in terms of psychological beliefs, the score calculated in pain free musicians (17.2) is higher than the score observed in a non-clinical sample of 3000 individuals (14.6) (Baird & Haslam, 2013). In the present study, psychological beliefs score in musicians reporting pain is about 14.7, very close to the score observed in pain free participants in the literature (Baird & Haslam, 2013). This shows that musicians seem to be more aware about the impact of depression, stress or anxiety on pain intensity and management than the general population. In terms of organic beliefs in participants reporting PRMDs, the score (28.2 in our sample) is quite comparable to what can be found in chronic pain participants (29.4) (Baird & Haslam, 2013), indicating that orchestra musicians with PRMDs have high beliefs about organic causes of pain.

Pain beliefs have often been investigated in patients with chronic pain and especially with low back pain. It has been observed that patients with chronic low back pain had higher scores in terms of organic beliefs than pain-free participants (Sloan et al., 2008). These organic beliefs were associated with higher catastrophising as well (people thinking irrationally that the situation or pain is much worse than it actually is). In this study, psychological beliefs were not influenced by the presence of chronic pain. Other studies show a significant relationship between organic beliefs and pain (Tocpu, 2018; Walsh & Radcliffe, 2001). On the contrary, in our sample, it appears that only psychological beliefs are affected by PRMDs. Significant correlations have been found between psychological beliefs scores and having suffered from PRMDs once in life or during the past month.

Concerning age, some studies observed no difference in terms of pain beliefs (Gagliese & Melzack, 1997) whereas some highlighted a slightly higher organic beliefs score in patients older than 65 years (experiencing pain associated with cancer) (Ruzicka et al., 2007). In our sample, significant correlations have been observed between age and organic beliefs. It seems that older musicians may particularly think that pain is caused by harming or injuring the body and less take into account psychological factors that could influence pain. This provides information to healthcare professionals about how much they have to modulate their discourse with their patients according to their age.

In terms of gender, in literature females may have more organic beliefs than males (Gül & Erel, 2018) but in our sample, as in other studies, no significant correlation has been highlighted between types of pain beliefs and gender (Babadağ et al., 2017).

Correlations between MPIIQM scores and answers have been calculated in our study. Some significant relationships between pain and type of answers have been found for:

- question 1: "Pain is the result of damage to the tissues of the body",
- question 2: "Physical exercise makes pain worse",
- question 5: "Experiencing pain is a sign that something is wrong with the body",
- question 9: "Thinking about pain makes it worse",
- question 12: "Feeling depressed makes pain seem worse".

These outcomes provide information about what musicians think about pain, how to manage it and how much it is affected by some mental state changes. This gives guidelines for healthcare professionals to educate their patients and explain them properly what pain is and is not. This provides also topics to integrate in prevention programme courses for musicians, professionals, teachers and students (Hildebrandt & Nübling, 2004).

5.3. Strengths of the study

To the best of our knowledge, although this topic has been investigated in general population and patients with chronic pain, pain beliefs have never been studied in musicians. This study provides more information about some psycho-social elements that could interfere with musicians' health. A validated French translation has been used for the Pain Beliefs Questionnaire, which increases the methodological strength of the study. The sample was quite large and representative of orchestra musicians. Moreover, this study was multi-centre and led on two different countries.

5.4. Limitations of the study

This study focused only on pain beliefs as psycho-social elements that could interfere and show relationships with pain, without taking into account any other factors such as depression, anxiety or pain catastrophizing. This should be investigated in the future to draw a comprehensive understanding about musicians' psychological health and well-being. Moreover, this study has not investigated specific beliefs of musicians such as: resting for few days when it hurts while playing, changing the posture, taking more breaks, training more, etc.

Moreover, a non-validated translation of the MPIIQM has been used, which is part of the study's limitations.

5.5. Perspectives

Future studies should investigate more psycho-social factors such as depression, anxiety, stress, catastrophizing and fear-avoidance. Building relationships between playing-related musculoskeletal disorders, pain beliefs and several other psycho-social factors could help to understand better musicians' health and improve injury prevention. More specific questions should also be developed, taking into account several pain beliefs musicians could have in relation to their instrumental practice and workload. This should also take into account several musical types, as this study focused on orchestra classical musicians only.

Finally, as this has been done in the general population but not specifically in our specific domain of study, further studies should also consider investigating chronic pain by considering the different types of pain, and more precisely nociplastic pain and the complexity of central sensitisation in musicians reporting chronic pain (Cohen et al., 2021).

6. CONCLUSION

Pain beliefs have been investigated in patients with chronic pain and compared with the pain-free population but not in musicians. This study highlighted that psychological beliefs were significantly correlated to presence of PRMDs (with lower scores in painful musicians) and organic beliefs show no relationship. This provides novel and useful information about pain beliefs in musicians but also suggests guidelines for healthcare practitioners or future prevention courses that should integrate learning about pain and knowledge from the field of neurosciences.

CHAPTER 6:

COVID-19, IMPACT OF RETURN-TO-WORK ON ORCHESTRA MUSICIANS' MENTAL AND PHYSICAL HEALTH AFTER FIRST LOCKDOWN

1. Abstract

Introduction: Covid-19 has impacted in an extensive way all our usual life activities. Performing arts were and remain still the most affected sector by this unprecedented disruption. During the “first lockdown”, between March and May 2021, orchestra musicians have stopped all their work activities, which had an influence on both their instrumental practice and daily life. This study aims to investigate how the return-to-work, after first lockdown, has impacted both the physical and psychological health of orchestra musicians.

Methods: A large questionnaire, mainly composed of existing and validated ones, has been sent to French orchestra musicians. Questions were about musculoskeletal disorders, psycho-social elements, sleep quality, physical activity, etc.

Results: Decrease in playing hours could partly explain the low percentage of musculoskeletal disorders among our sample, as well as higher physical activity levels and less anxiety after return-to-work. It seems from answer to open questions that musicians were pleased and not anxious to return to work, despite strong social restrictions as well as an altered work organisation.

Discussion: This study provides important information about personal instrumental practice in orchestra musicians during the first lockdown, and this should be taken into account to organise their return-to-work effectively and safely and help prevent injuries. Further investigation is needed in other musicians because the conditions of their return to play are different compared to orchestra musicians.

2. Introduction

The Covid-19 pandemic impacts immensely on our lives, considering the major disruptions of our social activities, particularly by shutting down public life and cancelling events of many types (concerts, sport, theatre, etc.) (Garcia et al., 2020). Despite existing preventative measures, such as facemask-wearing or physical distancing implemented, musical activities experience difficulties to restart. After having faced the emergence of streaming, music industry has now been seriously damaged by coronavirus, losing about 43% of its sales revenue (Tous pour la Musique, 2020).

In musicians, apart from being infected by Covid-19, risks on their health due to this unprecedented situation are multiple. Playing-related musculoskeletal disorders have been defined as “pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to" (Zaza et al., 1998). Several risk factors have been described to predispose musicians to PRMDs and among them, number of playing hours (Baadjou et al., 2016), anxiety and depression (Kenny & Ackermann, 2015), and sudden instrumental practice overload[6]. Indeed, Kok et al. (2016) have investigated the impact of a sudden increase in playing hours on musculoskeletal health among high-level amateur musicians during a summer camp and found a point-prevalence of 20% of musculoskeletal complaints, that increased to 80% after one week of intense playing.

Due to Covid-19, most of the world countries have decided to quarantine their population. By investigating the impact of disruptions in lives and work in China on working adults, Zhang et al. (2020) highlighted the existence of three different groups: people who are still working at the office, working from home or those have stopped working due to the situation. Among these groups, those who were not working anymore showed worse mental and physical health. Orchestra musicians cannot be classified in any of these categories: they still can practice their instrument, but they cannot properly "work" with their colleagues, i.e. playing in rehearsal or performing in concerts, even without any audience.

Finally, even if events have begun to restart, the music industry has experienced huge financial loss and musicians are currently facing uncertainties about their future and among them, job insecurity and anxiety (Brunt & Nelligan, 2020), which have been highlighted to be risk factors to develop PRMDs (Vervainioti & Alexopoulos, 2015), in addition to the impact of being forced to stop playing with others and feeling disconnected from their group (McCready, 2007). It is therefore important to understand the specific impact of the lockdown and the disruption from work, practice and performing on the health and well-being of musicians.

The aims of this exploratory study are to investigate the effects of the Covid-19 lockdown and then the progressive return-to-work on orchestra musicians' health, both physical and mental.

3. Methods

3.1. Sample

The samples consisted of musicians that volunteered to participate from several orchestras in France who were contacted:

- Firstly, about two weeks before their return-to-work (RTW), at T1, 84 musicians (ST1): 35 females, 48 males, one other, aged on average 41.5 ± 11,3;
- Then, about two weeks after their RTW, at T2, 51 musicians (ST2): 23 females, 27 males, one other, aged on average 45.2 ± 11.7.

As all musicians were contacted by emailing their management teams, the sample at T2 is not only constituted from musicians out of the sample at T1: 16 musicians have filled both questionnaires (see Figure 1). Participants at T1 (S16-T1) and T2 (S16-T2) were 16 self-selected musicians (6 females, 10 males) aged 45.2 (±11.0) years at T1.

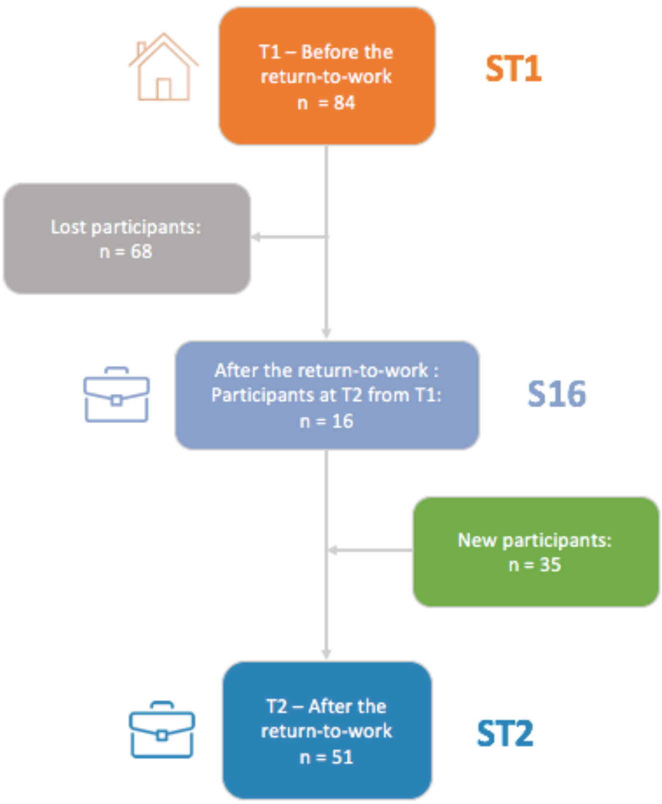


Figure 6.1: Flowchart of participants at each questionnaire session

3.2. Inclusion criteria

The inclusion criteria were:

- To be professional orchestra musician
- To have been in isolation because of the Covid-19
- To be part of an orchestra which plans to get back to work as soon as the physical distancing measures relax.

3.3. Protocol

Orchestras musicians were asked to fill two different online questionnaires: the first one two weeks before their RTW (i.e. first day at the orchestra with other musicians) and the second one after the first two weeks of getting back to work. Reminders have been sent one week after the first mailing for each questionnaire (see Figure 6.2).

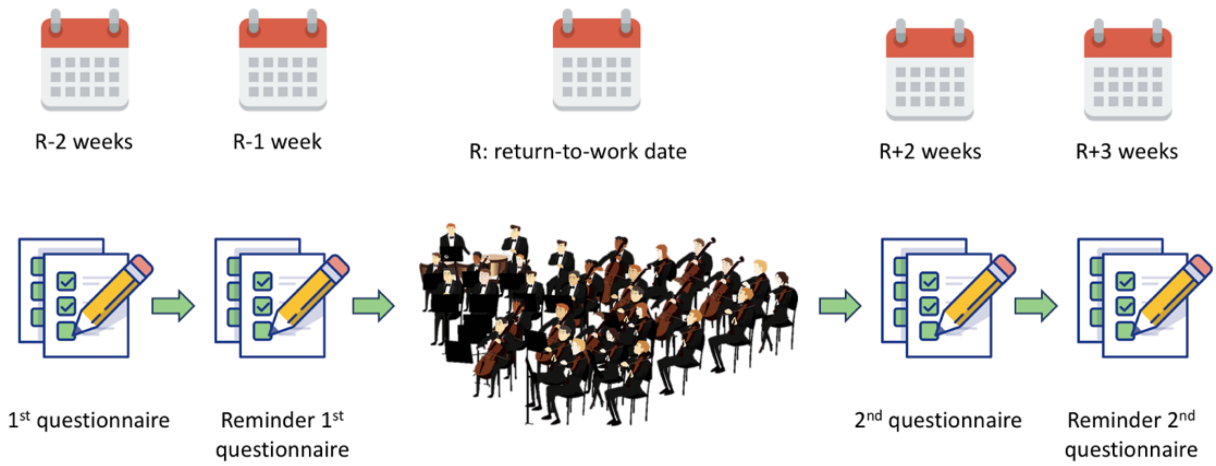


Figure 6.2: Questionnaire mailing timings in relation to RTW

The first questionnaire comprised:

1. A non-validated French translation of the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM) (Berque et al., 2014) to assess their musculoskeletal health;
2. The validated French translation of the Hospital Anxiety and Depression Scale (HADS) to assess their mental health (Zigmond & Snaith, 1983; Bocéréan & Dupret, 2014);
3. The validated French translation of the State-Trait Anxiety Inventory (STAI) (Spielberger, 1983; Gauthier & Bouchard, 1993);
4. The validated French translation of the Social Phobia Inventory (SPIN) to assess their relationship to others (Connor et al., 2000; Radomsky et al., 2006);
5. Few questions from the validated French translation of the Pittsburgh Sleep Quality Index (PSQI) to assess their sleep quantity and quality (Buysse et al., 1989; Blais et al., 1997);
6. Few questions from the validated French translation of the Global Physical Activity Questionnaire (GPAQ) to assess their physical activity (Armstrong & Bull, 2006; Rivière et al., 2018);
7. Few questions about how they organised their daily life during the lockdown, how they felt the isolation from others, family, friends and colleagues, how they found way to make music together, etc.

1. How have you organised your daily life during the lockdown?
2. Did your weight change during the lockdown?
3. Have you been staying at home with family during the lockdown? How many were you in your house? Did you have the possibility to isolate yourself to work or was it difficult?
4. Have you been staying in a place with green spaces, a garden, etc. during the lockdown?
5. Did you feel the isolation from others, family, friends and colleagues was difficult? (-5 to 5 Likert Scale)
6. Generally speaking, was the lockdown period a pleasant period for you or not?
7. Have you performed any new activities you have always wished to do before during the lockdown?
8. Have you found opportunities to play music together with colleagues or friends?
9. Have you changed your usual way to play your instrument (in terms of private practice)?
10. Have you trained yourself on music aspects different from playing your instrument (such as composing, listening more music, discovering new styles, etc.)?

The second questionnaire comprised:

1. The MPIIQM
2. The HADS
3. The STAI
4. The SPIN
5. Few questions from the PSQI
6. Few questions from the GPAQ
7. Few questions about their RTW, how they experienced it, how it has been managed by their orchestral team, how they managed themselves, their workload, etc.

1. How was your return-to-work organised by your management team:
   – in terms of repertoire?
   – in terms of playing hours?
2. Has return-to-work been difficult psychologically for you?
3. Are you satisfied with being back at work?
4. Have this situation and disruption raised questions about your professional future or any idea of professional retraining? If yes, what kind?
5. Have you been worried about catching the virus by returning to work? (Likert)
6. Has the disruption changed your consideration about your colleagues or about administration or artistic authority?
7. Has the disruption changed your consideration about the repertoire you've been asked to play?
8. Does the return-to-work create a feeling of time shortage in your life to do several other things?
9. Has the situation and disruption changed your perception about your way of life?
10. Has the situation and disruption changed your perception about the society?

3.4. Ethics

The study protocol received ethical approval from the Liverpool John Moores University Research Ethics Committee (20/SPS/025).

3.5. Statistical analysis

Descriptive analysis was performed using Excel® on both large samples at T1 (n=84) and T2 (n=51) as these samples could not be compared due to the studied situation in between.

On the 16 participants who have filled questionnaires at both times, descriptive and inferential statistics analysis was performed using Excel® and SPSS®. Data normality was evaluated with the Kolmogorov-Smirnov tests and as data were not confirmed as normally distributed, Wilcoxon test were used to compare the sample of 16 participants at both times. Degree of significance was set at 0.05.

4. Results

To facilitate the outcomes' reading, samples have been labelled:

- Sample at T1, n=84 (ST1)
- Sample at T1, n=16 (S16-T1)
- Sample at T2, n=51 (ST2)
- Sample at T2, n=16 (S16-T2).

Moreover, due to the amount of collected data, outcomes from the very last questions about musicians' experience of both lockdown and RTW will not be discussed here.

4.1. Epidemiological data

Years of overall instrumental practice, orchestra practice and workload per week are described in Table 6.1.

Table 6.1: Years of practice and work, type of workload

	Years of practice	Years of orchestra work	Workload
ST1	33.6 years (±10.5)	19.9 years (±11.5)	Full-time: 86% Part-time: 14%
ST2	36.7 years (±12.0)	22.5 years (±12.0)	Full-time: 90% Part-time: 10%
S16	37.8 years (±10.2)	24.3 years (±11.8)	Full-time: 75% Part-time: 25%

Playing hours have been described in Table 6.2.

Table 6.2: Playing hours across all samples and at both times

	T1					T2		
	Playing hours per week in the orchestra before the Covid-19	Playing hours per week (outside the orchestra) before the Covid-19	Playing hours per week (outside the orchestra) during the lockdown	**Total** of playing hours per week before the Covid-19	**Total** of playing hours per week during the lockdown and before the RTW	Playing hours per week in the orchestra after their RTW	Playing hours per week (outside the orchestra) after their RTW	**Total** of playing hours per week after the return-to-work
ST1 and ST2	17.6 (±5.1)	12.1 (±6.0)	10.4 (±6.6)	28.8 (±8.6)	10.4 (±6.6)	11.4 (±7.9) (ST2)	7.6 (±6.0) (ST2)	18.7 (±10.3)
S16	19.3 (±3.9)	11.4 (±5.1)	8.8 (±6.9)	30.6 (±3.1)	8.8 (±6.9)	13.3 (±6.9)	7.0 (±6.5)	20.3 (±9.8)

In samples S16-T1 and S16-T2, difference in terms of playing hours per week have been investigated between:

- Total of playing hours before the Covid-19 and after the RTW: Z=-2.638, p<0.01
- Total of playing hours before the Covid-19 and before the RTW: Z=-3.184, p<0.01
- Total of playing hours before and after the RTW: Z=-3.180, p<0.01
- Orchestra playing hours before the Covid-19 and after the RTW: Z=-2.447, p<0.05
- Private practice playing hours before the lockdown and before the RTW: Z=-0.834, p=0.350
- Private practice playing hours before and after the RTW: Z=-1.067, p=0.286.

Instruments played in samples were described in Figure 6.3.

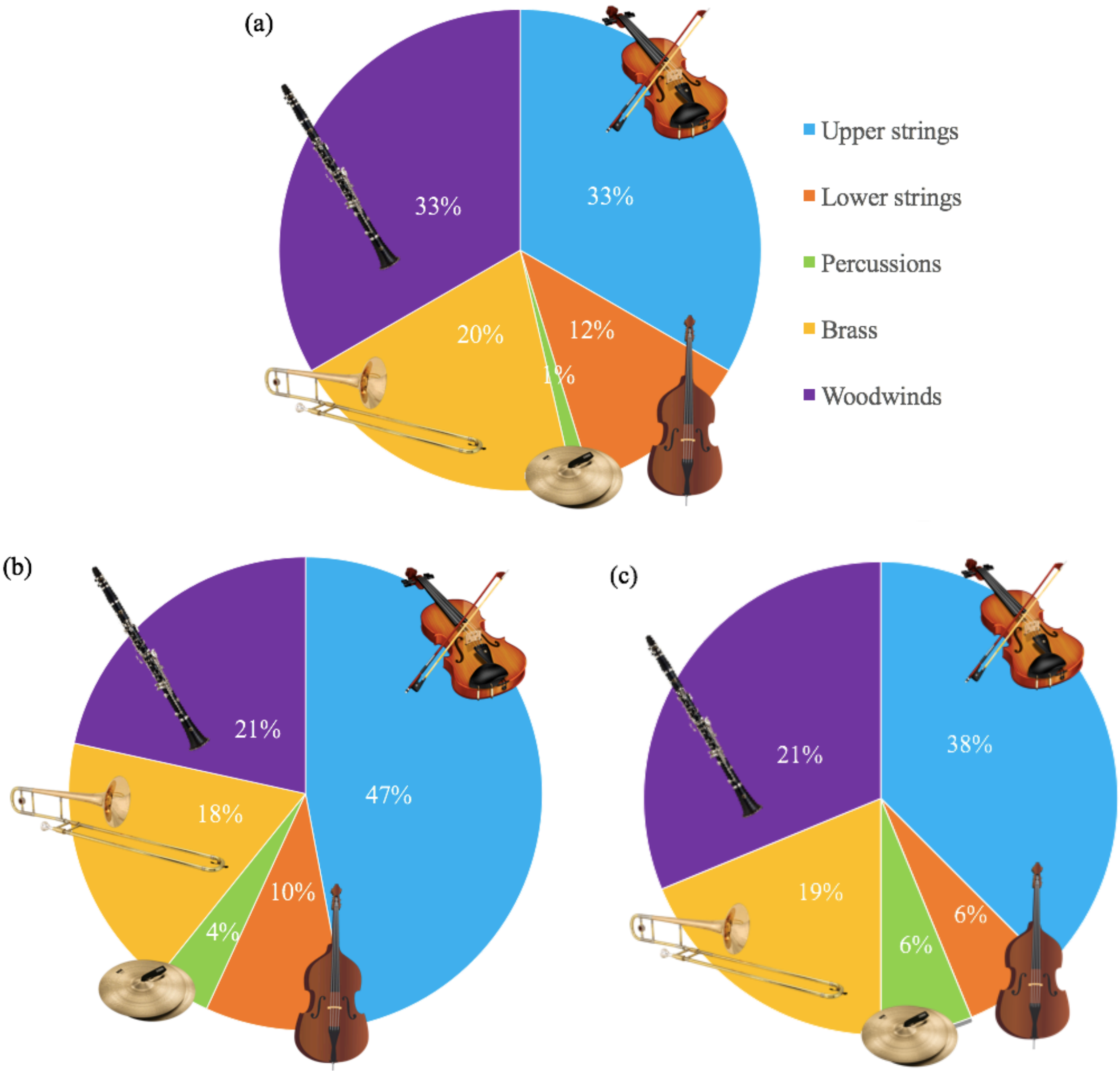


Figure 6.3: Instruments played in the samples: ST1 (a), ST2 (b) and S16 (c)

4.2. Playing-related musculoskeletal disorders

Playing-related musculoskeletal disorders have been investigated with the MPIIQM. Table 6.3 below described pain prevalence among all samples.

Table 6.3: Pain prevalence

Items	*Lifetime*	*1-year*	*4-weeks*	*7-days*
ST1	67%	45%	25%	17%
S16-T1	63%	19%	19%	19%
ST2	60%	37%	16%	16%
S16-T2	63%	19%	19%	19%

Across all samples and at both times, the most frequently reported painful locations were: both shoulders, neck, upper thoracic spine and left elbow. Because of the little number of participants reporting pain in the past 4 weeks of 7 days across both samples, pain intensity and interference (part of the MPIIQM) have not been further discussed here.

4.3. Mental health

Hospital Anxiety and Depression Survey

HADS scores have been described in Table 6.4.

Table 6.4: HADS scores across all samples

		Anxiety				Depression			
		Female	Male	Other	Total	Female	Male	Other	Total
ST1	Normal (≤7)	24	33	1	58	28	40	1	69
	Subtle (8-10)	7	7	0	14	5	4	0	9
	Abnormal (≥12)	4	8	0	12	2	4	0	6
S16-T1	Normal (≤7)	4	8		12	5	8		13
	Subtle (8-10)	2	2		4	1	2		3
	Abnormal (≥12)	0	0		0	0	0		0
ST2	Normal (≤7)	16	21	0	37	23	25	0	48
	Subtle (8-10)	4	4	1	9	0	2	0	2
	Abnormal (≥12)	3	2	0	5	0	0	1	1
S16-T2	Normal (≤7)	3	9		12	6	9		15
	Subtle (8-10)	3	1		4	0	1		1
	Abnormal (≥12)	0	0		0	0	0		0

In S16, no significant difference has been found between T1 and T2:

- for anxiety (Z=-0.225, p=0.822) and depression (Z=-1.611, p=0.107) in the whole sample,
- for anxiety (Z=0.000, p=1.000) and depression (Z=-1.160, p=0.246) in females,
- for anxiety (Z=-0.426, p=0.670) and depression (Z=-1.266, p=0.205) in males.

State-Trait Anxiety Inventory

STAI scores have been described across all samples, higher scores revealing greater anxiety.

Table 6.5: STAI scores across all samples

	Female	**Male**	**Other**	**Global average**
ST1	41,4 (±13.1)	39.4 (±9.6)	37 (0)	40.2 (±11.2)
ST2	40.2 (±11.6)	36.9 (±10.0)	53 (0)	38.7 (±10.9)
S16-T1	45.8 (±11.8)	34.0 (±8.0)		38.4 (±10.9)
S16-T2	40.7 (±10.6)	32.3 (±9.1)		35.4 (±10.2)

In S16, significant differences have been found among the whole sample (Z=-2.677, p<0.01) and in females (Z=-2.207, p<0.05) but not in males (Z=-1.479, p=0.139).

Social Phobia Inventory

SPIN scores have been described among both samples in the Table 6.6, understanding that a total score above 19 indicated an increased likelihood of social anxiety disorder.

Table 6.6: SPIN scores across all samples

	Female		**Male**		**Other**	
	< 20	≥ 20	< 20	≥ 20	< 20	≥ 20
ST1	24 (29%)	11(13%)	39 (46%)	9 (11%)	1 (1%)	0
ST2	15 (29%)	8 (16%)	22 (43%)	5 (10%)	0	1 (2%)
S16-T1	2	4	7	1		
S16-T2	2	4	7	1		

In S16, no significant difference between T1 and T2 has been found among the whole sample (Z=-0.070, p=0.944), in females (Z=0, p=1) and in males (Z=-0.171, p=0.864).

4.4. Life habits

Global Physical Activity Questionnaire

At T1, 45% of ST1 and 50% of S16 answered yes to the question “Have you increased your physical activity during lockdown”. Table 6.7 summarises physical activity across all samples.

Table 6.7: Physical activity per week across all samples

	Vigorous physical activity		Moderate physical activity	
	Participants (%)	Minutes/week	Participants (%)	Minutes/week
ST1	53%	198 min (±144)	75%	192 min (±162)
S16-T1	38%	144 min (±81)	56%	117 min (±91)
ST2	45%	198 min (±120)	80%	210 min (±132)
S16-T2	44%	189 min (±142)	73%	158 min (±121)

In S16, differences between T1 and T2 were not significant:

- for vigorous activity in terms of participants’ percentage (Z=-1.414, p=0.157) and activity duration (Z=-1.214, p=0.225).
- for moderate activity in terms of participants’ percentage (Z=-1.000, p=0.317) and activity duration (Z=-1.473, p=0.141).

Pittsburgh Sleep Quality Index

Table 6.8 describes sleep quality and hours of sleeping across all samples at both times.

Table 6.8: Physical activity per week across all samples

	Hours of sleep	Sleep quality*
ST1	7 hours and 24 min (± 1 hour)	3.0 (±0.8)
S16-T1	7 hours and 41 min (± 1 hour and 6 min)	3.0 (±0.8)
ST2	7 hours and 24 min (± 1 hours and 4 min)	2.9 (±0.7)
S16-T2	7 hours and 41 min (± 1 hours and 11 min)	3.0 (±0.6)

*evaluated from "very bad" (1) to "very good" (4)

In S16, no significant difference between T1 and T2 has been found for hours of sleep (Z=-0.365, p=0.715) and sleep quality (Z=-0.707, p=0.480).

Bedtime, alarm time and time before sleeping were described in Table 6.9.

Table 6.9: PSQI – Bedtime, alarm time and time before sleeping across all samples

	Bedtime			Alarm time				Time before sleeping			
	8–10pm	10pm–12am	> 12am	5–7am	7–9am	9–11am	> 11 am	< 15min	15–30min	30-60min	> 60 min
ST1	0	37	47	8	55	20	1	35	19	9	11
S16-T1	0	11	5	2	12	2	0	6	6	3	2
ST2	1	31	19	7	36	7	1	19	18	5	9
S16-T2	0	14	2	2	13	1	0	7	6	1	2

4.5. Answers to open questions

Before return-to-work

About their life organisation, musicians mentioned mainly their instrumental practice or their remote lessons (44/84), the importance of taking care of their children (26/84), the practice of a regular physical activity (19/84). Five participants have mentioned their difficulty to find a rhythm.

Weight modifications were on average about 0.44 (±2.34) kg, ranging from -6 to +6 kg. Participants have rated the difficulty of being socially isolated at 0.1 (±3.1) ranging from -5 (very difficult) to 5 (not difficult at all).

Among the sample:

- 51 (on 84 answers) had the possibility to withdraw from people they lived with,
- 67 (on 84) had access to green spaces,
- 41 (on 84) have felt the lockdown as a pleasant period (while 24 reported it as an unpleasant period, 11 having more neutral opinion about it),
- 58 (on 84) have used their lockdown time to discover new activities.

Concerning their musical practice:

- 44 (on 84) found a way to play music with family, colleagues or friends
- 39 (on 83) have changed their life habits
- 39 (on 84) have reported learning other aspects from their musical work.

After return-to-work

For 39 participants (among 49 answers), RTW has not been psychologically difficult (and among them, 3 mentioned the joy they had to be back at work) whether it has been difficult for 2 participants and a little for two others. Four participants have mentioned it was stressful and 2 an awkward situation. In terms of worry regarding catching the virus by being back at work, outcomes showed an average of 1.9 ± 2.5 (minimum: 0, maximum: 9) on a 11-point Likert scale (from 0 to 10).

Among the sample:

- 45 (on 50 answers) were satisfied to be back at work,
- 6 (on 45) reported that the disruption raised question about their professional future,
- 7 (on 50) reported it changed their consideration about their colleagues or administration and 3 (on 50) about the repertoire they play,
- 10 (on 50) felt they were lacking of time after their RTW, 2 felt this "a little" as well.

In a more holistic view, the situation changed the perception they had of their way of life for 29 participants (yes: 20, a little: 9, on 50 answers) and the one they had about society for 25 participants (yes: 18, a little: 7, on 50 answers).

Finally, answers about the organisation of their RTW haven't been analysed because of a too large variety concerning the type of answers, from personal feeling to number of played hours.

5. Discussion

5.1. Playing-related musculoskeletal disorders

In terms of lifetime pain prevalence, it seems that outcomes obtained with the large sample at T1 (67%) are more comparable with literature than observed percentages at T2 (60%) or on the common sample of musicians between T1 and T2 (63%). Indeed, depending on the investigated samples, a percentage of 80% PRMDs lifetime prevalence is often found (Silva et al., 2015; Ackermann et al., 2012; Abréu-Ramos & Micheo, 2007). Similarly, one-year point prevalence at T1 (45%) and T2 (37%) are slightly below what is commonly found in epidemiological studies (from 47% in cellists and woodwinds to 80% in 1st violinists) (Sousa et al., 2017; Kaneko et al., 2005) while in the multi-instrumentalist sample S16, only 19% have reported PRMDs during the past

year. This is much lower than the usual observed percentages and makes them difficult to compare with literature across other topics as well.
Moreover, in terms of shorter periods of recall, that is to say four weeks and seven days as it is described in the MPIIQM (Berque et al., 2014), percentages are again lower than what is expected in literature. During the last month, 25% of the sample at T1, 16% at T2 and 19% among the S16 report PRMDs and only 17% at T1, 16% at T2 and again 19% among the S16 currently (i.e. in the past 7 days). Again, this is quite different to what is commonly found in the literature for musicians (students and professionals) or what we found in past studies with orchestra musicians (unpublished work), that is to say around 30% (Silva et al., 2015; Ballenberger et al., 2018). What we suggest to partly explain these observations is related to the difference in terms of playing hours. As musicians have considerably decreased their private practice, it seems understandable that their point-prevalence at 7 days and 1 month are very different from what is commonly discussed in literature "in normal circumstances".
Finally, at both times T1 and T2, our samples have reported that the main affected body locations by PRMDs were spine, shoulders and elbows, which is comparable with the described painful areas in several epidemiological studies (Silva et al., 2015; Ackermann et al., 2012; Abréu-Ramos & Micheo, 2007).

5.2. Workload

Adding "before the Covid-19", "during the lockdown and before your return-to-work" or "after your return-to-work" to the initial MPIIQM questions gave us important information regarding the orchestra musician's workload. We observed that musicians after being back to work had not recovered their usual routine regarding instrumental practice in terms of playing hours, whether it is at the orchestra or on their own. Moreover, by comparing means in the sample S16, we highlighted significant differences in terms of playing hours in total before the Covid-19 and before their RTW, before and after their RTW ($p<0.01$), as well as orchestra playing hours before and after their RTW ($p<0.05$).
These large differences in terms of workload could partly explain the low percentages we have observed across all samples in terms of point-prevalence and in the past month, as we know number of playing hours is considered as one of the main PRMDs risk factors (Baadjou et al., 2016; Chan & Ackermann, 2014).
Nevertheless, even if an increase has been observed across all samples (in a significant way in S16) before and after the RTW, number of playing hours after their RTW is still lower for all musicians, significantly in S16, than before the Covid-19. These results could explain the

absence of PRMDs increase after the RTW and make them difficult to compare to previous studies about sudden increase in practice time (Kok et al., 2016).

5.3. Mental health and life habits

The general disruption has been very stressful and anxiety-provoking for people around the world (Salari et al., 2020) affecting more females than males and among others, young adults as well as individuals with psychiatric antecedents or chronic diseases (Özdin & Özdin, 2020; Rossi et al., 2020). By analysing all questionnaires related to mental health, we observed that in our samples, females seemed to report more mental health issues than males, which seems to be in accordance with literature findings. We could hypothesise, as it has been investigated in different papers, these results could be related with an important mental load, due to different factors such as school from home (that has been mentioned by several musicians) or increased house hold chores due to the lockdown situation, while working remotely (Sharma & Vaish, 2020). Moreover, by comparing STAI-T scores between both times among the S16 sample, a significant difference has been highlighted. Indeed, musicians seemed less anxious after their RTW and the hypothesis we could consider is their relief of being back to work and somehow restoring their previous routine, contradicting birds of ill omen who declared performing arts as dead. Being allowed to be out without filling authorisations, meeting people, seeing friends, all of these could also naturally explain the anxiety decrease among all samples.

Finally, in terms of life habits, sleep and physical activity have been investigated. In terms of sleep, no difference has been highlighted across all samples between both times, except a slight "recalibration" of their bedtime before noon after their RTW. We have observed that, after their RTW, musicians took slightly less time to sleep, which could be correlated with the decrease of their anxiety scores. Considering physical activity, about 50% of ST1 reported having increased their physical activity during the lockdown. However, it also seems by analysing the GPAQ answers that participants have also increased their moderate activity across all samples before and after RTW as well as vigorous activities in S16. This may be related to the gyms reopening as well as the end of the lockdown concerning outdoor activities. This increase in physical activity duration may also partly explain why musicians did not report more PRMDs after their RTW (Ballenberger et al., 2018).

5.4. Perception of lockdown life and return-to-work

5.4.1. During the lockdown

The majority of the sample have reported they were able to practice their instrument during the lockdown, even if many of them weren't able to withdraw for a moment from the people they lived with. This could partly explain the low number of playing hours that have been previously discussed. We could also point out that physical activity has been only mentioned by about 20% of the sample. By comparing S16-T1 and S16-T2, we observe that physical activity seemed to be less important during the lockdown compared to after RTW. This behavior has also been observed and discussed in the general population in France during the lockdown (Rossinot et al., 2020) were decrease in PA was associated with negative changes in terms of mental health. Many musicians have mentioned they were focusing their time on taking care of their children and their studies. Indeed, except for specific professionals, children were not admitted to school and this has been a large issue for a lot of people (Sharma & Vaish, 2020) and musicians were not exempted. Nonetheless, almost the sample's half have felt the lockdown as a pleasant period and have found ways to play music with other as well as discovering new activities both on personal and professional sides.

5.4.2. After the return-to-work

The main outcome we could discuss here is about positive changes in mental state among the whole sample at T2. Indeed, participants were massively satisfied to be back at work and the majority them didn't report any psychological difficulty related to their RTW. For about the half of the musicians, the disruption we faced seems to have potentially change for their perception on their way of life and on the society we live in, but not that much on their professional career or work. These outcomes could explain why anxiety scores were decreased after RTW. Moreover, being a musician is often described by themselves as more than a job (Schoeb & Zosso, 2012) and as culture has been very often highlighted as « non-essential » (Clément, 2020), this could explain why many musicians would like to persevere, despite the difficult times they were facing.

5.5. Strengths of the study

Studies have been lead with musicians to investigate Covid-19 effects on their health (Helding et al., 2020), on the aerosol generation for wind instruments (He et al., 2020) but to the best of our knowledge, no studies have investigated the impact of the lockdown and the RTW on both physical and mental health in musicians.

Even if recall in questionnaire is still difficult, it was very important for the evaluation of PRMDs to be able to compare orchestra and private practice hours before the Covid-19 from playing hours during the lockdown and while progressively returning to work. This is what provided very useful information about musicians' workload and partly how it has been managed by the orchestra administrations.

This exploratory study provided information and insights that need to be explored further by conducting interviews with both musicians and administrative employees to understand how RTW has been organised and experienced.

Finally, almost all questionnaires used for this study were validated in French as well, which is not commonly observed in survey studies.

5.6. Limitations of the study

First limits concern the questionnaires themselves. By analysing answers obtained at T1 and T2 from the 16 musicians who filled both questionnaires, we have observed that to the question "Have you ever had any …" 5 of them have answered "yes" at T1 but "no" at T2, which is not very coherent. This has partly explained the initial difference of lifetime prevalence between both large samples (68% vs 50%). After having analysed samples' homogeneity, we decided to re-score the MPIIQM at T2 according to the T1 answers for the 16 musicians, which changed the T2 prevalence (60% vs 50%).

Moreover, the questionnaires mailings have been quite difficult to set-up with all the different orchestra administrative teams who had, obviously in this unprecedented situation, many urgent matters to manage. This can partly explain why the questionnaire has not been filled by a large sample of musicians and the observed drop-out between T1 and T2 that lead to a common sample of only 16 musicians at both times.

Finally, the MPIIQM (Berque et al., 2014) was the only questionnaire that was not validated in French among all the questionnaires we used. This survey is distributed more often in France to investigate PRMDs among musicians and it would be very useful to publish a valid translation.

6. Conclusions/Perspectives

To the best of our knowledge, this study is the first to provide information about mental and physical health in orchestra musicians during lockdown and after RTW. Further work is still needed to study their lived experience further to better understand the considerable changes the pandemic and its economic and political management has made to their work and personal life, as it has been shown to be related with PRMDs (Baadjou et al., 2016; Chan & Ackermann, 2014). Moreover, it is necessary to take into account that our point of view is very limited by focusing on orchestra musicians. It has been highlighted that in some countries, orchestral/classical musicians are the minority and that their issues were not generalizable to other types of musicians (Stanhope & Weinstein, 2019). This is one crucial point: experts have hypothesised that the Covid-19 may be more a syndemic than a pandemic (Horton, 2020), affecting in most cases people who are also victims of socioeconomic inequalities and presenting various non-communicable diseases (diabetes, obesity, hypertension, etc.). Therefore, it is very important in our future research to also investigate the other most affected musicians.

CHAPTER 7:
GENERAL DISCUSSION

1. Clinical relevance of the findings

1.1. Understanding injury risk factors in musicians

As it has several times been mentioned in this thesis, epidemiological studies focusing on pain prevalence and risk factors for developing playing-related musculoskeletal disorders in musicians report frequent methodological flaws leading to lack of understanding of potential relationships between certain risk factors and pain or PRMDs. This observation has been highlighted by several authors who tried to conduct systematic reviews (Corrêa et al., 2018; Baadjou et al., 2016; Wu, 2007). For this main reason, we conducted a large non-systematic review and developed a theoretical model by combining the risk factors mentioned in literature, health experts' and musicians' opinions. From this mixed-method study, a comprehensive model comprising nine categories and more than 50 items was developed.

The major strength of this model is the adherence to the biopsychosocial model (Engel, 1977), in which healthcare practitioners consider patients and people as a whole, without separating body areas or considering body and mind as being totally independent. Therefore, in this model, posture is a risk factor category among nine others and not the main one as it could be thought by considering musicians' health as a solely biomedical issue. This highlights the importance of not overestimating posture's role in PRMDs development, yet without underestimating its potential impact. Indeed, the influence of posture as a potential cause for pain is still very controversial in literature (Swain et al., 2020) and relationships between postural impairments and PRMDs have not been thoroughly investigated as pointed out in our systematic review about posture in musicians (see Chapter 4 – Part 4). Indeed, as several authors pointed it out, PRMDs development of these disorders could also be related to heavy workload, whether this is a sudden increase in instrumental practice (Kok et al.; 2016) or an important and sustained number of playing hours (Kaufman-Cohen & Ratzon, 2011). As this risk factor has not been particularly highlighted in the systematic review from Baadjou et al. (2016) (mainly due to a broad heterogeneity in used method, from tools to period of recall or targeted population: instruments, professional or students, etc.), further research is particularly required to provide more information about the importance of both workload and posture in PRMDs development and help in building relevant programmes to prevent them successfully.

Limitations of this model have already been discussed in the paper dedicated to the description of its development, described in Chapter 3. Nonetheless, it seems to be necessary to add several thoughts about musicians' vulnerability. Indeed, living with and treating musicians taught me how much musicians could feel both very proud and exhausted from living of their passion.

Literature confirms this initial thought: Schoeb and Zosso (2012) in their qualitative study highlight how much music is a vocation, "clearly more than a job", the musicians they interviewed reporting "a strong sense of identity and feel that they are more in charge of their lives than they would be in an office job with an 8-to-5 schedule". In another qualitative study, Christine Guptill (2011) pointed out the particular relationship musicians have with their instrument: an instrumentalist reported that their instrument is "like a part of [her] body" and stated that it would be like "cutting of [her] whole way of communicating" if she were not able to play anymore. This vulnerability, sense of identity and importance of the vocation have been thought in our model as being part of the psychosocial risk factors, in between perfectionism and negative affectivity. However, this needs further research to be more comprehensive in describing the psychological factors which could interfere with musicians' both mental and, consequently, physical health.
Finally, and this may be relevant for general population as well, but it seems that the "social part" of the biopsychosocial model is not considered enough to understand and prevent pain, and perhaps here, playing-related pain. However, in previous years, authors have investigated how being marginalized by social conditions could influence pain as well as important health inequities (Craig et al., 2020) but also, and this may be really relevant for musicians as well, how pain could be a threat to our "social self" and more precisely to "the need for autonomy, the need to belong and the need for justice/fairness" (Karos et al., 2018), which could be transferred to musicians.

1.2. Assessing injury risk factors in musicians

Building this comprehensive model about injury risk factors in musicians provided us with strong and diverse foundations to develop tools in order to assess them. Depending on the factor's category, the way to evaluate it will be different. Therefore, three different tools have been designed to answer different needs of assessment: a questionnaire, a physical assessment and a tool to analyse posture.

1.2.1. Using questionnaires in musicians

Based on this model, we developed a questionnaire, the Injury Risk Factors Questionnaire for Musicians, which is composed of 88 items covering a very large number of the identified risk factors in the model, from the current literature. Unfortunately, it has not been possible to validate the whole tool within the given time frame and available resources. We used whenever possible validated questionnaires (part or all) for each item from the model that needed to be assessed, and particularly the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM) (Berque et al., 2014). A review highlighted the need of homogeneity between epidemiological studies, particularly in terms of tool and recall period (Stanhope et al., 2019), and authors recommended to use the Nordic Musculoskeletal Questionnaire to screen pain in musicians. However, the decision has been made to use the MPIIQM because its development has been precisely targeted for orchestra musicians, using Zaza's PRMDs definition (Berque et al., 2014; Zaza et al., 1998). This questionnaire is appropriate to screen large cohort of musicians, assess their health, both physical and mental, as well as their life habits and instrumental practice. Healthcare practitioners could also use it all along their patients' care to follow certain evaluation criteria and evaluate the effectiveness of the treatment they implemented or the preventive behaviour they taught.

Moreover, this questionnaire could be used as well by researchers to investigate a large range of risk factors in specific populations such as precise music instrument family or repertoire, compare employed to free-lance musicians, professionals to students or to amateur. This questionnaire could also provide very interesting information while monitoring their educational courses or training programmes. Indeed, they would be able to assess whether the preventive intervention they set up was useful and if it was, on which specific risk factors. This survey could be combined with more specific validated questionnaires if the study protocol needs to investigate further this risk factor or another factor (life habits, mental state, etc.).

1.2.2. Physical examination of musicians for risk factors

To address all categories from the theoretical injury risk factors model, tools to investigate musculoskeletal health and posture have been developed based on existing tests and assessment procedures described in literature, such as the physical examination developed by Ackermann and Driscoll (2010) combined with tests previously used in musicians (Schemann et al., 2018; Tawde et al., 2016) or in the general population (Jull et al., 2008; Luomajoki et al., 2007). This new physical examination has been thought to help physiotherapists and other healthcare practitioners to screen musicians musculoskeletal functioning, such as mobility, strength or motor control as well as to assess posture while playing, as these issues may not be a common knowledge in physiotherapists or general practitioners. This would help taking into account other potential risk factors that would not have been screened *a priori.* It is well known now that rehabilitation is a combination of different trainings: for example, tendinopathies may resist to treatments, in athletes, in general population (Rio et al., 2016) and as a consequence possibly also in musicians. And more than in athletes, strength training in musicians with tendon problems may be very non-functional and show no positive outcomes in terms of pain reduction and ability to play at the level they were accustomed to. It seems now that motor control exercises, without replacing strength training which needs to be done to recover tendon loading capacities, would play an important role to be able to perform the task both the muscle and therefore the patient were used to do (Rio et al., 2016). This physical examination, by its number of screened items, provides varied information that could be the combined to diagnose better and treat in a more efficient way.

Secondly, after having systematically reviewed how posture was examined in previous papers, a comprehensive tool has been developed, mainly based on the existing Postural Observation Instrument (POI) (Blanco-Piñeiro et al., 2015), but with substantial amendments. Indeed, contrariwise to the POI, raters are asked to evaluate how much the musician is moving while playing, instead than considering an "averaged" posture. This adding could possibly increase our knowledge regarding the importance of taking into consideration if musicians with fixed and rigid postures are more at risk to develop injuries or not, which has been so far under-investigated to the best of our knowledge.

Finally, it seems to us as well that using the physical examination, the Postural Analysis Tool for Musicians and the Injury Risk Factors Questionnaire for Musicians all together may be the best way to screen the greatest number of risk factors and to avoid focusing on a postural problem with patients who are in fact disabled by their performance anxiety and *vice versa*. This help having global pictures of our patients rather than fragmenting their health issues and consider them as independent when they are all linked. They could also provide a framework for further epidemiological researches to combine different items together, such postural analysis with motor control assessment.

1.3. Building useful courses and providing resources for musicians

All the studies and protocols for this thesis were conceived and developed in order to increase our knowledge of injury risk factors in musicians but mainly with a view to both design and provide useful resources for musicians, and to increase awareness about playing-related musculoskeletal risk factors and their prevention.

The very first step appears to be simply explaining to musicians that their potential or existing PRMDs are multifactorial, that only posture or workload cannot explain in isolation all PRMDs, in all individuals. The theoretical model described in Chapter 3, combining literature, professional musicians' opinions and healthcare professionals' views, could help in a large extent to raise awareness about the multifactorial origins and consequences of PRMDs.

It also provides key principles to design comprehensive interventions, such as educational programmes which could integrate:

- theoretical courses about PRMDs and their prevention, potentially similar to those previously developed in literature (Baadjou et al., 2018; Arnason et al., 2018) with specificities which have not been investigated and implemented, such as integrating Pain Neuroscience Education described in a systematic review as reducing kinesiophobia, catastrophising and helping patients to cope with their condition (Watson et al., 2019) to possibly handle wrong beliefs about pain (which could have deleterious effects) which could have musicians as it has been investigated in Chapter 5;
- workshops where musicians, music teachers and students could learn how to assess posture (and if appropriate alter and adapt it depending on their unique needs or complaints), understand that posture cannot be the only factor to explain PRMDs development and needs to be reintegrated in a multifactorial model for both acute and chronic pain (cf Chapter 3) (Rousseau et al., 2021);
- specific training programmes where musicians would be taught to perform task-specific warm-up and exercises, as for athletes (Rousseau et al., 2019, Cools et al., 2016).

This model and all the tools developed alongside it could also help developing and monitoring interventions which could focus on modifying different conditions in musicians' daily lives such as:

- Performing (during both concerts and rehearsals) standing (at least partially) to handle sitting position as a potential risk factor for health (in terms of posture and sedentary behaviour) (Spahn et al., 2014; Price et al., 2014; Ackermann et al., 2014; Owen et al., 2010).
- Taking more breaks while playing in private practice and potentially at the orchestra (Chan & Ackermann, 2014; Wu, 2007);
- Providing information to music teachers to assess posture while playing, possibly adjust it when appropriate and monitor how much it could interfere with their students reporting PRMDs or not, performances as well as opinion about their teachers' pedagogical techniques as it has already been intended (Hildebrandt & Nübling, 2004).

The Injury Risk Factors Questionnaire for Musicians, the physical examination as well as the Postural Analysis Tool for Musicians could be useful resources to monitor the effects of such interventions on both PRMDs prevalence and risk factors reduction (see Chapter 4 – Part 4). It may also be very interesting to monitor alterations in performance by collecting musicians' subjective feelings regarding their own performance and by asking external music experts to adjudicate the performance quality as it has been already done (McCrary et al., 2016).

2. Covid-19, a major disruption in musicians' lives

2.1. Covid-19: PRMDs catalyser or inhibitor?

The disruption related to the Covid-19 has dramatically impacted the music industry and musicians' lives, whether they were employed in orchestra or working freelance, and particularly during the first lockdown, observed in a great number of countries around the world. Employed musicians have been furloughed, festivals and performances have been cancelled, theatre and concert halls have been closed. Media coverage has largely discussed how much music industry has been hit by the social consequences of the pandemic and how this situation will probably change it forever (EY, 2020). In France, the music industry is expected to lose about €4,5 billion, that is to say about 43% of forecasted budget (EY, 2020).

This unprecedented situation required investigating and monitoring musicians' health. We used several validated questionnaires to investigate PRMDs, mental state (depression, anxiety, social phobia) and several life habits during the pandemic (cf Chapter 6). We added to these instruments a number of additional questions to explore in a greater detail how they organised their daily life and how the virus restrictions had impacted their way of living.

Even if the number of participants was very low and if our sample was not necessarily representative of what is frequently reported in larger epidemiological studies in literature, this study was a very useful attempt and provides clinical elements and thoughts about PRMDs that would be very helpful in the future, as after almost two years, this worldwide turmoil is not over (cf Chapter 6). Among the considered sample, some musicians practiced their instrument day-to-day, playing almost the same number of hours they were used to before the lockdown. But most of them had a lot of difficulties to set up for themselves a daily life programme. Musicians contacted often said they were rediscovering their instrument: working on technical flaws they could feel for years or practicing pieces of music they always wanted to play. To prevent further issues with musicians' health and well-being, "return-to-normal-work" (that is to say in the exact same conditions of work musicians used to have in February 2020) should be carefully thought. Repertoire, number of playing hours per day and per week, number of breaks during playing sessions need to be intently reflected and cannot be organised without considering the effects of lockdowns and associated disruptions..

2.2. Proposals for return-to-work guidelines

Furloughed or not, musicians had to stop playing with others overnight. Besides the consequences on their mental health of such an unprecedented disruption, this may have had an impact on their musculoskeletal health (Zhang et al., 2020; Brooks et al., 2020). It is very important to outline that this forced break, combined with an anxiety-provoking period of time, cannot be considered as a normal holiday break. A sudden return to long hours of instrumental practice could lead to the development of several musculoskeletal injuries in musicians, as it has already been studied in the past. Buckley and Manchester (2006) reported 44% of injured musicians at the end of a music camp for amateur musicians and Kok et al. (2016) reported an increase from 28% to 80% after one week of nine-hour rehearsing schedule for amateur orchestra musicians (Kok et al., 2016). Therefore, return-to-work must be planned carefully in terms of hours of playing and repertoire, but orchestra teams should also provide their musicians an individual support to return to work safely and avoid playing-related musculoskeletal disorders (PRMDs) development in the very first weeks of their return-to-work.

The aim of this discussion section is to describe what have been thought to be potential return-to-work guidelines for orchestra musicians, to be implemented few weeks before and after the return-to-work, based on the literature but also on several informal interviews with musicians across Europe.

2.2.1. Instrumental practice

First of all, before their return-to-work, musicians' personal practice should be investigated. The MPIIQM (Berque et al., 2014) could be used to assess both musculoskeletal health and number of playing hours during the whole lockdown period. This could be helpful for building the repertoire programme of the first weeks.

Orchestra musicians should also consider preparing themselves for their own return-to-work. A private practice programme has been developed (see Table 7.1) below to ensure their ability to play at least for 2 hours per day during their first week of return-to-work (RTW).

Table 7.1: Personal practice guidelines before the return-to-work

Weeks	Sessions' number and duration (five days a week)
1st week (5 weeks before the RTW)	One session of 25 minutes per day
2nd week	One session of 25 minutes twice per day (45 minutes of break at least)
3rd week	One session of 25 minutes three times per day (45 minutes of break at least)
4th week	One session of 45 minutes twice per day (45 minutes of break at least)
5th week (last week before the RTW	One session of 45 minutes twice per day (45 minutes of break at least) and one session of 25 minutes

Breaks should be longer than what is suggested in the literature (about 15 minutes of break for 45 minutes of instrumental playing – Chan & Ackermann, 2014) to ensure musicians are fully recovering from their practice and to prevent all musculoskeletal injuries related to their play. Indeed, as some of them have not played much during the lockdown-period, it is important for them to take longer breaks than described in literature for usual periods.

In terms of group practice, orchestra management teams should carefully think the organisation of the first weeks, and assess their return-to-work organisation programme before and after the initial return period through surveys or interviews. The proposed programme below could be followed for the first three weeks of orchestra rehearsals:

- First week: 2 hours per day, 25 minutes of playing and 15 minutes of break;
- Second week: 3 hours per day, 45 minutes of playing and 15 minutes of break;
- Third week: 4 hours per day, 45 minutes of playing and 15 minutes of break.

Breaks are the best way to prevent musculoskeletal injuries. Breaks "culture" should be disseminated as much as possible during this period, including breaks during private practice, specifically for "long duration" players. Moreover, in terms of repertoire, challenging ones should be progressively reintroduced from the third week.

2.2.2. *Physical activity*

Orchestra musicians, and particularly string or wind players, are considered as sedentary workers, due to their sitting position (Owen et al., 2010). The lockdown period has been completely different for most of the musicians in terms of lifestyle and these different life habits should be taken into account.

Several muscle strengthening programmes have been developed and tested on musicians:

- Endurance and strength protocols (Ackermann et al., 2002);
- Stabilisation exercises (Chan et al., 2014; Chan et al., 2012);
- Resistance training (Lundborg & Grooten, 2018);
- Fitness programmes (Baadjou et al., 2018).

Moreover, Chan et al. (2012) have developed a DVD of their exercises programme, dedicated to musicians. After a 12 week-period with at least two sessions a week, musicians showed significantly reduced PRMDs frequency and severity.

All these papers helped us to design an efficient and short fitness programme, easy to set-up for musicians and to include in their daily life. Table 7.2 (in Appendix S) describes the whole fitness programme developed for musicians to prepare them for a safe return-to-work. The programme below is common to all musicians. Task-specific exercises (described in Table 7.3

in Appendix S) should be incorporated progressively to the programme (from week 3). If manageable, this programme should be performed twice a week, in association with at least one session of running, swimming or cycling (to increase cardiovascular activity).

As mentioned in the literature, functional exercises are important to incorporate in injury prevention or rehabilitation programmes (Chan et al., 2014). Therefore, task-specific exercises have been described for string and wind players, as well as for percussionists.

2.2.3. Stretching

Several reviews and meta-analysis have highlighted the positive impact of yoga practice on mental health and depression (Hendriks et al., 2017; Cramer et al., 2013). Moreover, yoga has also been investigated for its impact on musculoskeletal injuries. A 13-week yoga intervention has been conducted with dental hygiene professionals, with several work stressors and shortened careers showing significant decrease in musculoskeletal pain (Monson et al., 2017). As some of their work stressors are quite comparable with musicians' ones, such as movements repetitions, musculoskeletal loads on the upper limbs, awkward postures, yoga could also be very valuable for musicians to decrease the PRMDs frequency and severity.

Finally, effect of yoga sessions' has also been investigated in musicians. It has shown positive results in term of performance anxiety, mood disturbance and performance in musicians (Khalsa et al., 2009; Khalsa & Cope, 2006). Therefore, a short-session yoga programme has been developed for beginners to be performed three times a week (cf Table 7.4. in Appendix S).

2.2.4. Weekly programme based on individuals

As individuals would have had different behaviours regarding the pandemic restrictions, it seems to be necessary to add "calculators" for instrumental practice and physical activity to allow musicians to build their own programme, based on these return-to-work guidelines.

- Instrumental private practice

Breaks are the best way to prevent musculoskeletal disorders but during their private practice, musicians tend to forget to stop their practice even for a few minutes (Chan & Ackermann, 2014). The main recommendation for musicians will be to play for 45 minutes and to stop for 15 minutes for each practice session they would do.

Musicians would be invited to calculate their number of playing hours per day and per week (to know how much they play per week but also if their sessions are homogeneously distributed during the week). Using the practice calculator (described in Figure 7.1), they would then be advised to follow the instrumental practice guidelines according to their individual number of playing hours and practice habits. Few questions below would help musicians to determine how they should practice their instrument to be prepared for their return to work:

1. Did I play my instrument regularly the last few months? (regularly = 4 times a week or more)
2. Did I play my instrument more than 10 hours per week?
3. Do I take breaks of at least 15 minutes when I play my instrument more than 45 minutes?
4. Do I have musculoskeletal disorders related to my instrumental play?

Musicians would answer these questions via the decision tree below and know from which week before their return-to-work they should start.

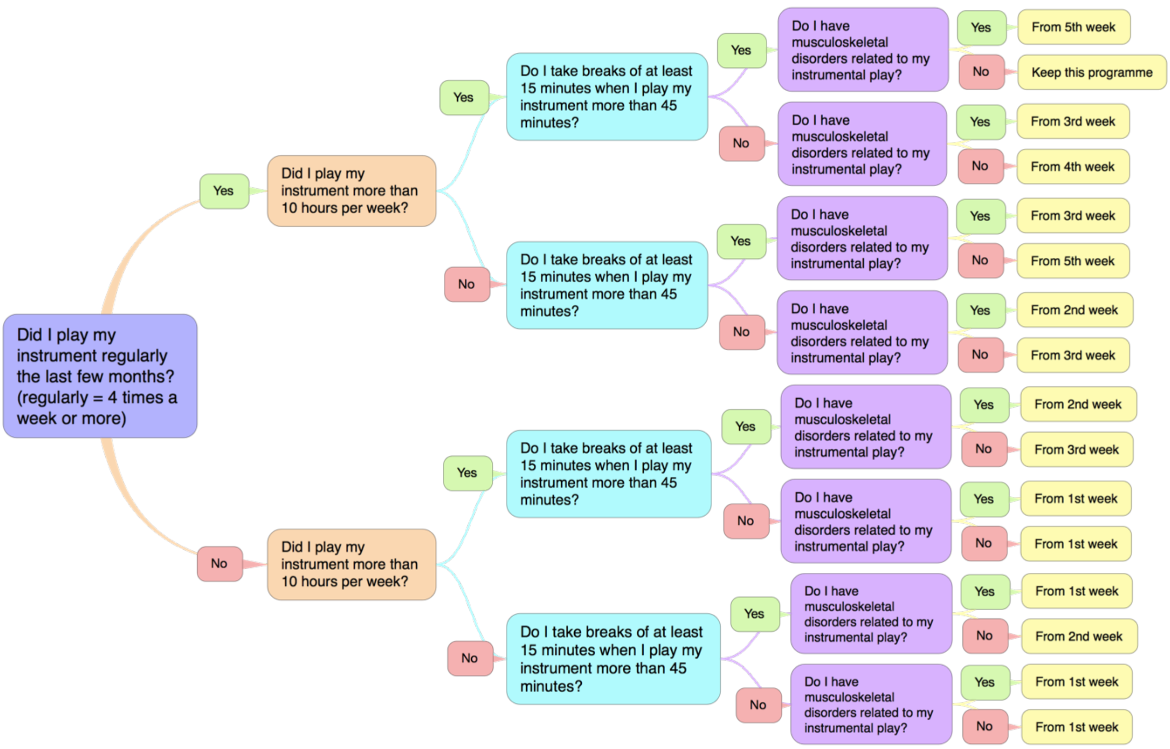


Figure 7.1: Decision-tree for private practice in musicians

- Physical activity

The World Health Organisation recommends 150 minutes of moderate physical activity or 75 minutes of vigorous physical activity per week (WHO, 2010).

Different situations could correspond to musicians' physical activity practice.

1. If musicians already practice physical activity according to the WHO recommendation, they should follow their own programme and add three days a week some task-specific exercises, depending on the instrument they play.

2. If musicians already practice some general fitness exercises at least two times a week, they are advised to add a cardiovascular session once a week (such as running or cycling) and three times a week some task-specific exercises, depending on the instrument they play.
3. If musicians already practice some cardiovascular activities, they are advised to add general fitness sessions twice a week (such as running or cycling) and three times a week some task-specific exercises, depending on the instrument they play.
4. If musicians are not active, they are advised to follow the general fitness exercises at least twice a week as well as a cardiovascular session once a week and task-specific exercises three times a week depending on the instrument they play.

- Plan

The plan below (in Table 7.5) has been developed to help musicians to organise their week, combining instrumental practice five days a week, physical activity (fitness/cardiovascular) and yoga sessions.

Table 7.5: Example of weekly plan

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
						
						

3. Limitations due to the Covid-19 pandemic: planned studies which could not be completed

This section will briefly describe two studies which were planned to be part of this PhD work, but were not possible to conduct due to the Covid-19 disruption. For both, some background information, the aim of the study and the envisaged methods will be briefly detailed.

3.1. Scapular motor control in upper string players

Upper string players, violinists and violists, know how much being an elite musician resonates with standing up to mechanical and postural loads and how this could lead to several playing-related musculoskeletal disorders (Silva et al., 2015; Moraes & Papini, 2012). Playing the violin or the viola requires an extremely awkward body posture, particularly caused by an asymmetrical use of the upper limbs. In orchestra, upper string players are sitting most of their time, sharing their stand with one of their colleagues (Spahn et al., 2014). While playing, the instrument is maintained between the left shoulder and the chin (Tawde et al., 2016; Shan & Visentin, 2003) and this exaggerated elevated position of the left shoulder has been reported to create muscular static tensions around the left upper trapezius (McCrary et al., 2016; Ackermann et al., 2002). While maintaining this position, the upper string player moves the bow back and forth against the strings using the right upper limb while the left hand is fingering the strings against the neck to determine the pitch of the note (Shan & Visentin, 2003).

All these biomechanical elements related to instrument gesture are part of the reasons why upper string players are frequently reporting playing-related musculoskeletal disorders (Kochem & Silva, 2017; Silva et al., 2015; Moraes & Papini, 2012; Zaza et al., 1998) and especially around the neck, the upper back, the shoulders and the forearms (Kochem & Silva, 2017; Moraes & Papini, 2012; Ackermann et al., 2012).

Although numerous studies in the general population have reported that scapular stabilisation, resulting from synergic activation of serratus anterior and trapezius (Mottram et al., 2009; Kibler & Sciascia, 2009), was the basis for upper limb movement controls (Yang et al., 2014; Worsley et al., 2013; Picco et al., 2010), many authors have found musicians and particularly upper string players' motor control as being insufficient (Ackermann et al., 2002). Indeed, several impairments such as craniocervical function or lumbar stabilisation as well as scapular dyskinesis have been highlighted in upper string players (Rousseau et al., 2019 and previous work; Silva et al., 2018; Tawde et al., 2016; Steinmetz et al., 2010). Impairments around the shoulders and thoracic spine seem to be related to the position of the shoulder blades while playing the violin: on the left, in a static protracted and elevated position and on the right, moving constantly to help the upper limb to orientate the bow (Dawson, 2011; Shan & Visentin, 2003; Ackermann et al., 2002).

Recently, functional exercises targeting scapular stabiliser muscles have been developed, based on the violin and viola instrumental gestures (Rousseau et al., 2019 and previous work). The immediate effect on activation of middle and lower trapezius as well as serratus anterior after performing these exercises has been investigated using EMG. These task-specific exercises have proved their value according to immediate changes in the muscles activation but also according to the musicians' perceptions.

The aim of the study would have been to investigate the effect of an 8-weeks protocol of functional instrument-specific exercises that target scapular stabilisation muscles on upper string players' posture while playing, performance and perceived ability to play.

Details about the planned methods can be found in Appendix T.

3.2. Abdominal muscles recruitment in woodwind and brass players

Playing a wind instrument at an elite level requires different skills, including the activation of the instrument keys or pistons while holding the instrument, as well as breathing support and control (Ackermann et al., 2014, Cossette et al., 2008), and particularly resisted and controlled expiration, mainly controlled by abdominal muscles (transverse and obliques, particularly the internal one) (Abe et al., 1996). Two types of wind instrument can be distinguished: woodwind and brass instruments. In an orchestra, woodwind such as flutes, clarinet, bassoon, oboe, English horn are generally described and brass instruments are usually represented by horn, trumpet, trombone and tuba. Despite their differences in terms of instrument-making, mouthpieces and related techniques, brass and woodwind players have been described to experience various musculoskeletal and other disorders (Chesky et al., 2002). Indeed, in several epidemiological studies, woodwind and brass players from all ages have reported playing-related musculoskeletal disorders in their musician life (Ackermann et al., 2012; Brandfonbrener et al., 2009; Ranelli et al., 2011; Abréu-Ramos & Micheo, 2007), particularly in the shoulders, neck, upper and lower back (Silva et al., 2015). The heavy weight of the instruments, brass ones in particular, have also lead researchers to develop ergonomics support (Price & Watson, 2018) aiming at distribute better the instruments' weight.

In terms of posture, Blanco-Pineiro et al. (2017) reported impairments in brass and woodwind students such as an overall slumped posture and forward head holding while performing. While standing, pelvis has been observed to be forward tilted in wind players but backward tilted in their usual sitting position (Blanco-Pineiro et al., 2017). Finally, shoulder tilt has also been rated in wind players. This can be explained by the instrument support that remains mainly on one upper limb rather than equally on both (e.g. trombone players) and also by the difference of movements complexity between both hands (e.g. bassoonist).

Breathing function and muscle recruitment have been investigated in woodwind and brass players (Ackermann et al., 204; Price et al., 2014; Cossette et al., 2008), using spirometry, inductive plethysmography and surface electromyography (EMG). Although studies were using surface EMG, this technique has been highlighted by Price et al. (2014) to be insufficient to fully understand abdominal recruitment while playing brass instruments. In Ackermann et al. (2014), the influence of standing and sitting positions on abdominal muscle recruitment and breathing parameters has been investigated and whereas musicians reported a clear preference for performing in standing, greater chest expansion and smaller abdominal one have been observed in standing compared to sitting.

In Cosette et al. (2008), breath support is defined as the recruitment of “inspiratory muscles as antagonists to the expiratory act of playing”. By analysing abdominal muscles function while playing the flute, these authors have found the lateral abdominal muscles to be more recruited with breath support in the first notes of a long phrase (about 50 seconds) whereas these muscles are much more recruited without breath support in the second part of the phrase. From these outcomes, they assumed that the abdominal muscles are activated for fine tuning and specific tasks rather than to decrease lung volume.

As for athletes, musicians’ body are known to be subjected to musculoskeletal loads. Several preventive programmes have been developed for musicians: effects of endurance (Chan et al., 2014a; Chan et al., 2014b), resistance (Lundberg & Grooten, 2018), warm-up (McCrary et al., 2016), educational trainings (Arnason et al., 2018) and even task-specific exercises (Rousseau et al., 2019 and previous work) have been investigated in musicians, and particularly in string players. As abdominal muscle function seems to be much important while performing wind instruments (Ackermann et al., 2014; Price & Watson, 2014; Cosette et al., 2008), increasing strength and awareness of motor control could have a positive impact on several performance parameters.

The aim of the study would have been to investigate the effect of an 8-weeks protocol of core stabilisation exercises (including transverse) on woodwind and brass players’ breathing parameters, abdominal muscle function, performance and perceived ability to play.

CHAPTER 8:
PERSPECTIVES AND GENERAL CONCLUSION

1. Future research, professional future and real-life application

The potential reliability of the Postural Analysis Tool for Musicians must be investigated among healthcare practitioners, music teachers and musicians. This assessment tool has an important potential to increase both PRMDs management or prevention and understanding of the complexity and diversity of instrumental postures. Existence of an association between posture and musculoskeletal disorders is more and more controversial and the observed outcomes could help providing arguments to one theory or the other. The most important is increasing knowledge about musicians' health to adapt their injury management. So many musicians have heard, perhaps wrongly, that their poor posture was the major explanation of their injuries, that they were presenting so much technical flaws that they need to learn it again from the beginning to stay healthy and pursue their career. Specialised musicians' healthcare professionals and researchers need to work side by side to dig deeper and increase our knowledge about posture, which remains one of the main concerns of injured musicians.

Moreover, as the Covid-19 dramatically altered our lives, both personal and professional, there are many ideas of research questions I had about musicians' injuries that were impossible to answer because of the pandemic and all the social restrictions we had to face. And even if social barriers are gradually dismantled, even if musicians were allowed and willing to come back to research laboratories, their lives changed too much. The Covid-19 pandemic has sharply changed musicians' way of working their instruments and performing with others. We need to seek how musicians are envisioning their future in a fast-moving world.

Nonetheless, all the studies mentioned previously which were impossible to complete due to the situation are still relevant. Investigating how chairs' height or types may influence both posture, ease of movements, muscle activation as well as performance could help musicians as well as tour managers or orchestra management teams and the music industry to a wider extent. Setting up programmes based on task-specific exercises and evaluating the influence of an improved motor control while playing on both pain and performance seems to be the next milestone.

2. General Conclusion

This thesis aimed to understand better injury risk factors for developing playing-related musculoskeletal disorders and building specific tools to assess them better. Developing a large model about predisposing risk factors and previous work in musicians' care provided foundations to build a comprehensive self-reported questionnaire to screen many health items, a physical examination (to be performed by a healthcare practitioner) and a tool to analyse posture while posing and playing (developed in order to be used by healthcare professionals but also musicians themselves and music teachers above all). Based on this model as well, a cross-sectional study about pain beliefs in musicians emerged and highlighted the importance of raising awareness about what really is pain. Finally, it helped also to monitor the Covid-19 situation effects on orchestra musicians, highlighting a lower PRMDs prevalence compared to literature combined with a large decrease in instrumental practice hours, pointed out the need of thinking return-to-work carefully to avoid a PRMDs outbreak once the situation may become "normal" again.

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APPENDICES

Appendix A: Interview with RLPO musicians

1. What do you think about your current health? (Kreutz et al., 2008)
2. What do you know about the playing-related musculoskeletal disorders? (Zaza et al., 1998)

Here, the investigator has to define PRMDs to the musician as “pain, weakness, numbness, tingling, or other symptoms that interfere with [their] ability to play [their] instrument at the level [they] are accustomed to” (Zaza et al., 1998).

3. Have you ever been suffering from PRMDs? (Ioannou et al., 2018; Ackermann & Driscoll, 2010)
4. What do you feel are the major PRMDs risk factors? (Ackermann & Driscoll, 2010; Ackermann & Adams, 2004)
5. What do you do when you have PRMDs to relieve your pain and/or your injury? (Ackermann & Driscoll, 2010)
6. What do you feel are the major physical stressors associated with your work? (Ackermann & Driscoll, 2010)
7. What do you feel are the major psychological stressors associated with your work? (Ackermann & Driscoll, 2010; Ackermann & Adams, 2004)
8. What changes do you think could be made to best improve the issues you have identified above? (Ackermann & Driscoll, 2010; Ackermann & Adams, 2004)
9. Do you pay attention to PRMDs when you teach? (Wood, 2014; Hildebrandt & Nübling, 2004)

Appendix B: First PowerPoint slides for experts' interviews

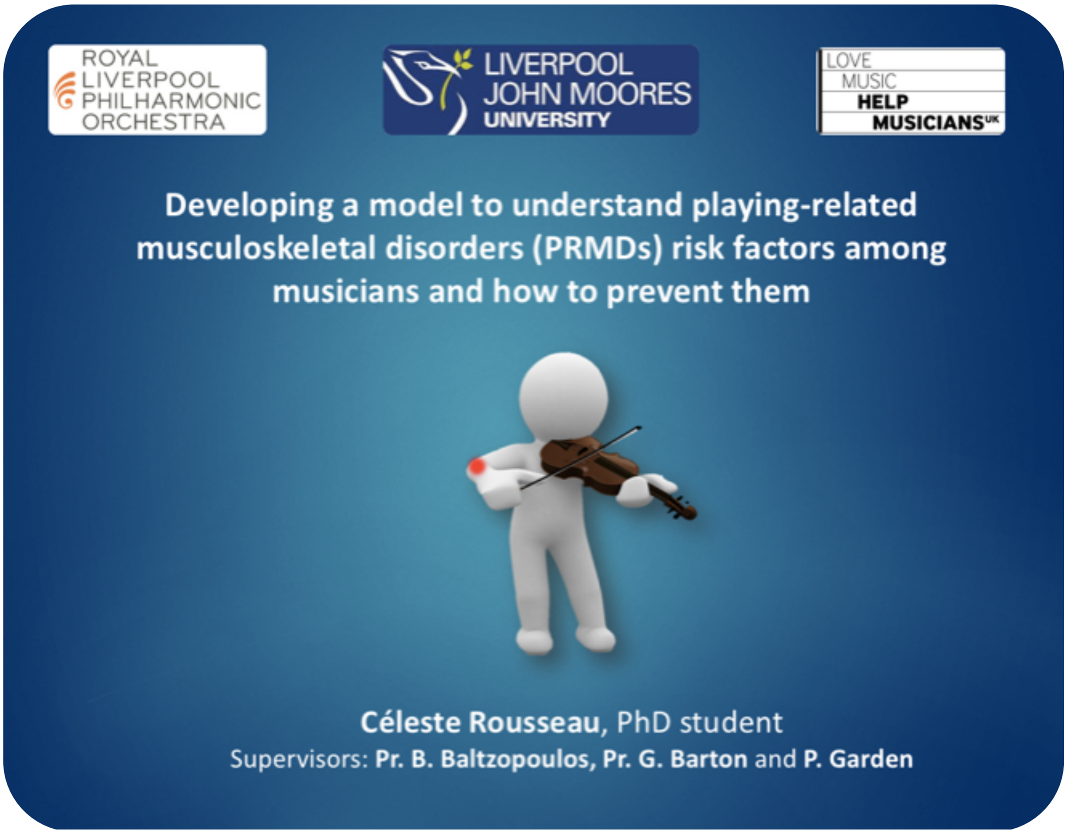


Figure 3.2: First PowerPoint slides presented to the experts

Appendix C : Initial model of PRMDs risk factors

Table 3.1: Theoretical initial model of PRMDs risk factors

Groups	Subgroups	References
Individual characteristics	Gender	Ioannou et al., 2018; Baadjou et al., 2016; Wu, 2007
	Age	Baadjou et al., 2016; Wu, 2007
	BMI and weight	Vinci et al., 2015
	Height and size of upper limbs/spine	Ackermann & Adams, 2003; Sakai & Shimawaki, 2002
	Genetic predispositions	Schaefer & Speier, 2012; Jankovic & Ashoori, 2008
Posture	Slouched posture	Blanco-Pineiro et al., 2017; Chan & Ackermann, 2014
	Fixed posture	Watson, 2009
	Elevation of the arm	Nyman et al., 2007
	Maximal range of motion used while playing	Watson, 2009
	Forward head posture	Chan & Ackermann, 2014; Price et al., 2014
Biomechanics	Hypermobility	Vinci et al., 2015
	Hypomobility	Rickert et al., 2012
	Poor breathing	Price & Watson, 2014
	Poor motor control around the back and hands	Silva et al., 2018; Steinmetz et al., 2012; Brandfonbrener, 2009
	Fatigue and muscles activation	Wood, 2014; Chan et al., 2000
	Sitting position	Spahn et al., 2014; Price & Watson, 2014
Injury management	Lack of early management	Chan et al., 2013b
	Absence of medical staff	Chan et al., 2013b
	"No pain, no gain"	Ioannou & Altenmüller, 2015; Zaza et al., 1998
	Lack of knowledge about PRMDs	Baadjou et al., 2018; Wood, 2014; Ioannou & Altenmüller, 2015; Hiildebrandt & Nübling, 2004
	Pressure of hierarchy/peers	Wu, 2007
	Non-progressive return-to-work	Chan & Ackermann, 2014
	Relapse	Baadjou et al., 2016
Workload	Lack of rest between and during rehearsals/concerts	Baadjou et al., 2016; Lopez & Martinez, 2013; Wu, 2007
	Lack of rest during private practice	Baadjou et al., 2016; Lopez & Martinez, 2013; Wu, 2007
	Performance related workload	Baadjou et al., 2016; Chan & Ackermann, 2014; Wu, 2007
	Ergonomics related: weight, support against gravity, etc.	Price & Watson, 2018; Kaufman-Cohen & Ratzon, 2011; Nyman et al., 2007
Physical conditionin g	Lack of daily moderate/vigorous activity	Ballenberger et al., 2018; Baadjou et al., 2015
	Lack of knowledge about physical activity	Baadjou et al., 2018; Barton & Feinberg, 2008
	Absence of warm-up	Baadjou et al., 2016; Wu, 2007
Life habits	Sleep	Chan & Ackermann, 2014
	Nutrition	Chan & Ackermann, 2014
	Hydration	Chan & Ackermann, 2014
	Tobacco	Baadjou et al., 2016
	Alcohol	Saltychev et al., 2016

	Hobbies	Ackermann & Driscoll, 2010
Environment	Noise	CIDB, 2013; Harper, 2002
	Light	Harper, 2002
	Temperature	Chan & Ackermann, 2014; Harper, 2002
	Touring	Ackermann, 2002
	Playing on stage or in the pit	Kenny et al., 2016
	Right/left side of the stand	Spahn et al., 2014
	Distance from the conductor	Spahn et al., 2014
Psychology	Anxiety	Chan & Ackermann, 2014
	Stress: work related or not	Wu, 2007
	Depression	Hildebrandt et al., 2007
	Social phobia	Chan & Ackermann, 2014
	Personality traits	Chan & Ackermann, 2014
	Stage fright	Baadjou et al., 2016; Hildebrandt et al., 2007
	Pressures	Wu, 2007

Appendix D : Experts' changes on the initial model

Table 3.2 : Experts' changes and additions concerning the initial model

Topics	Additions	Changes
Individual characteristics	• Spine curvatures • Instrument • Vision problems • Dental problems • Notion of master eye and ear	
Posture		• Maximal ROM should be in the biomechanics section • Great ROM are important to tackle fixed posture.
Biomechanics	• Chronic tension in the striated muscles due to anxiety • Modified body schema • Paradigm change: "Know pain, know gain" • Notion about fear avoidance of movements that musicians know would "trigger pain" (psychological has a direct impact on biomechanics)	• "Breathing has more to do with general tension" (whether instrumentalists have to blow or not) • Fatigue due to biomechanical challenge and due to chronic anxiety need to be separated • Careful usage of word like poor because of the current lack of knowledge about what is ideal • Add to the mentioned regions for poor motor control the "jaws, face and lips" • Sitting position is more postural than biomechanics (mentioned by 2 experts)
Injury management	• Orchestra management team's behaviour towards injury • Musician's behaviour toward reporting injuries: "dirty secret"/taboo	• Absence of medical staff should be "shortage of qualified health practitioners" (notion of excess of non-evidence based therapy mentioned by the expert) • "No pain no gain" but also playing through pain, which are slightly different
Workload	• Variety of repertoire should be highlighted in [performance workload] as "cognitive load" • Importance of taking into account hours of extra-playing (orchestra hours excluded)	
Physical conditioning	• Stretching should be added (even if not evidence-based for now) • Global recovery should be added	• No evidence-based relationship exists about lack of general physical activity in musicians • Warm-up has not been shown as predictive in literature
Life habits	• To alcohol should be added licit and illicit drugs (this has been mentioned by 2 experts) • Management of personal/family life with work	

<u>Environment</u>	• Chairs arrangement has been mentioned by 3 different experts • Dust should be included • Promiscuity with others should be also included (has been mentioned by 2 experts)	
<u>Psychology</u>	• Beliefs towards pain should be included • Pain representations should also be included	• Stage fright should be replaced with "music performance anxiety" • Anxiety should be replaced with "trait anxiety" • Personality traits (which is too large) should be replaced with "negative affectivity" • Pressures should be replaced with "perfectionism" • Stress should be split in two groups: "occupational stress" and "general stress"

Appendix E : Interviews with the musicians – Outcomes

Table 3.3: Risk factors, physical and psychological stressors mentioned by the musicians of the RLPO during the conducted interviews

Key-words	**General injury risk factors** (Q4)	**Physical stressors** (Q6)	**Psychological stressors** (Q7)	**IRF and stressors** (not mentioned in Q4-6-7)	**Total**
Individual characteristics					
Spine size				IM2*	**7%** (1/15)
Genetic predispositions				IM12	**7%** (1/15)
Posture					
Posture related to holding the instrument	IM1 – IM3 – IM5 – IM7 – IM14	IM2 – IM7 – IM14 – IM4 – IM6 – IM9 – IM15		IM11 – IM12	**80%** (12/15)
"Unnatural position"	IM4 – IM10 – IM12	IM7 – IM9 – IM11 – IM14		IM1 – IM6	**60%** (9/15)
Biomechanics					
Sitting for a long time/sitting position	IM3 – IM11	IM4 – IM6 – IM15 – IM7		IM1 – IM2	**53%** (8/15)
Repetitive movements	IM1 – IM3 – IM4 – IM12	IM3 – IM4 – IM15			**33%** (5/15)
Slower movements		IM9			**7%** (1/15)
Fatigue		IM13			**7%** (1/15)
Avoid pain	IM12				**7%** (1/15)
Injury management					
Absence of "checking"	IM2 – IM15				**13%** (2/15)
Absence of specific healthcare professional				IM6	**7%** (1/15)
Lack of knowledge	IM7				**7%** (1/15)
Workload					
Overwork (busy periods)	IM2 – IM5 – IM13 – IM14 – IM8 – IM9 – IM15				**47%** (7/15)
Absence of real day-off	IM2 – IM15				**13%** (2/15)
Lack of time for personal practice	IM15				**7%** (1/15)
Lack of rest	IM14	IM1 – IM14 – IM4 – IM12		IM1	**27%** (4/15)

Heaviness of the instrument	IM4	IM11			**13%** (2/15)
Repertoire difficulty/cogn. load	IM2 – IM13	IM14	IM2 – IM9		**27%** (4/15)
Length of time playing	IM4 – IM3 – IM5 – IM11 – IM8 – IM10 – IM9	IM1 – IM5 – IM7 – IM14 – IM4 – IM9 – IM12 – IM15		IM11 -	**80%** (12/15)
Problem of the bass section		IM8 – IM14		IM13	**20%** (3/15)
Sudden increase	IM9				**7%** (1/15)
Physical conditioning					
Warm-up				IM2	**7%** (1/15)
Life habits					
Hobbies		IM12		IM7	**13%** (2/15)
Work related travels		IM3		IM7	**13%** (2/15)
Alcohol/drugs				IM5 – IM10	**13%** (2/15)
Sleep		IM6			**7%** (1/15)
Environment					
Lack of space/proximity	IM6	IM2 – IM6	IM4 – IM10		**27%** (4/15)
Temperature and draught	IM1 – IM11 – IM6 – IM10	IM3 – IM11 – IM6 – IM10		IM2	**40%** (6/15)
Chairs	IM6	IM10			**13%** (2/15)
Lighting	IM6	IM6		IM2	**13%** (2/15)
Print music				IM2	**7%** (1/15)
Noise	IM6	IM6			**7%** (1/15)
Position towards conductor		IM2			**7%** (1/15)
Side of the stand		IM2 – IM6			**13%** (2/15)
Psychology					
Work-related stress	IM10 – IM13	IM3	IM1 – IM3 – IM13 – IM6 – IM8 – IM10 – IM12 – IM5		**53%** (8/15)
Personal-related stress			IM10 – IM13		**13%** (2/15)
Fatigue due to overwork			IM3 – IM14 – IM10		**33%** (5/15)
Feeling judged			IM15		**7%** (1/15)
Deal with others			IM11 – IM4 – IM8 – IM10 – IM15		**33%** (5/15)
Stage fright			IM7		**7%** (1/15)
Difficulty of planning personal life			IM4 – IM10		**13%** (2/15)
Self-pressure			IM6 – IM9		**13%** (2/15)

IM “x” : interview musicians number “x”

Appendix F: From the initial model to the final one

To understand better how the initial model has been changed, the following legend has been used to highlight the changes or additions and where they come from.

- *[e] changed from the initial model due to experts' opinions
- *[m] changed from the initial model due to musicians' answers
- ~~removed from the initial model~~
- *minor other additions/changes*

Table 3.5: Theoretical final model of PRMDs risk factors

Groups	Subgroups	References
Individual characteristics	Gender	Ioannou et al., 2018; Baadjou et al., 2016; Wu, 2007
	Age and *number of years playing*	Baadjou et al., 2016; Wu, 2007
	BMI and weight	Vinci et al., 2015
	*[e] Height and size of upper limbs	Ackermann & Adams, 2003; Sakai & Shimawaki, 2002
	*[e] Size and curvatures of the spine	Blanco-Pineiro et al., 2017
	Genetic predispositions	Schaefer & Speier, 2012; Jankovic & Ashoori, 2008
	*[e] Non-musculoskeletal disorders as vision, dental, skin problems	Harper, 2002
	*[e] Notion of master eye and ear	
Posture	Slouched posture	Blanco-Pineiro et al., 2017; Chan & Ackermann, 2014
	Fixed posture	Watson, 2009
	Elevation of the arm	Nyman et al., 2007
	Forward head posture	Chan & Ackermann, 2014; Price and Watson, 2014
	*[e] Sitting position	Spahn et al., 2014; Price et al., 2014
Biomechains	Hypermobility	Vinci et al., 2015
	Hypo-mobility	Rickert et al., 2012
	~~Maximal range of motion used while playing~~	~~Watson, 2009~~
	~~Poor breathing~~	~~Price et al., 2014~~
	*[e] Inadequate motor control in many body locations or functions: face (lips, jaws), spine, upper limbs, breath	Silva et al., 2018; Steinmetz et al., 2012; Brandfonbrener, 2009; Price et al., 2014
	*[e,m] Physical fatigue related to biomechanical challenge	Araujo et al., 2017; Chan et al., 2000
Injury management	Lack of early management: - *[e] Orchestra management team's behaviour towards injury - *[e] Musician's behaviour towards reporting injury - *[e] Shortage of qualified health practitioners *- Job status and position in the orchestra*	Ioannou & Altenmüller, 2015; Wood, 2014; Chan et al., 2013; Rickert et al., 2014; Zaza et al., 1998

	Lack of knowledge about PRMDs: - *[e] "No pain, no gain" and playing through pain vs "Know pain, no gain" - *[e] Absence of alternative pedagogy (and information about PRMDs) - *[e,m] Absence coaching during professional life	(Baadjou et al., 2018; Louw et al., 2016; Ioannou & Altenmüller, 2015; Hildebrandt & Nübling, 2004; Zaza et al., 1998)
	~~Pressure of hierarchy/peers~~	~~Wu, 2007~~
	Non-progressive return-to-work	Chan & Ackermann, 2014
	Relapse	Baadjou et al., 2016
Workload	~~Lack of rest between and during rehearsals/concerts~~	~~Baadjou et al., 2016; Lopez & Martinez, 2013; Wu et al., 2007~~
	Number of playing hours: - *[e] Amount of extra-orchestra hours of practice - *[e,m] Concerts and rehearsals program - *[m] Sudden increase	Kok et al., 2016; Kaufman-Cohen & Ratzon, 2011; Wu, 2007
	Performance related workload: - *[m] Repetitive movements - *[m] Length of playing time during rehearsals or concerts - *[e,m] Variety and difficulty of repertoire - *[m] Instruments' section size - Lack of rest during private practice	Baadjou et al., 2016; Baadjou et al., 2015; Chan & Ackermann, 2014; Lopez & Martinez, 2013; Wu, 2007
	Ergonomics related: weight, support against gravity, etc.	Price & Watson, 2018; Kaufman-Cohen & Ratzon, 2011; Nyman et al., 2007
Physical conditioning	Lack of daily moderate/vigorous activity	Ballenberger et al., 2018; Baadjou et al., 2015
	Lack of knowledge about physical activity	Baadjou et al., 2018; Barton & Feinberg, 2008
	Absence of warm-up	Baadjou et al., 2016; Wu, 2007
	*[e] Absence of recovery routine, like stretching	
Life habits	Sleep	Araujo et al., 2017
	Nutrition	Araujo et al., 2017
	Hydration	Chan & Ackermann, 2014
	Tobacco	Baadjou et al., 2016
	*[e,m] Alcohol and (licit/illicit) drugs	Saltychev et al., 2016; Ackermann et al., 2012; Kenny et al., 2015
	Hobbies	Ackermann & Driscoll, 2010
Environment	Noise	CIDB, 2013; Harper, 2012
	Light	Harper, 2002
	*[m] Temperature and draught	Chan & Ackermann, 2014; Harper, 2002
	*[e] Dust	Harper, 2002
	*[e,m] Chairs	Ackermann & Adams, 2004
	*[e,m] Lack of space	Kenny et al., 2016
	*[m] Touring and work-related travels	Ackermann, 2002
	Playing on stage or in the pit	Kenny et al., 2016
	Right/left side of the stand	Spahn et al., 2014
	*[e,m] Position from the conductor	Spahn et al., 2014
Psycho	Musicians' psychology:	
	*[e] Trait anxiety	Kenny et al., 2014

	Stress: - *[e,m] Occupational stress - *[e,m] General stress	Baadjou et al., 2016; Chan & Ackermann, 2014; Wood, 2014; Rickert et al., 2013
	Depression	Kenny & Ackermann, 2015; Hildebrandt et al., 2007
	*[e,m] Relationship to others: - Social phobia - *[e,m] Promiscuity with others	Rickert et al., 2014; Kenny et al., 2014
	*[e] Negative affectivity	Kenny et al., 2014
	*[e,m] Perfectionism	Kenny et al., 2014; Wu, 2007
	*[e] Music performance anxiety	Baadjou et al., 2016; Kenny et al., 2014
	*[e,m] Management of personal/family life	Araujo et al., 2017
	*[e,m] Mental fatigue	Araujo et al., 2017
	*[e,m] Musicians' behaviour towards pain:	
	*[e,m] Fear avoidance of movements	Wijma et al., 2016; Vlaeyen et al., 1995
	*[e] Beliefs towards pain and pain representations	Wijma et al., 2016; Britsch, 2005

Appendix G: Concept mind-map

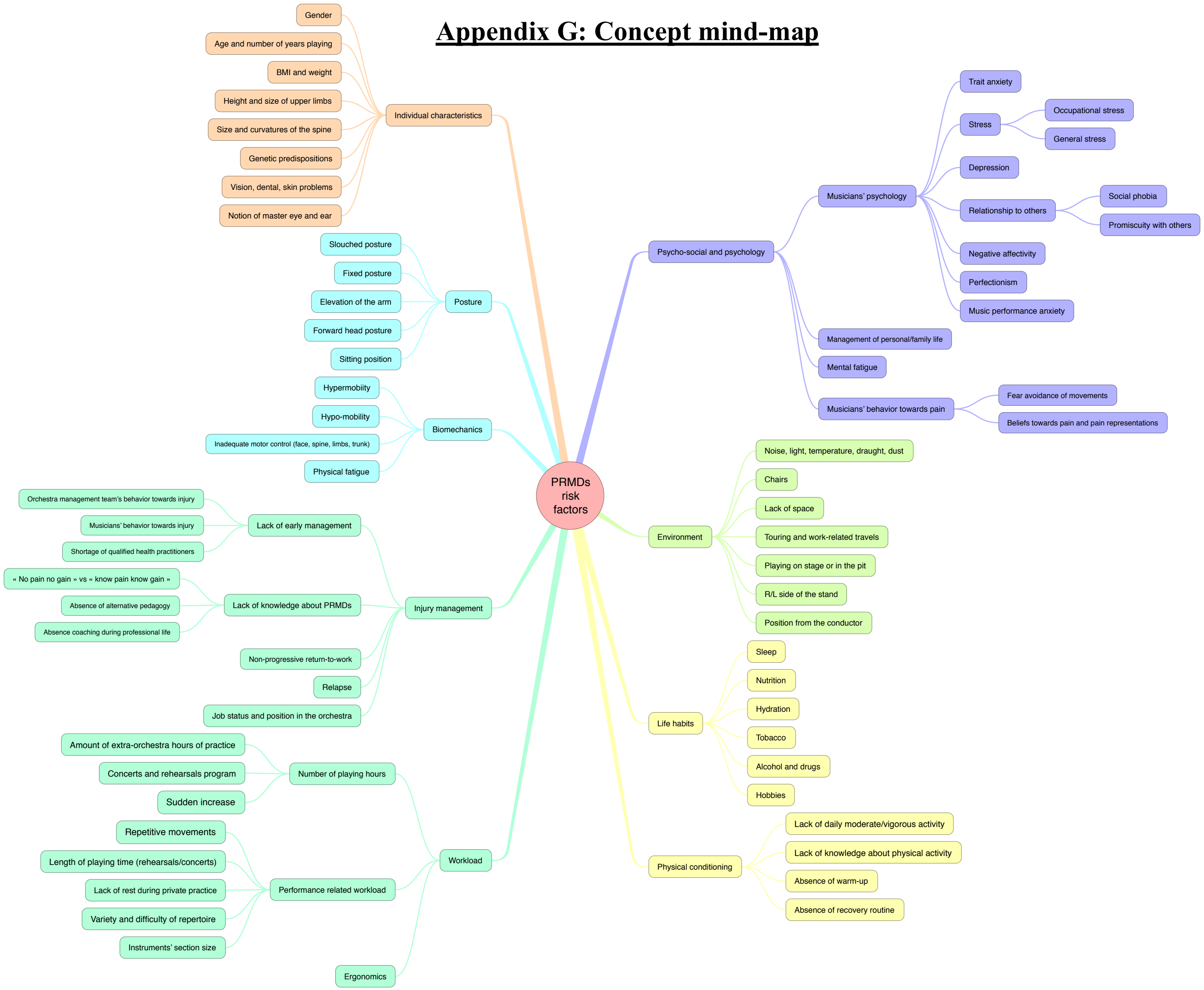


Figure 3.5: Theoretical final model – Concept mind-map

<u>**Appendix H: Injury Risk Factors Questionnaire for Musicians (IRFQM)**</u>

This questionnaire has been based on existing validated questionnaire investigating different elements from both our mental and physical health. The items have been chosen depending on playing-related musculoskeletal disorders risk factors that have been previously discussed and listed, based on literature, experts' advices and musicians' opinions (Rousseau et al., 2021).

<u>Section A: Epidemiological data</u>

1. Name:
2. Age:
3. Sex:
   ☐ Female
   ☐ Male
   ☐ Other
4. What instrument do you play in the orchestra?
5. For how many years have you played you instrument?
6. For how many years have you played professionally in an orchestra?

<u>Section B: Typical workload and work environment</u>

7. With respect to your position in the orchestra, do you work:
   ☐ Part-time
   ☐ Full-time
8. What is your job status?
   ☐ Free-lance
   ☐ Employed
   ☐ Other
9. Please estimate your typical weekly rehearsal workload:
10. Please estimate your typical weekly concert workload:
11. Please estimate your typical weekly private practice workload:
12. Please estimate how long are your average private practice sessions:
13. Please estimate how many practice sessions you would do normally per day:
14. Please estimate the length of time that you would rest for between practice sessions:
15. Please estimate your typical weekly teaching workload:
16. Please estimate your typical extra-orchestra workload (except teaching):
17. How uniform do you consider the concert and rehearsal program in term of workload?
    ☐ Mostly uniform the whole year
    ☐ Peak and valley the whole year
18. If peak and valley, are you:
    ☐ In a "peak" period
    ☐ In a "valley" period
19. How do you currently find the repertoire you are playing?

1	2	3	4	5	6
Easy					Really difficult

20. Are you often touring?

☐ Never	☐ Sometimes	☐ Mostly
☐ Rarely	☐ Often	☐ Always

21. During concert or rehearsal, are you mostly playing stand or sat?

1	2	3	4	5	6

Sat Stand

22. Concerning your private practice, are you mostly playing stand or sat?
    1 2 3 4 5 6
    Sat Stand
23. During concert or rehearsal, on which side of the stand are you sitting?
    ☐ Left ☐ Equally both
    ☐ Right ☐ Alone
24. Are you happy with this position?
    ☐ Yes
    ☐ No
25. Are you playing on stage or in the pit?
    ☐ On stage ☐ In the pit ☐ Equally both

Section C: Global physical activity

26. Do you warm-up before playing?
    ☐ Never ☐ Sometimes ☐ Mostly
    ☐ Rarely ☐ Often ☐ Always
27. Do you use a recovery routine after playing?
    ☐ Never ☐ Sometimes ☐ Mostly
    ☐ Rarely ☐ Often ☐ Always

The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent sitting at a desk, sitting with friends, traveling in car, bus, train, reading, playing cards or watching television, but do not include time spent sleeping.

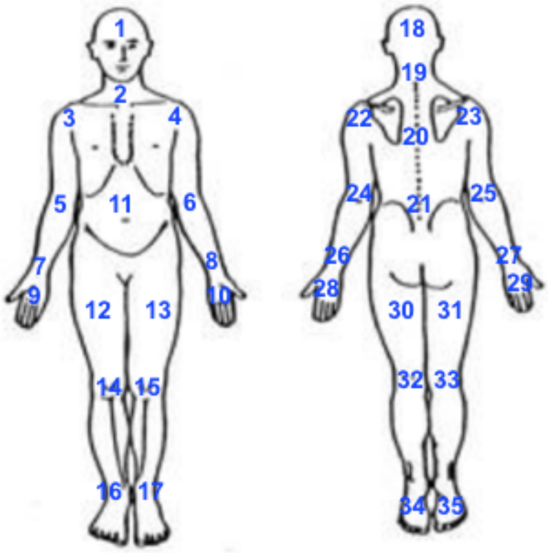
28. How much time do you usually spend sitting or reclining on a typical day?
29. During the past 12 months did you participate in any physical activities, exercise, recreation or sport?
    ☐ Yes
    ☐ No → Go to question 36
30. Do you do any vigorous-intensity sports, fitness or recreational (leisure) activities that cause large increases in breathing or heart rate like running or football for at least 10 minutes continuously?
    ☐ Yes
    ☐ No → Go to question 32
31. Please specify on a typical week:
32. Do you do any moderate-intensity sports, fitness or recreational (leisure) activities that cause a small increase in breathing or heart rate such as brisk walking, cycling, swimming, volleyball for at least 10 minutes continuously?
    ☐ Yes
    ☐ No → Go to question 34
33. Please specify on a typical week:
34. Do you walk or use a bicycle for at least 10 minutes continuously to get to and from places on a typical week?
    ☐ Yes
    ☐ No → Go to question 36
35. Please specify on a typical week:

Section D: Playing-related musculoskeletal disorders

Playing-related musculoskeletal problems are defined as "pain, weakness, numbness, tingling, or other symptoms that interfere with your ability to play your instrument at the level to which you are accustomed". This definition does not include mild transient aches and pains.

36. Have you ever had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed?
    - ☐ Yes
    - ☐ No
37. Have you had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed during the last 12 months?
    - ☐ Yes
    - ☐ No
38. Have you had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed during the last month (4 weeks)?
    - ☐ Yes
    - ☐ No
39. Have you had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed during the past 7 days?
    - ☐ Yes
    - ☐ No

40. If you have answered yes to the questions 38 and 39 (or both), you can continue the questionnaire. If not, go to question 52.



41. On the body chart (see above), mention each of the areas where you experience pain/problems.
42. On the body chart (see above), mention the area that hurts the most.

Please rate the pain on the body region you marked with an X by circling the one number that best describes your pain (0=no pain; 10= pain as bad as you can imagine):

43. At its worst in the last week:

0 1 2 3 4 5 6 7 8 9 10

No pain — Pain as bad as you can imagine

44. At its worst in the last week:

0 1 2 3 4 5 6 7 8 9 10

No pain | Pain as bad as you can imagine

45. On average

0	1	2	3	4	5	6	7	8	9	10
No pain										Pain as bad as you can imagine

46. Right now

0	1	2	3	4	5	6	7	8	9	10
No pain										Pain as bad as you can imagine

For each of the following, circle the one number that describes how, during the past week, pain/problems have interfered with (0=does not interfere; 10= completely interferes):

47. Your mood

0	1	2	3	4	5	6	7	8	9	10
Does not interfere										Completely interferes

48. Your enjoyment of life

0	1	2	3	4	5	6	7	8	9	10
Does not interfere										Completely interferes

For each of the following, during the past week, as a result of your pain/problems, did you have any difficulty (0: no difficulty, 10: unable):

49. Using your usual technique for playing your instrument?

0	1	2	3	4	5	6	7	8	9	10
No difficulty										Unable

50. Playing your musical instrument because of your symptoms?

0	1	2	3	4	5	6	7	8	9	10
No difficulty										Unable

51. Playing your musical instrument as well as you would like?

0	1	2	3	4	5	6	7	8	9	10
No difficulty										Unable

52. Do you have any genetic predisposition, medical conditions or previous surgery that may have an impact on playing your instrument?
 - ☐ Yes, specify:
 - ☐ No
53. Did you miss days of work because of physical pain/problems during the past year?
 - ☐ Yes, how many:
 - ☐ No

54. How much are you likely to report your injury to the orchestra hierarchy?

-5	-4	-3	-2	-1	0	1	2	3	4	5
Never reporting										Systematically reporting

55. How much do you feel the orchestra hierarchy helpful?

-5	-4	-3	-2	-1	0	1	2	3	4	5
Not helpful at all										The most helpful possible

56. Do you play through pain?

☐ Never ☐ Sometimes ☐ Mostly
☐ Rarely ☐ Often ☐ Always

57. Do you think pain is normal while playing?
☐ Never ☐ Sometimes ☐ Mostly
☐ Rarely ☐ Often ☐ Always

58. Do you think pain is the result of damage to the tissues of the body?
☐ Never ☐ Sometimes ☐ Mostly
☐ Rarely ☐ Often ☐ Always

59. What do you think could reduce your pain while playing?
☐ Take more breaks during practice
☐ Stop playing for few days
☐ Relax (meditation, breath exercises)
☐ Take medication or pills against pain
☐ Change your posture
☐ Avoid the movements that trigger pain
☐ Worry about feeling pain and thinking about it
☐ Increase your global physical activity
☐ Ignore pain
☐ Concentrate on pain
☐ None of those
☐ Other:

60. What do you think will increase your pain while playing?
☐ Take more breaks during practice
☐ Stop playing for few days
☐ Relax (meditation, breath exercises)
☐ Take medication or pills against pain
☐ Change your posture
☐ Avoid the movements that trigger pain
☐ Worry about feeling pain and thinking about it
☐ Increase your global physical activity
☐ Ignore pain
☐ Concentrate on pain
☐ None of those
☐ Other:

Section E: Psychological and mental health and well-being

In the past 3 months:

61. Did you ever have a spell or an attack when all of a sudden you felt frightened, anxious, or very uneasy?
☐ Yes
☐ No

62. Would you say that you have been bothered by nerves or feeling anxious or on edge?
☐ Yes
☐ No

63. Would you say that being anxious or uncomfortable around other people is a problem for you in your life?
☐ Yes
☐ No

64. Did you have a period of one week or more when you lost interest in most things like work, hobbies, and other things you usually enjoyed?
    - ☐ Yes
    - ☐ No

65. Do you have difficulty to manage your personal/family life?
    - ☐ Never ☐ Sometimes ☐ Mostly
    - ☐ Rarely ☐ Often ☐ Always
66. Do you consider that you are striving to achieve your musical goals?
    - ☐ Never ☐ Sometimes ☐ Mostly
    - ☐ Rarely ☐ Often ☐ Always
67. While playing, do you put yourself under pressure with your extremely high expectations?
    - ☐ Never ☐ Sometimes ☐ Mostly
    - ☐ Rarely ☐ Often ☐ Always
68. After playing, do you feel disappointed if your performance was not perfect?
    - ☐ Never ☐ Sometimes ☐ Mostly
    - ☐ Rarely ☐ Often ☐ Always
69. Do you accept things in your life you can't change?
    - ☐ Never ☐ Often
    - ☐ Sometimes ☐ Routinely
70. Do you practice relaxation or meditation for 15-20 minutes daily?
    - ☐ Never ☐ Often
    - ☐ Sometimes ☐ Routinely

Music performance anxiety is the experience of marked and persistent anxious apprehension related to musical performance (…) may occur in a range of performance settings, but is usually more severe in settings involving high ego investment, evaluative threat (audience), and fear of failure (Kenny, 2011).

71. Have you ever experienced music performance anxiety?
    - ☐ Yes
    - ☐ No
72. Do you currently (in the past month) experience music performance anxiety?
    - ☐ Yes
    - ☐ No

<u>Section F: Life habits</u>

73. Do you have problem with tiredness?
    - ☐ Less ☐ More
    - ☐ No more ☐ Much more
74. Do you need to rest more?
    - ☐ Less ☐ More
    - ☐ No more ☐ Much more
75. Do you get enough sleep?
    - ☐ Never ☐ Often
    - ☐ Sometimes ☐ Routinely
76. How many hours do you sleep at night?
77. Please evaluate your current sleep quality:
    - ☐ Very bad ☐ Fairly good
    - ☐ Fairly bad ☐ Good

78. How much water do you drink on a typical day?
79. Do you currently smoke tobacco?
 - ☐ No
 - ☐ Less than daily
 - ☐ Daily
80. How often do you drink alcohol?
 - ☐ Never
 - ☐ 2-4/month
 - ☐ 4 or more/week
 - ☐ monthly or less
 - ☐ 2-3/week
81. How many drinks containing alcohol do you have on a typical day when you are drinking?
 - ☐ 1-2
 - ☐ 5-6
 - ☐ 10+
 - ☐ 3-4
 - ☐ 7-9
82. Do you take some drugs?
 - ☐ Yes
 - ☐ No
83. If yes, are they:
 - ☐ Recreational drugs
 - ☐ Performance drugs
84. Concerning your extra-work activities, how many hours per week do you spend doing activities using your arms, hands and fingers? (e.g.: using a computer, tinkering, gardening, sewing, etc):
85. Concerning your extra-work activities, how many hours per week do you spend doing activities with elevated arms? (e.g. tinkering something high, painting a ceiling, etc):
86. Eat 3-5 servings of fruit/vegetables each day?
 - ☐ Never
 - ☐ Often
 - ☐ Sometimes
 - ☐ Routinely
87. Limit use of sugars and food containing sugars?
 - ☐ Never
 - ☐ Often
 - ☐ Sometimes
 - ☐ Routinely
88. Have a special nutritional regime?

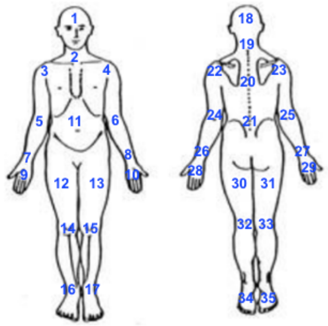
Appendix I: Injury Risk Factors Questionnaire M – References

No.	Model's group – items	Question	Type/scale	Source	Reference
Dear participant, Many thanks for your interest. The aim of this study is to develop and validate a specific questionnaire that will investigate injury risk factors in musicians, to prevent them before the onset of any musculoskeletal disorders related to playing music. This questionnaire won't take you more than 30 minutes to fill in. Many thanks for your help, Céleste, PhD student at Liverpool John Moores University					
Section A: Epidemiological data					
1.	Demographics	Name:	Open-ended		
2.	IC – Age	Age:	Open-ended (years)	MPIIQM	Berque et al., 2014
3.	IC - Gender	Sex:	Male/female/other	MPIIQM	Berque et al., 2014
4.	Demographics	What instrument do you play in the orchestra?	Open-ended	MPIIQM	Berque et al., 2014
5.	IC – Number of years playing	For how many years have you played you instrument?	Open-ended (years)	MPIIQM	Berque et al., 2014
6.	IC – Number of years playing	For how many years have you played professionally in an orchestra?	Open-ended (years)	MPIIQM	Berque et al., 2014
Section B: Typical workload and work environment					
7.	Workload – Position in orchestra	With respect to your position in the orchestra, do you work:	Part-time/Full-time	MPIIQM	Berque et al., 2014
8.	Workload – Job status	What is your job status?	Free-lance/ Employed/other		
9.	Workload – Number of hours playing (rehearsal)	Please estimate your typical weekly rehearsal workload:	Open-ended (hours per week)	Inspired from MPIIQM	Berque et al., 2014
10.	Workload - Number of hours playing (concert)	Please estimate your typical weekly concert workload:	Open-ended (hours per week)	Inspired from MPIIQM	Berque et al., 2014
11.	Workload – Number of hours (private practice)	Please estimate your typical weekly private practice workload:	Open-ended (hours per week)	Inspired from MPIIQM	Berque et al., 2014

12.	Workload – Lack of rest (private practice)	Please estimate how long are your average private practice sessions:	Open-ended (hours per day)		Ackermann & Driscoll, 2010
13.	Workload – Lack of rest (private practice)	Please estimate how many practice sessions you would do normally per day:	Open-ended		Ackermann & Driscoll, 2010
14.	Workload – Lack of rest (private practice)	Please estimate the length of time that you would rest for between practice sessions:	Open-ended (minutes)		Ackermann & Driscoll, 2010
15.	Workload – Amount of extra-orchestra hours of practice	Please estimate your typical weekly teaching workload:	Open-ended (hours per week)		Ackermann & Driscoll, 2010
16.	Workload – Amount of extra-orchestra hours of practice	Please estimate your typical extra-orchestra workload (except teaching):	Open-ended (hours per week)		Ackermann & Driscoll, 2010
17.	Workload – Concert and rehearsal program	How uniform do you consider the concert and rehearsal program in term of workload?	Mostly uniform the whole year/ Peak and valley the whole year		Kok et al., 2016
18.	Workload – Concert and rehearsal program/Sudden increase	If peak and valley, are you:	In a "peak" period/ In a "valley" period		Kok et al., 2016
19.	Workload – Variety and difficulty of the repertoire	How do you currently find the repertoire you are playing?	6-Likert scale: easy – really difficult		Ackermann & Driscoll, 2010
20.	Life habits - Touring	Are you often touring?	6-Likert Scale: never – rarely – sometimes – often – mostly - always		Ackermann et al., 2002
21.	Posture – Sitting position	During concert or rehearsal, are you mostly playing stand or sat?	6-Likert Scale: sat - stand		Price et al., 2014
22.	Posture – Sitting position	Concerning your private practice, are you mostly playing stand or sat?	6-Likert Scale: sat – stand		Price et al., 2014
23.	Environment – Side of the stand	During concert or rehearsal, on which side of the stand are you sitting?	Left/right/equally both/alone		Spahn et al., 2014
24.	Environment – Side of the stand	Are you happy with this position?	Yes/No		Spahn et al., 2014

25.	Environment – Pit or stage	Are you playing on stage or in the pit?	On stage/in the pit/equally both		Kenny et al., 2016
Section C: Global physical activity					
26.	Physical conditioning – Warm-up	Do you warm-up before playing?	6-Likert Scale: never – rarely – sometimes – often – mostly - always		McCrary et al., 2016
27.	Physical conditioning – Recovery	Do you use a recovery routine after playing?	6-Likert scale: never - always		
The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent sitting at a desk, sitting with friends, traveling in car, bus, train, reading, playing cards or watching television, but do not include time spent sleeping.					
28.	Physical conditioning – Sedentary behaviour	How much time do you usually spend sitting or reclining on a typical day?		GPAQ	WHO, 2002
29.	Physical conditioning – Global physical activity	During the past 12 months did you participate in any physical activities, exercise, recreation or sport?	Yes/No → go on question 33	GPAQ	WHO, 2002
30.	Physical conditioning – Vigorous activity	Do you do any vigorous-intensity sports, fitness or recreational (leisure) activities that cause large increases in breathing or heart rate like running or football for at least 10 minutes continuously?	Yes/No	GPAQ	WHO, 2002
31.	Physical conditioning – Vigorous activity	If yes to 30, please specify on a typical week:	Open-ended (session per week and minutes per session)	Inspired from GPAQ	WHO, 2002
32.	Physical conditioning – Moderate activity	Do you do any moderate-intensity sports, fitness or recreational (leisure) activities that cause a small increase in breathing or heart rate such as brisk walking, cycling, swimming, volleyball for at least 10 minutes continuously?	Yes/No	GPAQ	WHO, 2002
33.	Physical conditioning – Moderate activity	If yes to 32, please specify on a typical week:	Open-ended (session per week and minutes per session)	Inspired from GPAQ	WHO, 2002

34.	Physical conditioning – Moderate activity	Do you walk or use a bicycle for at least 10 minutes continuously to get to and from places on a typical week?	Yes/No	GPAQ	WHO, 2002
35.	Physical conditioning – Moderate activity	If yes to 34, please specify on a typical week:	Open-ended (days per week and minutes per day)	Inspired from GPAQ	WHO, 2002
Section D: Playing-related musculoskeletal disorders *Playing-related musculoskeletal problems are defined as "pain, weakness, numbness, tingling, or other symptoms that interfere with your ability to play your instrument at the level to which you are accustomed". This definition does not include mild transient aches and pains.*					
36.	Pain – Prevalence	Have you ever had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed?	Yes/No	MPIIQM	Berque et al., 2014
Have you had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed:					
37.	Pain – Prevalence	During the last 12 months?	Yes/No	Inspired from MPIIQM	Berque et al., 2014
38.	Pain – Prevalence	During the last month (4 weeks)?	Yes/No	Inspired from MPIIQM	Berque et al., 2014
39.	Pain – Prevalence	During the past 7 days?	Yes/No	Inspired from MPIIQM	Berque et al., 2014
40.	Pain – Prevalence	Have you answered yes to the 38 or 39 questions (or both)?	Yes/No → go on question 52	Inspired from MPIIQM	Berque et al., 2014
41.	Pain – Body locations	On the body chart, mention each of the areas where you experience pain/problems.	Number on body chart	Inspired from MPIIQM	Berque et al., 2014

					
42.	Pain – Body locations	On the body chart (see above), mention the area that hurts the most.	Number on body chart	Inspired from MPIIQM	Berque et al., 2014
<u>Please rate the pain on the body region you marked with an X by circling the one number that best describes your pain (0=no pain; 10= pain as bad as you can imagine):</u>					
43.	Pain – Intensity	At its worst in the last week:	11-Likert Scale: no pain – pain as bad as you can imagine	Inspired from MPIIQM	Berque et al., 2014
44.	Pain – Intensity	At its least in the last week:	11-Likert Scale: no pain – pain as bad as you can imagine	Inspired from MPIIQM	Berque et al., 2014
45.	Pain – Intensity	On average:	11-Likert Scale: no pain – pain as bad as you can imagine	Inspired from MPIIQM	Berque et al., 2014
46.	Pain – Intensity	Right now:	11-Likert Scale: no pain – pain as bad as you can imagine	Inspired from MPIIQM	Berque et al., 2014
<u>For each of the following, circle the one number that describes how, during the past week, pain/problems have interfered with (0=does not interfere; 10= completely interferes):</u>					
47.	Pain - Interference	Your mood	11-Likert Scale: does not – completely interferes	Inspired from MPIIQM	Berque et al., 2014

48.	Pain – Interference	Your enjoyment of life	11-Likert Scale: does not – completely interferes	Inspired from MPIIQM	Berque et al., 2014
<u>For each of the following, during the past week, as a result of your pain/problems, did you have any difficulty (0: no difficulty, 10: unable):</u>					
49.	Pain – Interference	Using your usual technique for playing your instrument?	11-Likert Scale: no difficulty - unable	Inspired from MPIIQM	Berque et al., 2014
50.	Pain – Interference	Playing your musical instrument because of your symptoms?	11-Likert Scale: no difficulty - unable	Inspired from MPIIQM	Berque et al., 2014
51.	Pain – Interference	Playing your musical instrument as well as you would like?	11-Likert Scale: no difficulty - unable	Inspired from MPIIQM	Berque et al., 2014
52.	Individual characteristics – Genetic predispositions, non-musculoskeletal disorders	Do you have any genetic predisposition, medical conditions or previous surgery that may have an impact on playing your instrument?	Yes/No → go on question 53		Ackermann & Driscoll, 2010
		If yes, specify:	Open-ended		Ackermann & Driscoll, 2010
53.	Pain – Interference	Did you miss days of work because of physical pain/problems during the past year?	Yes/No → go on question 54		Ackermann & Driscoll, 2010
	Pain – Interference	If yes, how many:	Open-ended (days this past year)		Ackermann & Driscoll, 2010
54.	Injury management – Orchestra management behaviour towards injury	How much are you likely to report your injury to the orchestra hierarchy?	11(-5/5)-Likert scale: never reporting – systematically reporting		Heredia et al., 2016
55.	Injury management – Musicians' behaviour towards injury	How much do you feel the orchestra hierarchy helpful?	11(-5/5)-Likert scale: not helpful at all – the most helpful possible		Heredia et al., 2016

56.	Injury management – No pain no gain and knowledge Musicians' behaviour – Beliefs towards pain	Do you play through pain?	6-Likert Scale: never – rarely – sometimes – often – mostly - always		Britsch et al., 2005
57.	Injury management - No pain no gain and knowledge Musicians' behaviour – Beliefs towards pain	Do you think pain is normal while playing?	6-Likert Scale: never – rarely – sometimes – often – mostly - always		Britsch et al., 2005
58.	Injury management - No pain no gain and knowledge Musicians' behaviour – Beliefs towards pain	Do you think pain is the result of damage to the tissues of the body?	6-Likert Scale: never – rarely – sometimes – often – mostly - always		Edwards et al., 1992
59.	Injury management - No pain no gain and knowledge Musicians' behaviour – Beliefs towards pain	What do you think could reduce your pain while playing?	Multiple choice question: Take more breaks during practice - Stop playing for few days - Relax (meditation, breath exercises) - Take medication or pills against pain - Change your posture - Avoid the movements that trigger pain - Worry about feeling pain and thinking about it − Increase your global physical activity - Ignore pain - Concentrate on pain	Inspired from PBQ	Edwards et al., 1992
60.	Injury management - No pain no gain and knowledge Musicians' behaviour – Beliefs towards pain	What do you think will increase your pain while playing?		Inspired from PBQ	Edwards et al., 1992

			- None of those - Other		
Section E: Psychological and mental health and well-being					
In the past 3 months:					
61.	Psychosocial/psychology – Anxiety	Did you ever have a spell or an attack when all of a sudden you felt frightened, anxious, or very uneasy?	Yes/No	ADD	Means-Christensen et al., 2006
62.	Psychosocial/psychology – Anxiety	Would you say that you have been bothered by nerves or feeling anxious or on edge?	Yes/No	ADD	Means-Christensen et al., 2006
63.	Psychosocial/psychology – Social phobia	Would you say that being anxious or uncomfortable around other people is a problem for you in your life?	Yes/No	ADD	Means-Christensen et al., 2006
64.	Psychosocial/psychology – Depression	Did you have a period of one week or more when you lost interest in most things like work, hobbies, and other things you usually enjoyed?	Yes/No	ADD	Means-Christensen et al., 2006
65.	Psychosocial/psychology – Management of personal life	Do you have difficulty to manage your personal/family life?	6-Likert Scale: never – rarely – sometimes – often – mostly - always		
66.	Psychosocial/psychology – Perfectionism	Do you consider that you are striving to achieve your musical goals?	6-Likert Scale: never – rarely – sometimes – often – mostly - always	Inspired from MIPS	Stoeber et al., 2004
67.	Psychosocial/psychology – Perfectionism	While playing, do you put yourself under pressure with your extremely high expectations?	6-Likert Scale: never – rarely – sometimes – often – mostly - always	Inspired from MIPS	Stoeber et al., 2004

68.	Psychosocial/psychology – Perfectionism	After playing, do you feel disappointed if your performance was not perfect?	6-Likert Scale: never – rarely – sometimes – often – mostly - always	Inspired from MIPS	Stoeber et al., 2004
69.	Psychosocial/psychology – Stress (management)	Do you accept things in your life you can't change?	4-Likert Scale: never – sometimes – often – routinely	Inspired from HPLP II	Walker et al., 1987
70.	Psychosocial/psychology – Stress (management)	Do you practice relaxation or meditation for 15-20 minutes daily?	4-Likert Scale: never – sometimes – often – routinely	Inspired from HPLP II	Walker et al., 1987
"Music performance anxiety is the experience of marked and persistent anxious apprehension related to musical performance (…) may occur in a range of performance settings, but is usually more severe in settings involving high ego investment, evaluative threat (audience), and fear of failure."					
71.	Psychosocial/psychology – Music Performance Anxiety	Have you ever experienced music performance anxiety?	Yes/No		Kenny, 2011
72.	Psychosocial/psychology – Music Performance Anxiety	Do you currently (in the past month) experience music performance anxiety?	Yes/No		Kenny, 2011
Section F: Life habits					
73.	Psychosocial/psychology – Fatigue	Do you have problem with tiredness?	4-Likert Scale: less/no more / more/much more	Inspired from CFS	Cella & Chalder, 2010
74.	Psychosocial/psychology – Fatigue	Do you need to rest more?	4-Likert Scale: less/no more / more/much more	Inspired from CFS	Cella & Chalder, 2010
75.	Life habits – Sleep Psychosocial/psychology – Stress (management)	Do you get enough sleep?	4-Likert Scale: never – sometimes – often – routinely	Inspired from HPLP II	Walker et al., 1987
76.	Life habits – Sleep	How many hours do you sleep at night?	Open-ended (hours per night)	Inspired from PSQI	Buysse et al., 1989
77.	Life habits – Sleep	Please evaluate your current sleep quality:	4-Likert Scale: very bad – fairly bad/good – very good	Inspired from PSQI	Buysse et al., 1989

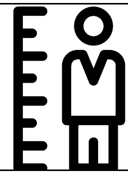
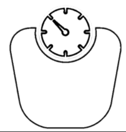
78.	Life habits – Hydration	How much water do you drink on a typical day?	Open-ended (litre per day)		Chan & Ackermann, 2014
79.	Life habits – Tobacco	Do you currently smoke tobacco?	No/less than daily/daily	Inspired from GATS	WHO, 2011
80.	Life habits – Alcohol	How often do you drink alcohol	5-Likert scale: never – monthly or less, 2-4/month, 2-3/week, 4 or more/week	Inspired from AUDIT	Saltychev et al., 2016; WHO, 2001
81.	Life habits – Alcohol	How many drinks containing alcohol do you have on a typical day when you are drinking?	5-Likert scale: 1-2, 3-4, 5-6, 7-9, 10+	Inspired from AUDIT	Saltychev et al., 2016; WHO, 2001
82.	Life habits – Drugs	Do you take some drugs?	5-Likert scale: never – monthly or less, 2-4/month, 2-3/week, 4 or more/week	Inspired from AUDIT	Kenny et al., 2015
83.	Life habits – Drugs	If yes, are they:	Performance or recreational drugs?		Kenny et al., 2015
84.	Life habits – Hobbies	Concerning your extra-work activities, how many hours per week do you spend doing activities using your arms, hands and fingers? (e.g.: using a computer, tinkering, gardening, sewing, etc):	Open-ended (hours per week)		Ackermann & Driscoll, 2010
85.	Life habits – Hobbies	Concerning your extra-work activities, how many hours per week do you spend doing activities with elevated arms? (e.g. tinkering something high, painting a ceiling, etc):	Open-ended (hours per week)		Ackermann & Driscoll, 2010
Concerning what you eat per day, do you:					
86.	Life habits – Nutrition	Eat 3-5 servings of fruit/vegetables each day?	4-Likert Scale: never – sometimes – often – routinely	Inspired from HPLP II	Walker et al., 1987
87.	Life habits – Nutrition	Limit use of sugars and food containing sugars?	4-Likert Scale: never – sometimes – often – routinely	Inspired from HPLP II	Walker et al., 1987

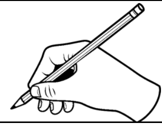
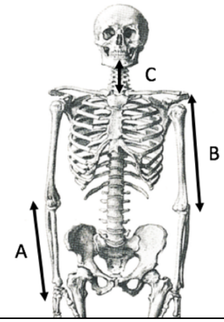
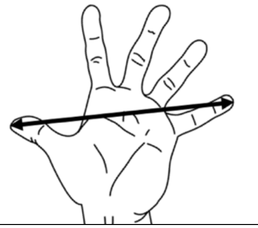
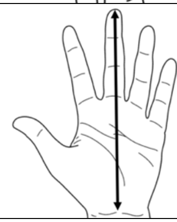
88.	Life habits – Nutrition	Have a special nutritional regime?	Open-ended		Ackermann & Driscoll, 2010

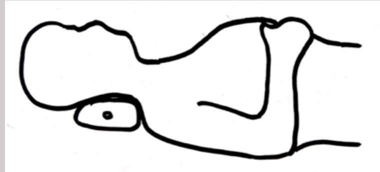
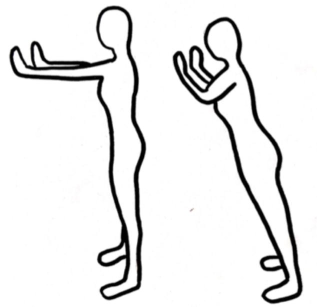
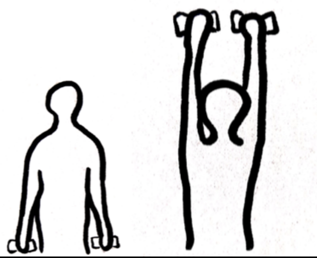
Legend:
ADD: Anxiety Depression Detector (Means-Christensen et al., 2006)
AUDIT: Alcohol Use Disorders Identification Test (WHO, 2001)
CFS: Chalder Fatigue Scale (Cella & Chalder, 2010)
GPAQ: Global Physical Activity Questionaire (WHO, 2002)
GTSS: Global Tobacco Surveillance System (Global Adult Tobacco Survey Collaborative Group, 2011)
HPLP II: Health Promoting Lifestyle Profile II (
MPIIQM: Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (Berque et al., 2014)
MPIS: Multidimensional Inventory of Perfectionism in Sport (Stoeber et al., 2004)
PBQ: Pain Beliefs Questionnaire (Edwards et al., 1992)
PSQI: Pittsburgh Sleep Quality Index (Buysse et al., 1989)

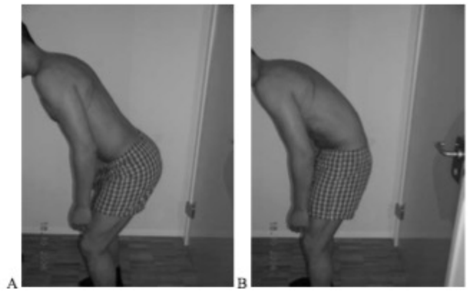
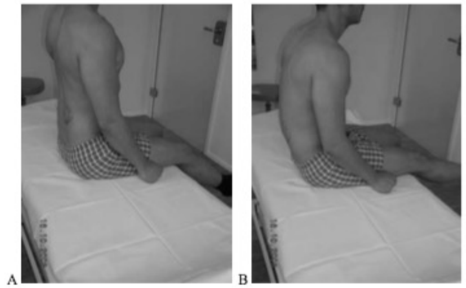
Appendix J : Physical examination

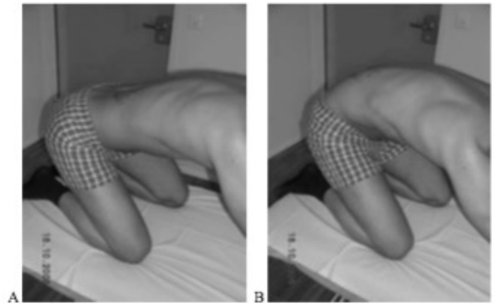
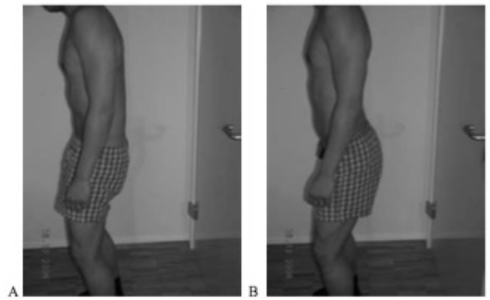
This physical assessment has been based on existing tests, already described in literature, to investigate muscle function, joint range of movements, motor control or others such as anthropometrics measures.
All of these tests have been listed to fit with playing-related musculoskeletal disorders risk factors. This is not an exhaustive list: depending on the body location and on the symptoms, you should add as much tests as needed.

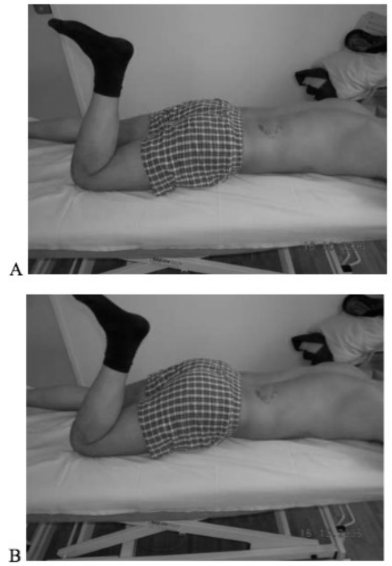
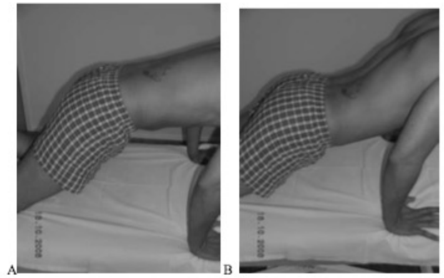
<table>
<tr><td colspan="4"><u>Section A: Epidemiological data</u>
Participant code/name:
Gender: Female / Male / Other
Age:
Instrument:</td></tr>
<tr><td colspan="4"><u>Section B: Medical history:</u></td></tr>
<tr><td colspan="2">- Previous surgery:
- Recent injury/ongoing pain:
- Open wounds:
- Fractures, dislocation, injury, pain or numbness:</td><td colspan="2">- Osteoporosis:
- Diabetes:
- Asthma or any pulmonary chronic disease:
- AIDS:</td></tr>
<tr><td colspan="4"><u>Section C: Global examination</u>
Material: tape, scale</td></tr>
<tr><td><u>Test</u></td><td><u>Procedure</u></td><td><u>Picture</u></td><td><u>Results</u></td></tr>
<tr><td>Height
(Ackermann & Driscoll, 2010)</td><td>Tape measure</td><td></td><td>cm</td></tr>
<tr><td>Body mass
(Ackermann & Driscoll, 2010)</td><td>Scale measure</td><td></td><td>kg</td></tr>
<tr><td>BMI
(Vinci et al., 2015)</td><td>Mass/(Height^2)</td><td></td><td></td></tr>
</table>

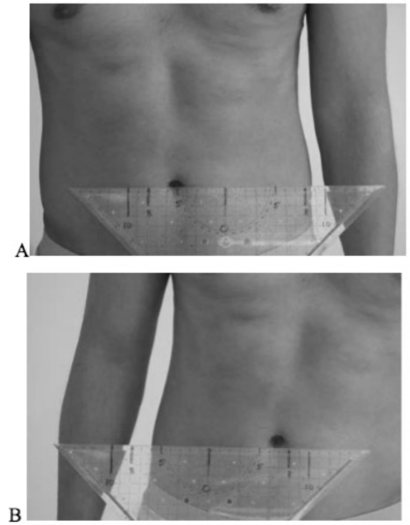
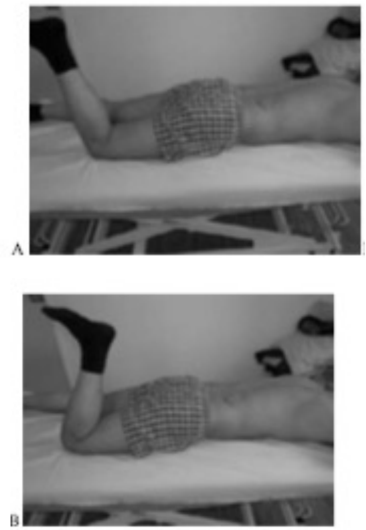
Handedness (Ackermann & Driscoll, 2010)	Ask the participant		cm
Lower arm length (Ackermann & Driscoll, 2010)	Tape measure: standing, lateral epicondyle → radial styloid (note any abnormalities that could affect readings) (A)		cm
Upper arm length (Ackermann & Driscoll, 2010)	Tape measure: standing, acromion → lateral epicondyle (note any abnormalities that could affect readings) (B)		cm
Neck length (post) (George et al., 2017)	Tape measure: standing, C7 spinous process → external occipital protuberance (C)		cm
Hand span (Ackermann & Driscoll, 2010)	**Sitting**, forearm in pronation, ask to spread his/her hand out as far as he can. Distance measured with tape: between mid thumb tip and mid little finger marks.		cm
Hand length (Kono et al., 2013)	**Sitting**, forearm supported in supination, distance between 1st line of flexion and top of the 3rd finger.		cm
Ergonomics: describe every element such as thumb rest (e.g. clarinet), chin/shoulder-rest (e.g. violin/viola), support (e.g. brass players)			

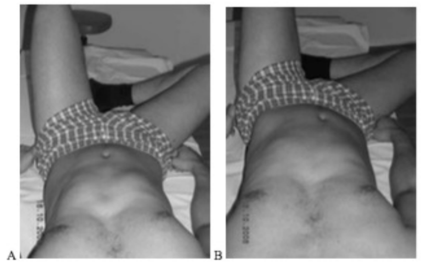
Section D: Motor control and endurance				
Test		**Procedure**	**Picture**	**Results**
Cervical spine	Cranio-cervical function test (Jull et al., 2008)	**Supine**, cuff inflated to starting pressure of 20mmHg. Ask subject to nod the head forward as if he was saying yes, maintain the pressure for 10 seconds. Count number of 10 seconds achieved (max 10 repetitions). Note any use of superficial flexors (not allowed).		
Shoulder blades	Wall push-ups (Madsen et al., 2011)	Participant is asked to stand in front of a wall or door with 90° elevated arms and extended elbows and instructed to push forward against the resistance. Positive test if the scapula loses contact with the chest wall (scapula alata) or if the medial edges of the scapulae move together.		
	Scapular dyskinesia test – abduction (McClure et al., 2009)	**Standing**, performance of 5 repetitions of bilateral, active and weighted shoulder flexion and abduction. Dumbbells: - 1.4 kg if < 68,1 kg - 2,3 kg if > 68,1 kg		
	Scapular dyskinesia test – flexion (McClure et al., 2009)			
	Distance acromion wall – Relaxed (Cleland et al., 2011; Struyf et al., 2009)	Horizontal distance between posterior border of the acromion and the wall, back facing to the wall, participant asked to relax his/her shoulder.		cm
	Distance acromion wall – Retracted (Cleland et al., 2011; Struyf et al., 2009)	Horizontal distance between posterior border of the acromion and the wall, back facing to the wall, participant asked to retract his/her shoulder.		cm

Trunk	Waiters bow (Luomajoki et al., 2007; 2008; 2018)	Movement: Flexion of the hips in upright standing without movement (flexion) of the low back. A Correct – Forward bending of the hips without movement of the low back (50–70° Flexion hips). B Not correct – Angle hip Fx without low back movement less than 50° or Flexion occurring in the low back. Rating protocol: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a relevant movement dysfunction.	 © Luomajoki et al.	C / NC
	Sitting knee extension (Luomajoki et al., 2007; 2008; 2018)	Upright sitting with corrected lumbar lordosis; extension of the knee with- out movement (flexion) of low back A Correct – Upright sitting with corrected lumbar lordosis; extension of the knee without movement of LB (30–50° Extension normal). B Not correct – Low back moving in flexion. Patient is not aware of the movement of the back. Rating protocol: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a relevant movement dysfunction.	 © Luomajoki et al.	C / NC

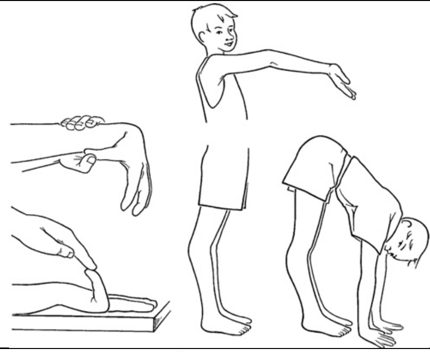
	Rocking backwards (Luomajoki et al., 2007; 2008; 2018)	Transfer of the pelvis backwards ("rocking") in a quadruped position keeping low back in neutral. A Correct – 120° of hip flexion without (Fx) movement of the low back by transferring pelvis backwards. B Not correct – Hip flexion causes flexion in the lumbar spine (typically the patient not aware of this). Rating proto- col: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement con- trol improved by instruction and correction, it was consid- ered that it did not infer a relevant movement dysfunction.	 © Luomajoki et al.	C / NC
	Dorsal tilt of pelvis (Luomajoki et al., 2007; 2008; 2018)	Actively in upright standing. A Correct – Actively in upright standing (Gluteus activity); keeping thoracic spine in neutral, lumbar spine moves towards Fx. B Not correct – Pelvis doesn't tilt or low back moves towards Ext./No gluteal activity/compensatory Fx in Thx. Rating protocol: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a rele- vant movement dysfunction.	 © Luomajoki et al.	C / NC

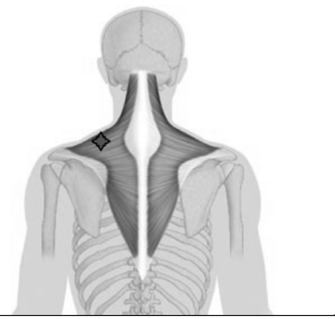
	Prone lying active knee flexion (Luomajoki et al., 2007; 2008; 2018)	A Correct - Active knee flexion at least 90° without extension movement of the low back and pelvis. B Not correct - By the knee flexion low back does not stay neutral maintained but moves in Ext. Rating protocol: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a relevant movement dysfunction.	 © Luomajoki et al.	C / NC
	Rocking forwards (Luomajoki et al., 2007; 2008; 2018)	A Correct – Rocking forwards without extension movement of the low back. B Not correct – Hip movement leads to extension of the low back Rating protocol: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a relevant movement dysfunction.	 © Luomajoki et al.	C / NC

	One leg stance (Luomajoki et al., 2007; 2008; 2018)	From normal standing to one leg stance: measurement of lateral movement of the belly but- ton. (Position: feet one third of trochanter distance apart). A Correct – The distance of the transfer is symmetrical right and left. Not more than 2 cm difference between sides. B Not correct – Lateral transfer of belly button more than 10 cm. Difference between sides more than 2 cm. Rating protocol: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a relevant movement dysfunction.	 © Luomajoki et al.	cm
	Prone lying active knee flexion (Luomajoki et al., 2007; 2008; 2018)	A Correct – Prone lying active knee flexion at least 90° without (rot) movement of the low back and pelvis. B Not correct – Pelvis rotates with knee flexion. Rating protocol: As patients did not know the tests, only clear movement dys- function was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a relevant movement dysfunction.	 © Luomajoki et al.	C / NC

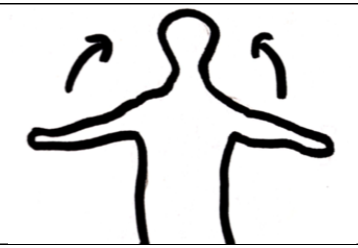
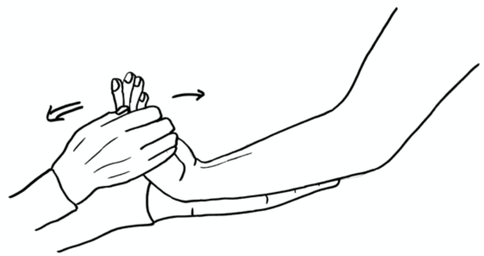
	Crook lying (Luomajoki et al., 2007; 2008; 2018)	A Correct – Active abduction of the hip without rotational move- ment of the pelvis and low back. B Not correct – Belly button moves sidewards, pelvis rotates or tilts. Rating pro- tocol: As patients did not know the tests, only clear move- ment dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a relevant movement dysfunction. Rating protocol: As patients did not know the tests, only clear movement dysfunction was rated as "not correct". If the movement control improved by instruction and correction, it was considered that it did not infer a rele- vant movement dysfunction.	 © Luomajoki et al.	C / NC
	Plank test (inspired from Tong et al., 2013)	Participant asked to hold the plank position the longest time possible.		seconds
Hand	Independence FDS test (Godwin et al., 2014)	Subject is asked to flex his little finger when other fingers are maintained in extension, independence if the participant can perform isolated PIPJ flexion.	 Absent independent FDS function in the small finger	Y / N

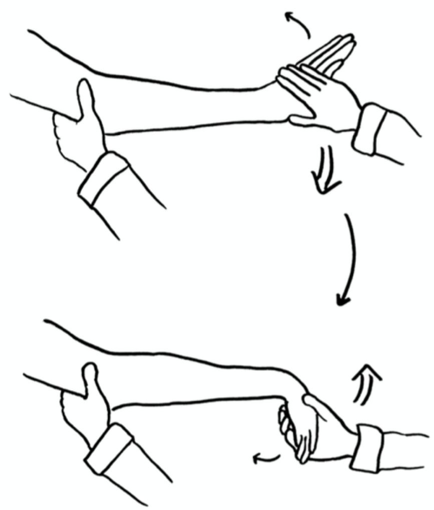
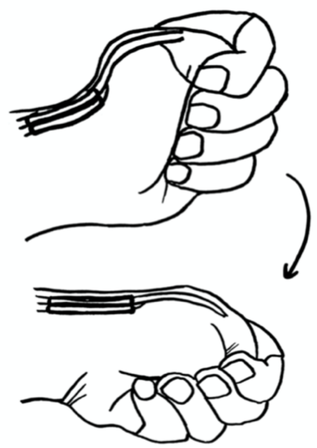
			 Independent FDS function in the small finger	
	Thomas sign (Schreuders et al., 2007)	Tendency of a patient with weak interosseous muscles to flex the wrist in an attempt to gain a better opening of the hand, i.e. MCP extension, by means of increasing the pull on the common extensors.	 Absence of Thomas sign  Presence of Thomas sign	Y / N
<u>Section E: Mobility</u> Material: goniometer, inclinometer, tape, surgical pen				

Test		Procedure	Picture	Results
Beighton scale (used in Ackermann & Driscoll, 2010)		**Standing**: finger to floor, elbow and knee hyper-extension, pressing thumbs against forearm, little finger extending. Lumbar/1; elbow and knee /4; thumbs /2; little fingers /2.		/5
Shoulder	Appley 1 (Kendall et al., 2005)	**Standing**, participant is asked to take his/her hand behind the head and reach down as far as he/she can along the spine with the tip of the middle finger. Measure distance T1 – fingertip, note any pain.		cm
	Appley 2 (Kendall et al., 2005)	**Standing**, participant is asked to take his/her hand backwards and reach up as far as he/she can along the spine, sliding the wrist. Measure T1 – radial styloid process, note any pain.		cm
	Appley 3 (Kendall et al., 2005)	**Standing**, participant is asked to grab the top of his other shoulder. Note ability, any pain or shoulder hitching.		Y / N

Elbow and wrist	Flexion, extension of elbow and wrist, supination and pronation will be asked to perform quickly. If any pain or obvious limitation is noted, goniometry will be realised.		Pain / No pain
Cervical spine	Flexion, extension, side bending and rotations will be asked to perform actively and quickly. If any pain or obvious limitation is noted, goniometry will be realised.		Pain / No pain
Global spine: FFD (Robinson et al., 2014)	Subject is asked to bring his fingers as close to floor as he/she can, keeping their knees, arms and fingers extended. Measure of distance between tip of mid finger (fully extended) and floor with tape. Photography of the curvatures will be also taken.		Pain / No pain
<u>Section F: Pain</u> Material: handheld dynamometer			
<u>Test</u>	**<u>Procedure</u>**	**<u>Picture</u>**	**<u>Results</u>**
Trigger point (Ackermann & Driscoll, 2010)	**Standing**, arm by side, apply pressure to the UT point, halfway between acromion and C7 with dynamometer to 5kg of pressure. Record level of pressure if tolerated maximum is under 5kg.		kg
Any tingling, numbness, weakness sensations? Y / N If yes:			

ULNT	Ulnar nerve (Butler, 2010)	Sequencing: wrist extension, pronation, elbow flexion, shoulder external rotation, shoulder girdle depression, shoulder abduction. Note any pain or reduction of nerve tension. If any, measure ROM of each joint.	 $ULNT_{ULNAR(3)}$ © *Butler*	Pain / No pain If pain: note ROM of each joint.
	Radial nerve (Butler, 2010)	Sequencing: shoulder girdle depression, elbow extension, shoulder internal rotation, pronation, wrist flexion, shoulder abduction. Note any pain or reduction of nerve tension. If any, measure ROM of each joint.	 $ULNT_{RADIAL(2b)}$ © *Butler*	Pain / No pain If pain: note ROM of each joint.
	Medial nerve (1) (Butler, 2010)	Sequencing: shoulder girdle fixation, shoulder abduction, wrist extension, supination, shoulder external rotation, elbow extension. Note any pain or reduction of nerve tension. If any, measure ROM of each joint.	 $ULNT_{MEDIAN(1)}$ © *Butler*	Pain / No pain If pain: note ROM of each joint.
	Medial nerve (2) (Butler, 2010)	Sequencing: shoulder girdle depression, elbow extension, shoulder external rotation, supination, wrist extension, shoulder abduction. Note any pain or reduction of nerve tension. If any, measure ROM of each joint.	 $ULNT_{MEDIAN(2a)}$	Pain / No pain If pain: note ROM

		© Butler	of each joint.
Any pain in the shoulder? Y / N If yes:			
Painful arc test (Cleland et al., 2011; Ackermann & Driscoll, 2010)	**Standing**, arm by sides, subject is asked to raise the arm as far as he can in flexion and in abduction. Note any pain or ROM reduction.		Y / N
Any pain in the elbow? Y / N Medial pain? If yes:			
Golfer elbow test (Zwerus et al., 2016)	**Sitting**, elbow extended and forearm supinated. Subject is asked to move the hand to palmar flexion against resistance. Note any pain.		Y / N
Lateral pain? If yes:			

Cozen's test (Saroja et al., 2014)	**Sitting**, elbow fully extended and forearm pronated, subject ask to make a full fist with wrist extension against resistance followed by pronation and passive radial deviation. Note any pain.		Y / N
Pain in the wrist or in the hand? If yes:			
Finkelstein's test (Ackermann & Driscoll, 2010)	Arm by side, elbow and forearm resting supported, hand unsupported. Subject is asked to hold his thumb inside his fist and then the assessor brings the wrist in slight flexion and ulnar deviation. Note any pain.		Y / N

Appendix K: Table K.1 – Physical examination - Measurements in males among the sample

Measurements	Upper strings (n=7)	Lower strings (n=4)	Woodwinds (n=1)	Brass (n=1)	Percussions (n=2)	Total (n=15)
Epidemiological data						
Age	48.1 (±14.3)	42.0 (±9.2)	62.0	46.0	35.0 (±2.8)	45.5 (±12.2)
Height (cm)	179.8 (±3.6)	179.0 (±2.5)	183.0	179.0	183.0 (±8.5)	180.1 (±3.8)
Mass (kg)	84.1 (±13.9)	85.4 (±6.1)	89.0	102.3	77.7 (±9.8)	85.1 (±11.3)
BMI	26.0 (±4.0)	26.7 (±2.1)	26.8	31.9	23.2 (±0.8)	26.2 (±3.4)
Anthropometrics						
Handedness	Right: 7	Right: 4	Right: 1	Right: 1	Right: 1 Left: 1	Right: 14 Left: 1
Left lower arm (cm)	25.9 (±1.8)	27.3 (±1.5)	28.0	28.0	28.0 (±1.4)	26.9 (±1.8)
Right lower arm (cm)	26.4 (±2.3)	28.3 (±1.0)	29.0	28.0	27.5 (±3.5)	27.3 (±2.1)
Left upper arm (cm)	33.9 (±1.8)	33.5 (±1.3)	35.0	34.0	34.5 (±2.1)	33.9 (±1.5)
Right upper arm (cm)	34.3 (±1.5)	32.3 (±0.5)	34.0	34.0	36.0 (±0)	33.9 (±1.6)
Neck length (cm)	14.9 (±2.6)	14.8 (±3.6)	15.5	14.5	12.8 (±1.8)	14.6 (±2.6)
Left hand span (cm)	21.9 (±1.4)	22.4 (±1.7)	24.0	22.0	21.3 (±0.4)	22.1 (±1.4)
Right hand span (cm)	21.6 (±1.2)	21.4 (±2.1)	23.0	21.0	21.5 (±0)	21.6 (±1.3)
Left hand length (cm)	19.1 (±0.5)	19.5 (±0.4)	21.0	20.0	19.8 (±1.8)	19.5 (±0.8)
Right hand length (cm)	19.0 (±0.3)	19.3 (±0.3)	20.0	19.0	19.8 (±1.8)	19.3 (±0.7)
Motor control, endurance and strength						
Left SDT Abduction	Physio: 2 Subtle: 2 Obvious: 3	Physio: 2 Subtle: 1 Obvious: 1	Physio: 0 Subtle: 0 Obvious: 1	Physio: 1 Subtle: 0 Obvious: 0	Physio:1 Subtle: 1 Obvious: 0	Physio: 6 Subtle: 4 Obvious: 5
Right SDT – Abduction	Physio: 0 Subtle: 3 Obvious: 4	Physio: 0 Subtle: 1 Obvious: 3	Physio: 1 Subtle: 0 Obvious:0	Physio: 1 Subtle: 0 Obvious: 0	Physio: 0 Subtle: 2 Obvious: 0	Physio: 2 Subtle: 6 Obvious: 7
Left SDT – Flexion	Physio: 1 Subtle: 2 Obvious: 4	Physio: 1 Subtle: 0 Obvious: 3	Physio: 0 Subtle: 1 Obvious: 0	Physio: 1 Subtle: 0 Obvious:0	Physio: 1 Subtle: 0 Obvious: 1	Physio: 4 Subtle: 3 Obvious: 8
Right SDT – Flexion	Physio: 1 Subtle: 1 Obvious: 5	Physio: 0 Subtle: 0 Obvious: 4	Physio: 1 Subtle: 0 Obvious: 0	Physio: 1 Subtle: 0 Obvious: 0	Physio: 1 Subtle: 0 Obvious: 1	Physio: 4 Subtle: 1 Obvious: 10

Left distance acromion – wall (relaxed shoulders) (cm)	8.6 (±1.7)	9.0 (±2.3)	6.5	8.0	8.3 (±1.1)	8.5 (±1.7)
Right distance acromion – wall (relaxed shoulders) (cm)	7.4 (±1.6)	9.6 (±1.5)	8.0	9.5	8.0 (±0.7)	8.3 (±1.6)
Left distance acromion – wall (retracted shoulders) (cm)	4.3 (±0.6)	6.5 (±2.0)	3.5	6.5	6.3 (±0.4)	5.2 (±1.5)
Right distance acromion – wall (retracted shoulders) (cm)	4.1 (±0.5)	6.8 (±1.3)	4.5	7.5	5.8 (±0.4)	5.3 (±1.5)
Luomajoki's tests	3.9 (±1.2)	3.8 (±1.7)	3	3	1.5 (±0.7)	3.4 (±1.4)
Plank test	80.1 (±30.5)	57.3 (±19.8)	54	30	71.5 (±19.1)	69.3 (±30.2)
Deep neck flexors	20.7 (±7.3)	22.0 (±9.5)	30	24	28.5 (±13.4)	23.2 (±8.0)
Left hand 5th flexion	0.9 (±0.4)	0.8 (±0.5)	1	1	0.5 (±0.7)	0.8 (±0.4)
Right hand 5th flexion	0.7 (±0.5)	1.0 (±0)	1	1	0.5 (±0.7)	0.8 (±0.4)
Left Thomas sign	0.0 (±0)	0.5 (±0.6)	0	1	1.0 (±0)	0.3 (±0.5)
Right Thomas sign	0.1 (±0.4)	0.3 (±0.5)	0	0	0.5 (±0.7)	0.2 (±0.4)
Left grip strength	33.9 (±6.0)	37.7 (±6.6)	33.9	43.4	31.0 (±1.8)	35.1 (±5.9)
Right grip strength	37.3 (±9.6)	34.2 (±2.2)	33.5	39.7	30.1(±7.8)	33.4 (±5.1)
Mobility						
Beighton Scale	1.4 (±1.4)	0.0 (±0)	1	0	2.0 (±2.8)	0.9 (±1.4)
Left short Apley	0.4 (±0.5)	0.5 (±0.7)	0	1	0.5 (±0.7)	0.4 (±0.5)
Right short Apley	0.9 (±0.4)	0.5 (±0.7)	0	0	1.0 (±0)	0.8 (±0.4)
Left Apley 1 (cm)	10.1 (±3.0)	10.8 (±1.3)	8.5	7.0	10.3 (±0.4)	10.1 (±2.3)
Right Apley 1 (cm)	9.9 (±2.8)	10.7 (±1.2)	12.0	6.5	11.8 (±0.4)	10.2 (±2.3)
Left Apley 2 (cm)	21.6 (±1.8)	27.0 (±12.8)	29.0	38.0	22.0 (±4.2)	23.4 (±5.9)
Right Apley 2 (cm)	24.7 (±3.5)	30.8 (±10.8)	28.5	34.0	21.5 ±(0.7)	26.5 (±5.9)
Left elbow supination (°)	87.9 (±6.4)	85.0 (±0)	85	85	87.5 (±3.5)	86.3 (±4.8)
Right elbow supination (°)	83.6 (±3.8)	81.7 (±2.9)	80	85	87.5 (±3.5)	83.7 (±3.5)
Left elbow pronation (°)	74.3 (±4.5)	78.3 (±2.9)	80	70	82.5 (±3.5)	76.3 (±4.8)
Right elbow pronation (°)	77.1 (±2.7)	80.0 (±5.0)	80	75	80.0 (±0)	78.0 ±3.2)
Left wrist flexion (°)	72.1 (±8.1)	70.0 (±0)	75	75	75.0 (±7.1)	73.3 (±6.7)

Right wrist flexion (°)	72.1 (±7.6)	76.7 (±2.9)	75	80	77.5 (±10.6)	75.0 (±6.5)
Left wrist extension (°)	67.9 (±5.9)	63.3 (+5.8)	70	60	70.0 (±7.1)	66.7 (±5.2)
Right wrist extension (°)	63.6 (±10.7)	68.3 (±7.6)	70	60	67.5 §±3.5)	66.0 (±8.5)
Left wrist radial inclination (°)	34.3 (±4.5)	40.0 (±0)	30	25	37.5 (±3.5)	35.3 (±5.2)
Right wrist radial inclination (°)	29.3 (±4.5)	36.7 (±2.9)	30	30	30.0 (±0)	31.7 (±4.9)
Left wrist ulnar inclination (°)	19.2 (±3.8)	16.7 (±2.9)	20	20	20.0 (±0)	19.7 (±4.0)
Right wrist ulnar inclination (°)	17.1 (±3.8)	18.3 (±2.9)	20	15	20.0 (±0)	18.3 (±3.1)
Cervical flexion (°)	62.5 (±12.9)	57.5 (±10.6)	55	55	72.5 (±10.6)	60.4 (±12.0)
Cervical extension (°)	60.0 (±14.1)	52.5 (±3.5)	45	45	50.0 (±7.1)	55.7 (±12.1)
Left cervical lateral bending (°)	31.4 (±5.6)	35.0 (±0)	25	25	35.0 (±7.1)	32.9 (±7.3)
Right cervical lateral bending (°)	30.0 (±7.6)	42.5 (±3.5)	35	25	35.0 (±14.1)	33.2 (±8.5)
Left cervical rotation (°)	72.1 (±7.0)	65.0 (±7.1)	65	65	75.0 (±7.1)	71.1 (±7.1)
Right cervical rotation (°)	70.7 (±5.3)	75.0 (±7.1)	70	70	75.0 (±0)	72.5 (±5.1)
Pain						
Left TP (kg)	5.0 (±0)	5.0 (±0)	5.0 (±0)	5.0 (±0)	5.0 (±0)	5.0 (±0)
Right TP (kg)	5.0 (±0)	5.0 (±0)	5.0 (±0)	5.0 (±0)	5.0 (±0)	5.0 (±0)
Left TP (EVA)	1.3 (±0.6)	Missing data	1.0 (±0)	Missing data	1.0 (±0)	1.5 (±0.8)
Right TP (EVA)	1.0 (±0)	Missing data	1.0 (±0)	Missing data	1.0 (±0)	1.3 (±0.8)

Appendix L: Table L.1 – Physical examination - Measurements in females among the sample

Measurements	Upper strings (n=11)	Lower strings (n=0)	Woodwinds (n=3)	Brass (n=0)	Percussions (n=2)	Total (n=16)
Epidemiological data						
Age	45.8 (±7.9)		36.3 (±11.8)		48.0 (±12.7)	44.3 (±9.3)
Height (cm)	166.3 (±6.8)		169.0 (±6.1)		165.0 (±11.3)	166.6 (±6.7)
Mass (kg)	66.4 (±13.2)		72.4 (±13.6)		60.5 (±12.7)	66.8 (±12.7)
BMI	24.1 (±4.1)		25.6 (±5.8)		22.1 (±1.6)	24.1 (±4.1)
Anthropometrics						
Handedness	Right: 10 Mixed: 1		Left: 2 Right: 1		Right: 2	Right: 13 - Left: 2 Mixed: 1
Left lower arm (cm)	23.9 (±1.2)		25.3 (±0.6)		24.5 (±2.1)	24.3 (±1.3)
Right lower arm (cm)	24.3 (±1.6)		25.6 (±0.6)		24.5 (±3.5)	24.6 (±1.7)
Left upper arm (cm)	31.2 (±1.9)		32.7 (±1.2)		30.5 (±0.7)	31.7 (±1.7)
Right upper arm (cm)	32.0 (±1.6)		33.0 (±1.0)		30.5 (±2.1)	32.0 (±1.6)
Neck length (cm)	12.7 (±1.9)		15.0 (±1.8)		16.0 (±0.7)	13.6 (±2.2)
Left hand span (cm)	19.6 (±0.9)		20.3 (±1.2)		21.0 (±0)	19.9 (±1.0)
Right hand span (cm)	19.4 (±1.0)		20.2 (±1.4)		20.8 (±0.4)	19.7 (±1.1)
Left hand length (cm)	17.5 (±0.9)		18.5 (±0.5)		17.3 (±1.1)	17.7 (±0.9)
Right hand length (cm)	17.4 (±0.9)		18.2 (±0.8)		17.5 (±0.7)	17.6 (±0.9)
Motor control, endurance and strength						
Left SDT Abduction	Physio: 6 Subtle: 1 Obvious: 4		Physio: 1 Subtle: 1 Obvious: 1		Physio: 1 (50%) Subtle: 1 Obvious: 0	Physio: 8 (50%) Subtle: 3 (19%) Obvious: 5 (31%)
Right SDT – Abduction	Physio: 4 Subtle: 2 Obvious: 5		Physio: 2 Subtle: 0 Obvious: 1		Physio: 2 Subtle: 0 Obvious: 0	Physio: 8 Subtle: 2 Obvious: 6
Left SDT – Flexion	Physio: 6 Subtle: 4 Obvious: 2		Physio: 1 Subtle: 1 Obvious: 1		Physio: 2 Subtle: 0 Obvious: 0	Physio: 9 Subtle: 5 Obvious: 3
Right SDT – Flexion	Physio: 3 Subtle: 5		Physio: 1 Subtle: 1		Physio: 1 Subtle: 0	Physio: 5 Subtle: 6

	Obvious: 3		Obvious: 1		Obvious: 1	Obvious: 5
Left distance acromion – wall (relaxed shoulders) (cm)	7.5 (±1.8)		7.0 (±0.5)		4.8 (±1.1)	7.6 (±1.8)
Right distance acromion – wall (relaxed shoulders) (cm)	6.7 (±1.4)		6.3 (±0.6)		5.5 (±1.4)	6.5 (±1.3)
Left distance acromion – wall (retracted shoulders) (cm)	4.2 (±1.7)		4.5 (±1.8)		3.3 (±1.1)	4.2 (±1.6)
Right distance acromion – wall (retracted shoulders) (cm)	4.2 (±1.6)		4.0 (±2.2)		3.5 (±2.1)	4.1 (±1.6)
Luomajoki's tests	4.5 (±1.7)		3.3 (±0.6)		4.0 (±1.4)	4.2 (±1.5)
Plank test (seconds)	49.9 (±27.2)		78.3 (±52.7)		99.0 (±52.3)	61.4 (±37.3)
Deep neck flexors (seconds-	22.4 (±6.3)		33.3 (±11.1)		20.0 (±1.4)	24.4 (±8.2)
Left hand 5th flexion	Independence: 0.6 (±0.5)		Independence: 0.7 (±0.6)		Independence: 1.0 (±0)	Independence: 0.7 (±0.5)
Right hand 5th flexion	Independence: 0.5 (±0.5)		Independence: 1.0 (±0)		Independence: 1.0 (±0)	Independence: 0.6 (±0.5)
Left Thomas sign	Presence: 0.5 (±0.5)		Presence: 0.3 (±0.6)		Presence: 0.5 (±0.7)	Presence: 0.5 (±0.5)
Right Thomas sign	Presence: 0.5 (±0.5)		Presence: 0.3 (±0.6)		Presence: 0.5 (±0.7)	Presence: 0.5 (±0.5)
Left grip strength (N)	22.8 (±2.7)		27.0 (±7.2)		23.6 (±2.5)	23.7 (±3.9)
Right grip strength (N-	23.2 (±1.9)		26.4 (±3.5)		27.3 (±1.8)	24.3 (±2.7)
Mobility						
Beighton Scale	2.6 (±2.2)		1.7 (±1.5)		4.0 (±1.4)	2.6 (±2.0)
Left up short Apley	0.4 (±0.5)			0.7 (±0.6)	0.5 (±0.7)	0.4 (±0.5)
Right up short Apley	0.8 (±0.4)			1.0 (±0)	1.0 (±0)	0.8 (±0.4)
Left Apley 1 (cm)	9.8 (±1.9)			10.3 (±4.5)	9.0 (±2.8)	9.8 (±2.4)
Right Apley 1 (cm)	10.8 (±1.8)			11.0 (±2.6)	9.0 (±4.2)	10.6 (±2.2)
Left Apley 2 (cm)	21.3 (±3.4)			18.8 (±2.9)	20.5 (±1.4)	20.8 (±3.1)

Right Apley 2 (cm)	23.2 (±2.8)			19.3 (±1.5)	25.8 (±6.7)	22.8 (±3.5)
Left elbow supination (°)	88.2 (±4.0)			95.0 (±0)	92.5 (±3.5)	90.0 (±4.5)
Right elbow supination (°)	86.8 (±5.1)			91.7 (±2.9)	90.0 (±7.1)	88.1 (±5.1)
Left elbow pronation (°)	78.6 (±2.3)			80 (±5.0)	80.0 (±0)	79.1 (±2.7)
Right elbow pronation (°)	80.9 (±2.0)			85.0 (±5.0)	80.0 (±0)	81.6 (±3.0)
Left wrist flexion (°)	77.7 (±4.1)			76.7 (±5.8)	77.5 (±3.5)	77.5 (±4.1)
Right wrist flexion (°)	77.3 (±4.1)			80.0 (±5.0)	80.0 (±0)	78.1 (±4.0)
Left wrist extension (°)	70.9 (±9.7)			76.7 (±7.6)	75.0 (±0)	72.5 (±8.8)
Right wrist extension (°)	69.1 (±12.8)			76.7 (±7.6)	72.5 (±3.5)	70.9 (±11.3)
Left wrist radial inclination (°)	36.4 (±5.0)			33.3 (±2.9)	35.0 (±0)	35.6 (±4.4)
Right wrist radial inclination (°)	33.6 (±4.5)			33.3 (±5.8)	32.5 (±3.5)	33.4 (±4.4)
Left wrist ulnar inclination (°)	18.6 (±4.5)			21.7 (±2.9)	17.5 (±3.5)	19.1 (±4.2)
Right wrist ulnar inclination (°)	19.5 (±4.7)			18.3 (±2.9)	20.0 (±7.1)	19.4 (±4.4)
Cervical flexion (°)	63.0 (±7.5)			60.0 (±8.7)	70.0 (±7.1)	63.3 (±7.7)
Cervical extension (°)	60.0 (±10.5)			66.7 (±12.6)	62.5 (±3.5)	61.7 (±10.1)
Left cervical lateral bending (°)	38.0 (±8.5)			31.7 (±14.4)	32.5 (±3.5)	36.0 (±9.3)
Right cervical lateral bending (°)	34.5 (±7.6)			30.0 (±5.0)	37.5 (±3.5)	34.0 (±6.9)
Left cervical rotation (°)	72.5 (±9.2)			71.7 (±18.9)	75.0 (±7.1)	72.7 (±10.5)
Right cervical rotation (°)	74.5 (±6.4)			75.0 (±10.0)	75.0 (±7.1)	74.7 (±6.7)
Pain						
Left TP (kg)	5.0 (±0)		5.0 (±0)		5.0 (±0)	5.0 (±0)
Right TP (kg)	5.0 (±0.1)		5.0 (±0)		5.0 (±0)	5.0 (±0.1)
Left TP (EVA)	4.2 (±1.9)		4.7 (±3.5)		6.0 (±0)	4.6 (±2.4)
Right TP (EVA)	6.0 (±1.1)		4.3 (±3.1)		5.0 (±0)	5.3 (±1.9)

Appendix M: Development of the Postural Analysis Tool for Musicians to investigate musicians' playing posture – A protocol proposal

1. INTRODUCTION

Posture, and more precisely postural impairments while playing a musical instrument, have often been described as one of the potential factors leading musicians to develop several injuries related to their play (Blanco-Pineiro et al., 2017; Chan & Ackermann, 2014; Ranelli et al., 2011; Watson, 2009). Elevated arm positions, asymmetrical instruments, sitting postures compared to standing ones were described as potential postural impairments that could influence the physical health of most instrumentalists (Ramella et al., 2014; Ackermann et al., 2014; Price & Watson, 2014; Nyman et al., 2007).

A recent systematic review has investigated how musicians' posture was investigated while they were playing their instrument (see Chapter 4 – Part 4). This study has determined that videography combined with visual assessment and 3D-motion capture were the two main methods used to explore musicians' playing posture. Among the tools developed to assess musicians' posture, the Postural Observation Instrument (POI) has been developed to investigate a large number of items such as overall posture, shoulder position or head alignment. One of the main qualities of this instrument is to be comprehensive and time-efficient, which allows its use during a music lesson or an initial physiotherapy assessment.

This new instrument has been described as being reliable between experts and useful to rate posture in musicians, but one of its major drawback is to rate postural components as "fixed", not considering the potential ancillary movements the musicians could perform while playing. In fact, even if musicians' posture has been rated thanks to videos, experts were told to analyse it as "neutral or average position while performing, that is ignoring transient excursions in the course of performance" (Blanco-Pineiro et al., 2015). However, ignoring that the musician could be moving during performance and not rating the difference between mobile and fixed posture among instrumentalists could potentially lead researchers to assessment misinterpretations.

In contrast, Ackermann & Adams (2004) developed a scale for expert to assess musicians' posture and included this measurement to their tool, asking their assessors to evaluate the postural mobility of musicians between static and dynamic on a visual analogue scale.

The aim of this study is to develop a new instrument assessing posture in musicians without their instrument and while playing, by including the analysis of how much a musician is moving while playing. This new instrument should be clear enough to be used by healthcare practitioners to screen postural impairments in instrumentalists but also for music teachers to control and possibly correct their students' posture and even for musicians themselves to adjust their own posture and raise awareness about how they play. The protocol proposal to validate this tool will be further described.

2. Description of the Postural Analysis Tool for Musicians (PATM)

2.1. Development of the Postural Analysis Tool for Musicians

The Postural Analysis Tool for Musicians (PATM) has been inspired from the Postural Observation Instrument (POI), described by Blanco-Pineiro et al. (2015). Nonetheless, this new tool, the PATM, presents several differences compared to the POI.

The whole tool has been described in Table 4.9.

First of all, this tool includes now the section "movements" when analysing the musicians' postures while playing. This section includes a 3-point Likert scale:

- 1 = The musician is playing in a very fixed posture, without any movement.
- 2 = The musician is playing whilst moving, movements are noticeable and frequent.
- 3 = The musician is almost playing almost all the time whilst moving with a large of motion.

From the POI, some pejorative terms such as "excessive" or "insufficient" have been replaced by "increased" or "decreased" to avoid negative judgments while rating.

Moreover, answers for the overall posture items were "physiological", "rigid" or "slumped" in the POI and have been replaced by "ideal" and "not ideal alignment". The reasons of this replacement are multiple: a wide range of spine curvatures exist (Korakakis et al., 2019; O'Sullivan et al., 2012) and adding combination of postures that could be frequently encountered would have added complexity in this scale. Also, as items after are very specific, if the overall posture is considered as not ideal, answers after will help to understand further the potential postural impairments.

Table M.1: Description of the Postural Analysis Tool for Musicians (PATM)

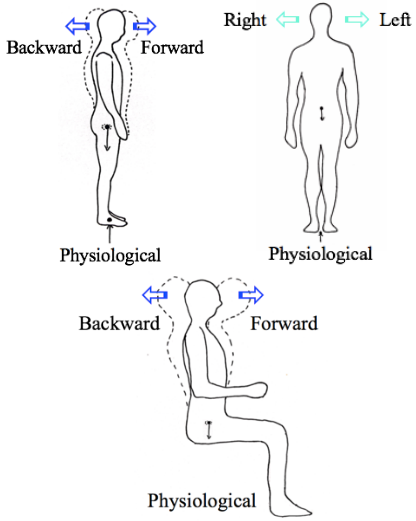
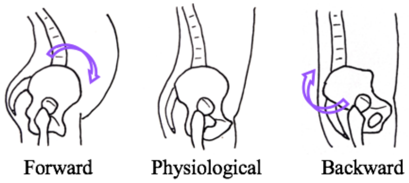
To advance functional postural assessment in musicians, we developed the Postural Analysis Tool for Musicians (PATM) base on the Postural Observation Instrument (POI) described by Blanco-Pineiro et al. (2015). The proposed new tool includes the analysis of how much a musician moves while playing, in contrast to the POI that describes a musician's average posture only, without taking into account transient postural changes and movement during the performance, that is to say that the POI does not include the mobility of the musicians, nor their fixed posture, that are taken into account by the present PATM.

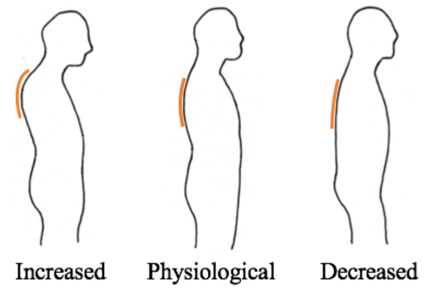
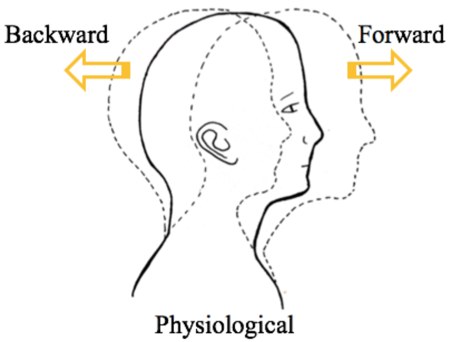
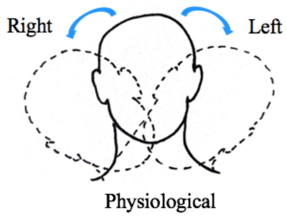
The table below summarises all the items you are expected to rate in a musician's posture. You will rate each of the items several times in different conditions: sitting and standing without the instrument in a still position on photographs and sitting and standing while playing on videos. You'll be able to observe the musicians from three views: front, back and right side ones (photographs and video).

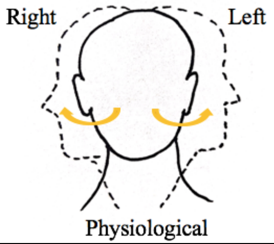
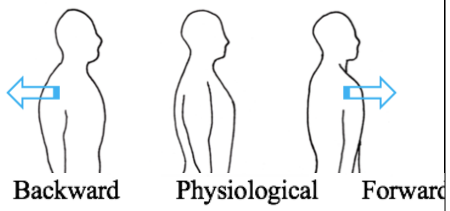
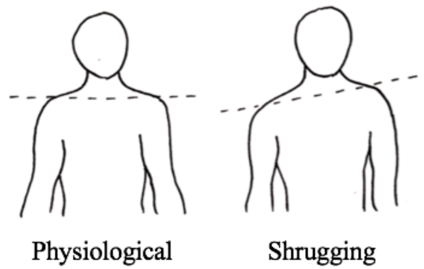
To rate how much the musician is moving while playing, you should consider the scale below:

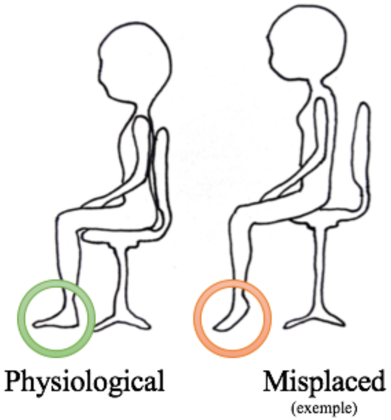
1: The musician is playing in a really fixed posture, without any movement.
2: The musician is playing whilst moving, movements are noticeable and frequent.
3: The musician is almost playing almost all the time whilst moving and the range of the movements is great.

Item	**Description of the item/element of posture assessed**	**Pictures**	**Outcomes**					
			Sitting			**Standing**		
			Still (Position)	**Playing**		**Still (Position)**	**Playing**	
				Position	**Motion**		**Position**	**Motion**
1. Overall posture	Physiological/Ideal alignment: "Should approximate as closely as possible the correct posture without any instrument" (Lahme, 2010 in Blanco-Piñeiro et al., 2015) Not ideal alignment: Presence or combination of different postural alterations compared to the ideal alignment such as an increase or a decrease in the spine curvatures (neck, upper or lower back).	 Ideal alignment			❶ ❷ ❸			❶ ❷ ❸

Item	**Description of the item/element of posture assessed**	**Pictures**	**Outcomes**					
			Sitting			**Standing**		
			Still (Position)	**Playing**		**Still (Position)**	**Playing**	
				Position	**Motion**		**Position**	**Motion**
2. Axis of gravity (all planes) (Blanco-Piñeiro et al., 2015)	Physiological: The weight of the body rests on the entire sole of the feet (standing) and on the ischium (sitting). Forward-shifted: The weight of standing body rests mainly on the anterior third of the feet (standing) and forward on the seat (sitting). Backward-shifted: The weight of the body rests mainly on the heels (standing) and backward on the seat (sitting). Left-shifted: The weight of the body rests mainly on the left side. Right-shifted: The weight of the body rests mainly on the right side.				❶ ❷ ❸			❶ ❷ ❸
3. Pelvic attitude (inspired from Blanco-Piñeiro et al., 2015)	Physiological: Comparable to the ideal lumbar curvature. Forward-tilted: Excessive lumbar curvature. Backward-tilted: Reduced lumbar curvature.				❶ ❷ ❸			❶ ❷ ❸

Item	Description of the item/element of posture assessed	Pictures	Outcomes					
			Sitting			Standing		
			Still (Position)	Playing		Still (Position)	Playing	
				Position	Motion		Position	Motion
4. Dorsal curvature (inspired from Blanco-Piñeiro et al., 2015)	Physiological: Comparable to the ideal curvature of the spine. Increased: Back hunched, with excessively separated shoulder blades. Decreased: Back flat, with shoulder blades excessively close.				❶ ❷ ❸			❶ ❷ ❸
5. Head alignment (sagittal plane) (Blanco-Piñeiro et al., 2015)	Physiological: Neck muscles relaxed, head well balanced on the spine. Forward: Neck and face pushed forward, chin lifted. Backward: Neck stretched, generally with chin tucked in, compressing the throat.				❶ ❷ ❸			❶ ❷ ❸
6. Head alignment (frontal plane) (inspired from Blanco-Piñeiro et al., 2015)	Physiological: Head centred, well balanced on the spine. Tilted sideways: Head tilted towards one shoulder, potential imbalance in the lateral neck muscles.				❶ ❷ ❸			❶ ❷ ❸

Item	Description of the item/element of posture assessed	Pictures	Outcomes					
			Sitting			Standing		
			Still (Position)	Playing		Still (Position)	Playing	
				Position	Motion		Position	Motion
7. Head alignment (transverse plane) (Blanco-Piñeiro et al., 2015)	Physiological: Head well centred. Rotated sideways: Head rotated towards one shoulder.				❶ ❷ ❸			❶ ❷ ❸
About the shoulders, both shoulders could have different position and should be evaluated separately.								
8. Shoulders position (sagittal plane) (inspired from Blanco-Piñeiro et al., 2015)	Physiological: Shoulder(s) in line with the trunk. Forward: Shoulder(s) brought forward, shoulder blades excessively separated. Backward: Shoulder(s) brought back, shoulder blades too close together.				❶ ❷ ❸			❶ ❷ ❸
9. Shoulders position (frontal plane) (inspired from Blanco-Piñeiro et al., 2015)	Physiological: Shoulder(s) relaxed, respecting the natural distance between shoulders and ears. Elevated: Shoulder(s) raised towards the ears.				❶ ❷ ❸			❶ ❷ ❸

Item	**Description of the item/element of posture assessed**	**Pictures**	**Outcomes**					
			Sitting			**Standing**		
			Still (Position)	**Playing**		**Still (Position)**	**Playing**	
				Position	**Motion**		**Position**	**Motion**
10. Legs and feet (Blanco-Piñeiro et al., 2015)	Physiological: Legs supported in stable equilibrium, with knees free to move (neither too straight nor too bent), feet completely planted on the floor (neither too close together nor too far apart). In seated musicians: ankles vertically below the knees (neither in front nor behind), knees level with, or just slightly below, the hip joints. Misplaced: Knees excessively straight or bent; legs too close together or too separated; feet incompletely planted, putting weight on only a part of the sole instead of the whole. In seated musicians, knees very much above or below the hip joints.				❶ ❷ ❸			❶ ❷ ❸

Besides, the following sentence from the POI has been removed:

> *"Certain positions with slightly excessive curvature were considered as physiological in the case of instruments such as the double bass, so long as movement was fluent and consonant with economy of effort."* (Blanco-Pineiro et al., 2015)

As the aim of our tool is to analyse how playing an instrument will alter the posture while being still and how musician will move with their instrument, it seems this sentence will confuse the raters as well as the outcomes and their interpretation (Blanco-Pineiro et al., 2015).
Finally, the POI counted three items about shoulder position that could be combined in only two items by asking the raters to evaluate shoulders separately. In terms of head posture, we also decided to add the evaluation of potential rotation in the transverse plane, as it can be part of the required posture to play some instruments (e.g.: violin).

2.2. Items of the PATM

Each items composing the PATM are listed below:

- Overall posture (assessed as physiological, flat-back, sway-back or kyphosis-lordosis)
- Axis of gravity in all planes (assessed as physiological, forward-, backward-, left or right shifted)
- Pelvic attitude (assessed as physiological, backward- or forward-tilted)
- Dorsal curvature (assessed as physiological, increased or decreased)
- Head alignment in all planes (assessed as physiological, forward, backward, tilted or rotated sideways)
- Shoulders position in all planes (assessed separately as physiological, forward, backward or elevated)
- Legs and feet (assessed as physiological or misplaced).

3. PROTOCOL PROPOSAL

3.1. Inter- and intra-reliability protocol

Firstly, the first version of the tool will be presented to an expert in biomechanics and human motion (HD), who has been asked to read and give an opinion about the full tool. Changes will be made according to the experts' comments, who will then be asked to proofread a second time the full tool and to rate the usefulness of each item as (Lawshe, 1975):

- Essential

- Useful but not essential
- Not necessary

The inter- and intra-reliability protocol will be developed in order to follow the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) (Kottner et al., 2011) and the Quality Appraisal of Reliability Studies (QAREL) checklist (Lucas et al., 2010).

3.2. Raters

Three physiotherapists, and one musician (who is both professional musician and teacher) will be chosen to assess the posture of 10 musicians in order to be representative of the target tool's users (Lucas et al., 2010). Among these raters, one physiotherapist and the musicians will assess all participants' posture twice, within at least 14 days between both assessments, in order to measure the intra-reliability of this new tool.

Among the three physiotherapists, two will be specialised in musicians' pathologies. All raters will be aware they will not be the only ones to measure musicians' posture and will know their answers would then be compared to other ones but they will be fully blinded from the findings of other raters (Lucas et al., 2010). For the intra-reliability, raters will be blinded to their own first ratings (Lucas et al., 2010).

3.3. Sample of musicians

Ten orchestra musicians will be asked:

- to fill in the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (Berque et al., 2014)
- to stand and sit while pictures were taken from three sides (front, back, right side);
- to play on their instrument a piece they are familiar and were video recorded from three sides (front, back, right side) using three video cameras.

3.4. Procedure

For sitting and standing posture without the instrument, pictures from anterior, posterior and right lateral sides will be rated. Concerning postures while playing, videos from the same three sides will be assessed. Raters will be allowed to see the photos and the videos as many times and as long as they needed.

This assessment will take place in different locations for all raters. All ratings will be conducted independently and in a quiet space. As providing enough information is very important to allow the best reliability and agreement possible between raters and moments of ratings, the tool will be standardly and extensively explained. All raters will be asked to evaluate two participants to familiarise with the tool before beginning the assessment of the whole sample. These two participants will be the same for all raters, assessed in the same order, and will be excluded from the assessed sample. To reduce the possibility of a Hawthorne effect (Kottner et al., 2011), the principal investigator will then leave each rater alone to evaluate the participants posture (although it will not be possible for them to ask for help). The order of conditions while playing (1. sitting without instrument, 2. sitting while playing, 3. standing without instrument, 4. standing while playing) will be standardised. The order of participants will be randomised and different among the raters.

3.5. Statistical analysis

Descriptive statistical analysis will be performed using Excel® and inferential statistics analysis was performed using SPSS® (version 25.0.0.1). Concerning nominal variables (all items excepting assessment of movements while playing) and ordinal ones (movements while playing), kappa statistics will be used.

<u>**Appendix N: Cellist case study – Markers' placement**</u>

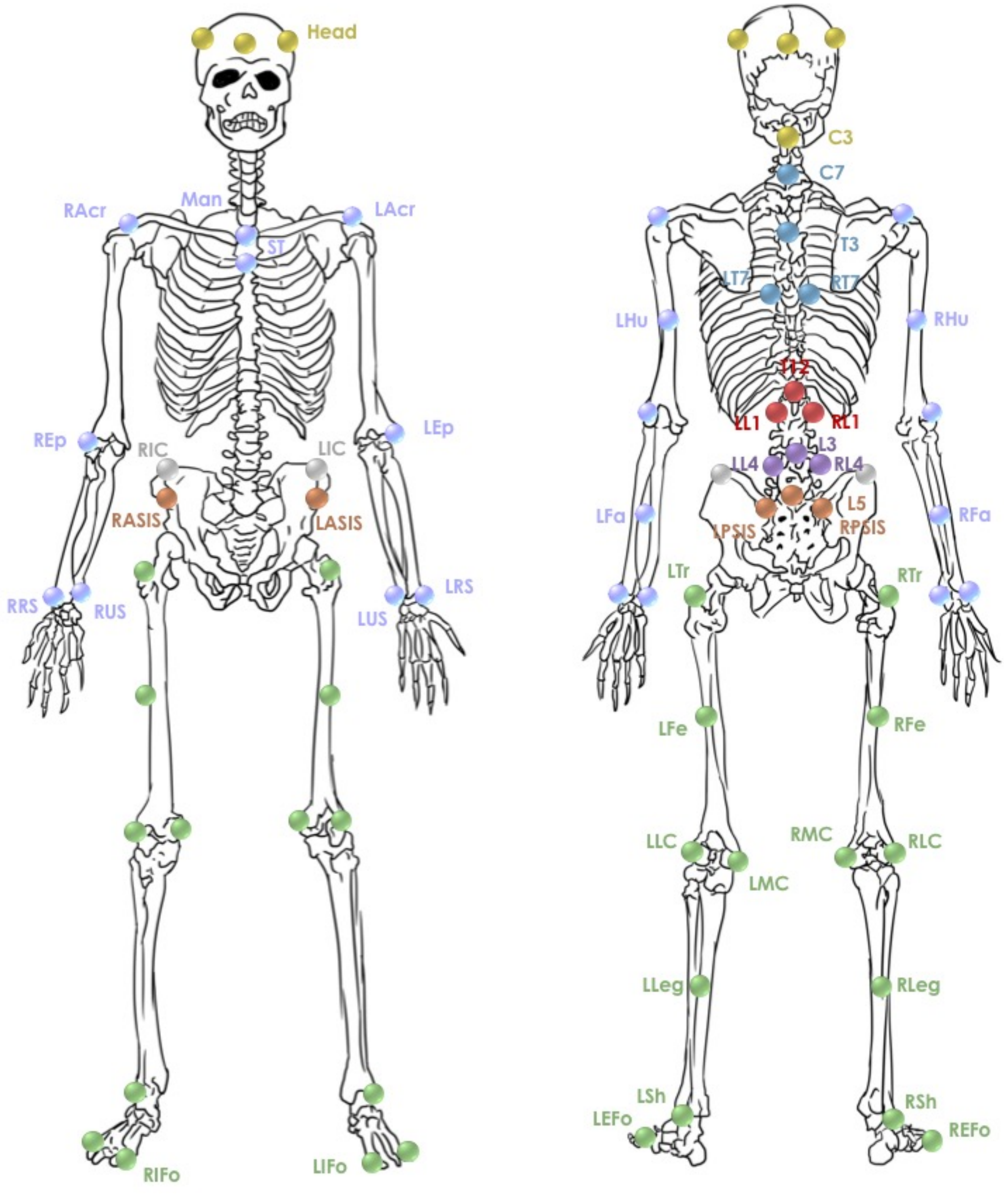


Figure M.1: Markers' placement model

Appendix O: Cellist case study – Scales and questionnaires

Performance adjudication sheet used in McCrary et al., 2016

N.B.
- each performance is ranked on its own individual merits and not in comparison to other performances prior or following.
- A field for comment has been left should the adjudicator would like to make a comment
- Decimal points may be used if required

Grade descriptors:
6: An extraordinary performance
5: An outstanding performance – a performance which may have contained a minor blemish
4: An excellent performance – a performance that may have contained a few minor blemishes
3: A competent performance – a performance that shows occasional lapses
2: An insecure performance – a performance showing frequent lapses
1: Unsuccessful attempt – a performance of generally unacceptable quality

Performance Reference	Intonation accuracy (1-6)	Tone Clarity (1-6)	Overall Impression (1-6)	Comment

Borg Scale (1998)

While exercising we want you to rate your perception of exertion, i.e., how heavy and strenuous the exercise feels to you. The perception of exertion depends mainly on the strain and fatigue in your muscles and on your feeing of breathlessness or aches in the chest.

Look at this rating scale; we want you to use in this scale from 6 to 20, where 6 means “no exertion at all” and 20 means “maximal exertion”.

6	**No exertion at all**
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

9: corresponds to “very light” exercise. For a normal, healthy person it is like walking slowly at his or her own pace for some minutes.

13: on the scale is “somewhat hard” exercise, but it still feels OK to continue

17: “very hard” is very strenuous. A health person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired.

19: on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feeling of exertion as honestly as possible, without about what the actual physical loads is. Don’t underestimate it, but don’t overestimate it either. It’s your own feeling of effort and exertion that’s important, not how it compares to other people’s. What other people think is not important either. Look at the scale and the expressions and then give a number.

Any questions?

Pre-intervention questionnaire

1. What made you interested in volunteering for this study?
2. What do you understand the sitting position while playing the cello to be?
3. What chair do you use at home when you're practicing your cello?
4. Have you ever had any advice about your sitting position?
   - ☐ Yes (go to question 5.)
   - ☐ No (you have finished to fill the survey)
5. If yes, was it:
   - ☐ One of your teacher
   - ☐ One of your colleague
   - ☐ A healthcare professional? If yes, which one:
   - ☐ Other:

Post-intervention questionnaire

1. What effect did the change of chair height have on your playing immediately afterwards?

For each item below:

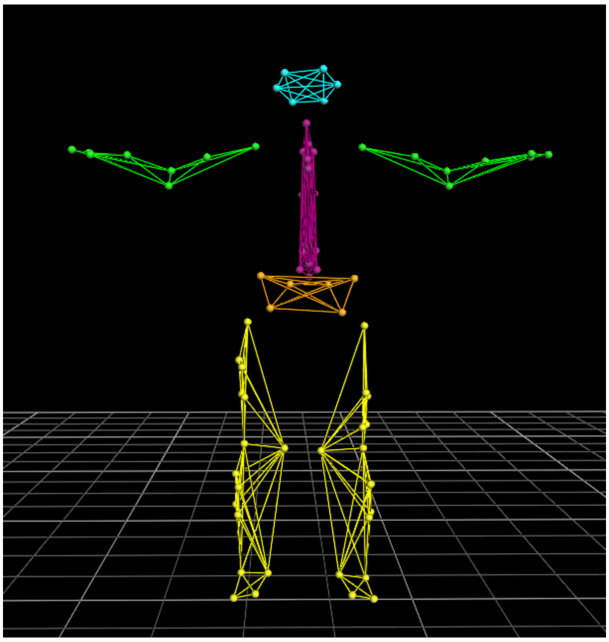
(-5 = Worst possible effect) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Best possible effect)

1. On your overall perceived playing capacity
2. On your posture
3. On your ease of movement
4. On your music sound
5. On your confidence
6. On your technique

7. How likely would you be to play all the time with this new height?

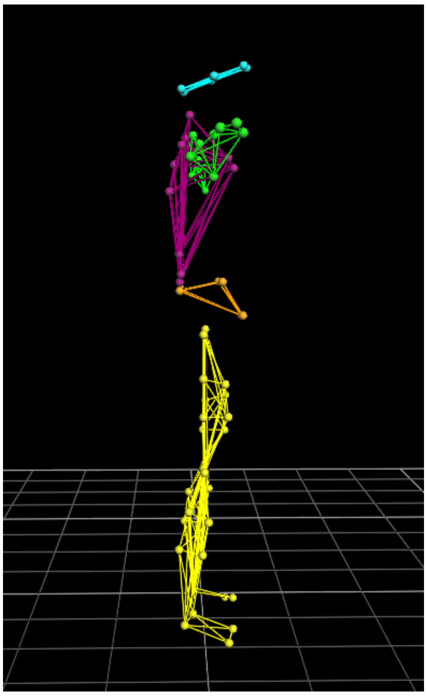
   (-5 = Not at all) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Greatest possible likelihood)
8. Are there any other comments that you would like to add about your experience?

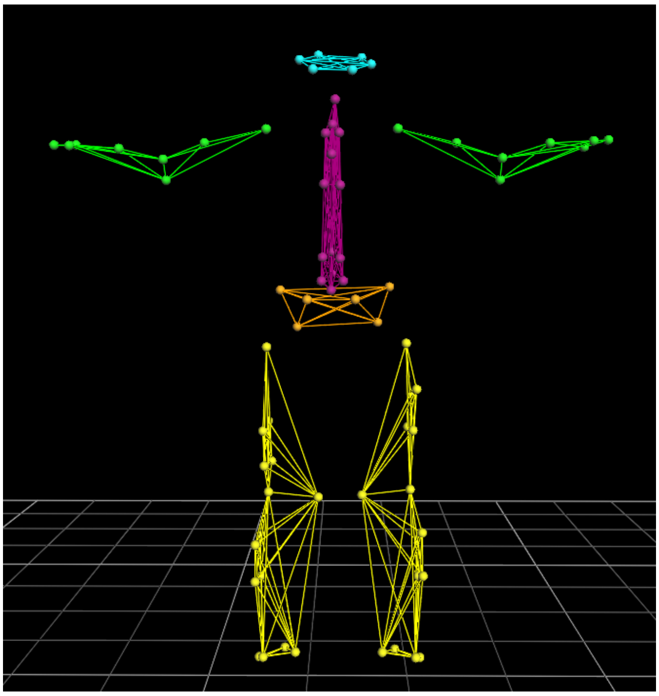
Appendix P: Cellist case study – Static trials



(1)

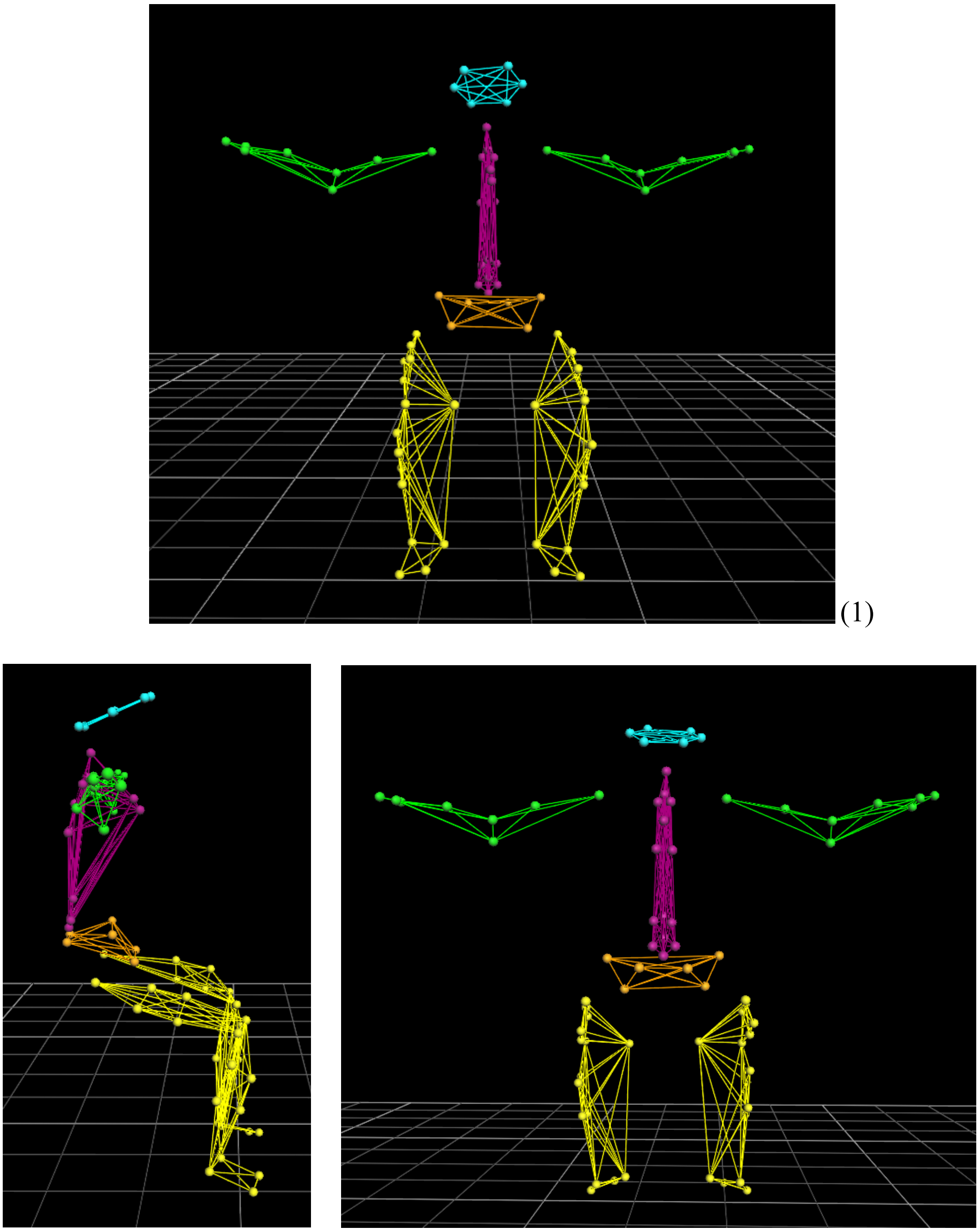
(2)





(3)

Figure X.X: Standing trial from the front (1), the right side (2) and the back (3)



(1)

(2)

(3)

Figure X.X: Sitting trial from the front (1), the right side (2) and the back (3)

Appendix Q: Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians

(Berque et al., 2014)

1. What is your age? ___________ **years**
2. Gender: ☐ Male ☐ Female
3. What instrument do you play in the orchestra? ___________________________
4. With respect to your position in the orchestra, do you work: ☐ Full time ☐ Part time
5. For how many years have you played your instrument? _____________ **years**
6. For how many years have you played professionally in an orchestra? _____________ **years**

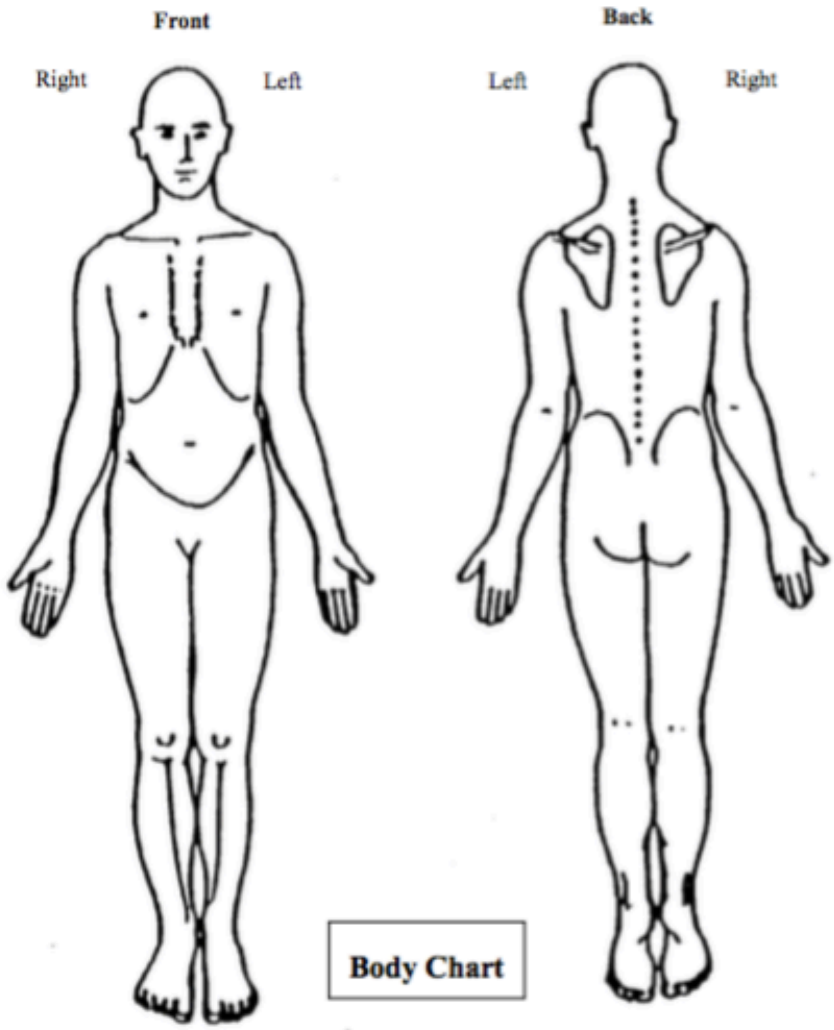
7. On average, how many hours per week do you spend playing your instrument **in the orchestra** (this includes rehearsals, performances, recordings)? _________________ **hours per week**
8. On average, how many hours per week do you spend playing your instrument **outside** orchestra duties (this includes individual practice, chamber music, solo performances, demonstration when teaching, gigs, other)? _________________ **hours per week**

Playing-related musculoskeletal problems are defined as "pain, weakness, numbness, tingling, or other symptoms that interfere with your ability to play your instrument at the level to which you are accustomed". This definition <u>does not include</u> mild transient aches and pains.

9. Have you **ever** had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed? ☐ Yes ☐ No
10. Have you had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed **during the last 12 months**? ☐ Yes ☐ No
11. Have you had pain/problems that have interfered with your ability to play your instrument at the level to which you are accustomed **during the last month (4 weeks)**? ☐ Yes ☐ No
12. **Currently (in the past 7 days)**, do you have pain/problems that interfere with your ability to play your instrument at the level to which you are accustomed? ☐ Yes ☐ No

If your answer to questions 11 and/or 12 is YES, please continue. Otherwise stop here, and hand your survey back or post it back using the stamped addressed envelope provided.

13. On the body chart, SHADE IN **each** of the areas where you experience **pain/problems**.
Put an X on the **ONE area** that HURTS the most.



The next four questions relate ONLY to PAIN. Please answer with reference to the ONE area that you **marked with an X** on the body chart. Otherwise go to Question 18.

14. Please rate your pain by circling the one number that best describes your pain at its **worst** in the last week.

0	1	2	3	4	5	6	7	8	9	10
No pain										Pain as bad as you can imagine

15. Please rate your pain by circling the one number that best describes your pain at its **least** in the last week.

0	1	2	3	4	5	6	7	8	9	10
No pain										Pain as bad as you can imagine

16. Please rate your pain by circling the one number that best describes your pain on **average** in the last week.

0	1	2	3	4	5	6	7	8	9	10
No pain										Pain as bad as you can imagine

17. Please rate your pain by circling the one number that tells how much pain you have **right now**.

0	1	2	3	4	5	6	7	8	9	10
No pain										Pain as bad as you can imagine

The remainder of the survey relates to both PAIN and/or PROBLEMS.

For each of the following, circle the one number that describes how, during the past week, **pain/problems have interfered** with your:

18. Mood

0	1	2	3	4	5	6	7	8	9	10
Does not interfere										Completely interferes

19. Enjoyment of life

0	1	2	3	4	5	6	7	8	9	10
Does not interfere										Completely interferes

For each of the following, during the past week, as a result of your **pain/problems**, did you have any **difficulty** (please circle ONE number):

20. Using your usual technique for playing your instrument?

0	1	2	3	4	5	6	7	8	9	10
No difficulty										Unable

21. Playing your musical instrument because of your symptoms?

0	1	2	3	4	5	6	7	8	9	10
No difficulty										Unable

22. Playing your musical instrument as well as you would like?

0	1	2	3	4	5	6	7	8	9	10
No difficulty										Unable

Thank you for your participation.
Please hand your survey back or post it back using the stamped addressed envelope provided.

Appendix R: Pain Beliefs Questionnaire

(Edwards et al., 1992)

1. Pain is the result of damage to the tissues of the body.
2. Physical exercise makes pain worse.
3. It is impossible to do much for oneself to relieve pain.
4. Being anxious makes pain worse.
5. Experiencing pain is a sign that something is wrong with the body.
6. When relaxed pain is easier to cope with.
7. Being in pain prevents you from enjoying hobbies and social activities.
8. The amount of pain is related to the amount of damage.
9. Thinking about pain makes it worse.
10. It is impossible to control pain on your own.
11. Pain is a sign of illness.
12. Feeling depressed makes pain seem worse.

Appendix S: Programmes for returning-to-work post Covid-19

Table 7.2: Fitness programme for orchestra musicians

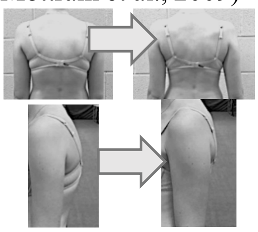
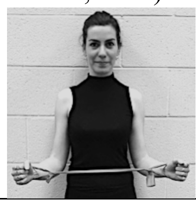
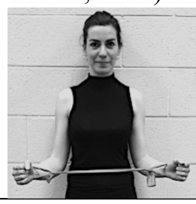
	Early (weeks 1 & 2)	Mid (weeks 3 & 4)	Late (weeks 5 & 6)
Neck	Deep neck flexor in supine and self-active cervical lengthening (SACL) (Chan et al., 2014)	Deep neck stabilisation under constant light resistance and SACL (Chan et al., 2014)	Deep neck stabilisation with cervical movements under changing resistance (with a towel) (Chan et al., 2014)
Shoulders	Scapular orientation exercise (Mottram et al., 2009) 	Bilateral external rotation with Theraband® or towel (5"x10) (unpublished work, Chan et al., 2012) 	Bilateral external rotation with Theraband® or towel (15"x10) (unpublished work, Chan et al., 2012) 
Spinal and abdominal (Chan et al., 2012; Lundborg & Grooten, 2018)	1. Glute bridge (10"x10)  2. Cat/cow in 4 point (5')  3. Plank (20"x3) 	1. Glute bridge with one leg lift (10"x10)  2. Superman (x10)  3. Plank (30"x3) 	1. Glute bridge with one leg lift (10"x20)  2. Superman (x20)  3. Plank (40'x4) 
Lower limbs (Chan et al., 2012; Lundborg & Grooten, 2018)	Squats (x30) 	Squats (x60 – 2x30) 	Squats (x90 – 3x30) 

Table 7.3: Task-specific exercises designed for musicians

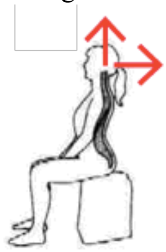
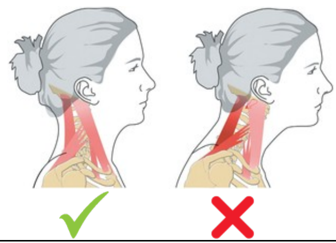
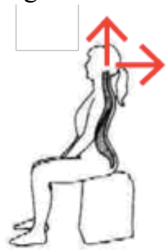
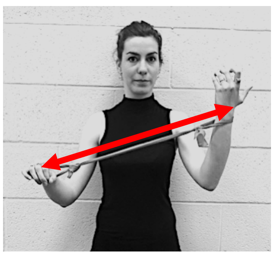
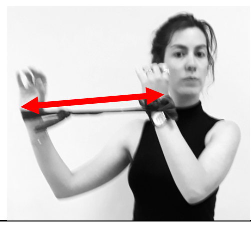
	String	Wind	Percussion
			
Neck	As a routine, for each practice session, play the violin/viola/cello/DB while thinking to the alignment and lengthening of the neck. 	As a routine, for each practice session, work on the alignment of the head with the spine. Think about the way the instrument goes to the mouth, instead of draw the head near the embouchure. 	As a routine, for each practice session, think to the alignment and lengthening of the neck while playing your instrument, looking far ahead. 
Shoulders	Task-specific bilateral external rotation: stretch the elastic by spreading your wrists with a movement of your right upper limb, as if you were bowing, in position of playing the violin, feeling your shoulder blade muscles and opening your chest (unpublished work, Chan et al., 2012). 	Scapular orientation exercise while playing: make your shoulder blades down and closer, with opening your chest and feeling your shoulder blade muscles (inspired from Mottram et al., 2009) (cf Table 1). Specifically, for flutist: stretch the elastic by spreading your wrists, in position of playing the flute, feeling your shoulder blade muscles and opening your chest (unpublished work, Chan et al., 2012). 	Scapular orientation exercise while playing: make your shoulder blades down and closer, with opening your chest and feeling your shoulder blade muscles (inspired from Mottram et al., 2009) (cf Table 1).
Spinal and abdominal	As while performing the exercises, mind to breath and blow with belly's movements. Few deep breathes should be taken before playing.	As while performing the exercises, mind to breath and blow with belly's movements. Few deep breathes should be taken before playing.	As while performing the exercises, mind to breath and blow with belly's movements. Few deep breathes should be taken before playing.

Table 7.4: Yoga sessions for musicians

<table>
<tr><th>1st session</th><th>2nd session</th><th>3rd session</th></tr>
<tr><td colspan="3">Mountain pose (1’)
</td></tr>
<tr><td colspan="2">Uttanasana and flat back position (1’)
</td><td>Tree (both sides) (1’)
</td></tr>
<tr><td colspan="3">Plank (5”)
</td></tr>
<tr><td>Baby cobra (10”)
</td><td>Cat/Cow (30”)
</td><td>Cobra (10”)
</td></tr>
<tr><td>Plank (5”)
</td><td>Child Pose (30”)
</td><td>Plank (5”)
</td></tr>
<tr><td colspan="3">Downward Facing Dog (10”)
</td></tr>
<tr><td>Warrior Pose I (L) (1’30”)
</td><td>Warrior Pose II (L) + Reverse Warrior (1’30”)
</td><td>Warrior Pose I (L) + Triangle (1’30”)
</td></tr>
<tr><td colspan="3">Plank (5”)
</td></tr>
</table>

<table>
<tr><td colspan="3">Downward Facing Dog (5”)
</td></tr>
<tr><td>Warrior Pose I (R) (1’30”)
</td><td>Warrior Pose II (R) + Reverse Warrior (1’30”)
</td><td>Warrior Pose I (R) + Triangle (1’30”)
</td></tr>
<tr><td>Pigeon and progression (both sides) (2’)
</td><td>Pigeon and progression (both sides) (2’)
</td><td>Pigeon and progression (both sides) (2’)
</td></tr>
<tr><td>Supine, knees to the chest (30”)
</td><td>Happy baby (30”)
</td><td>Supine, knees to the chest (30”)
</td></tr>
<tr><td colspan="3">Shavasana (30”)
</td></tr>
</table>

Appendix T: Scapular exercises in upper string players

Participants

The inclusion criteria to participate to this study would have been: being a professional violinist or violist from the Royal Liverpool Philharmonic Orchestra (RLPO), aged above 18 years and able to speak English fluently.

Participants would not have been included if they reported any shoulder or spine recent severe injury or surgery. This study was aimed to be submitted for approval to the Liverpool John Moores University Research Ethics Committee.

Global procedure

Participants would have been asked three days before their first laboratory session to fill online the Injury Risk Factors Questionnaire for Musicians (IRFQM) (cf Chapter 4) to assess several elements of their daily and professional life.

On the first session day, after having delivered to the participant of an information sheet and asked the musician to sign an informed consent, the procedure described in Figure S.1 would have been followed with all the upper string players.

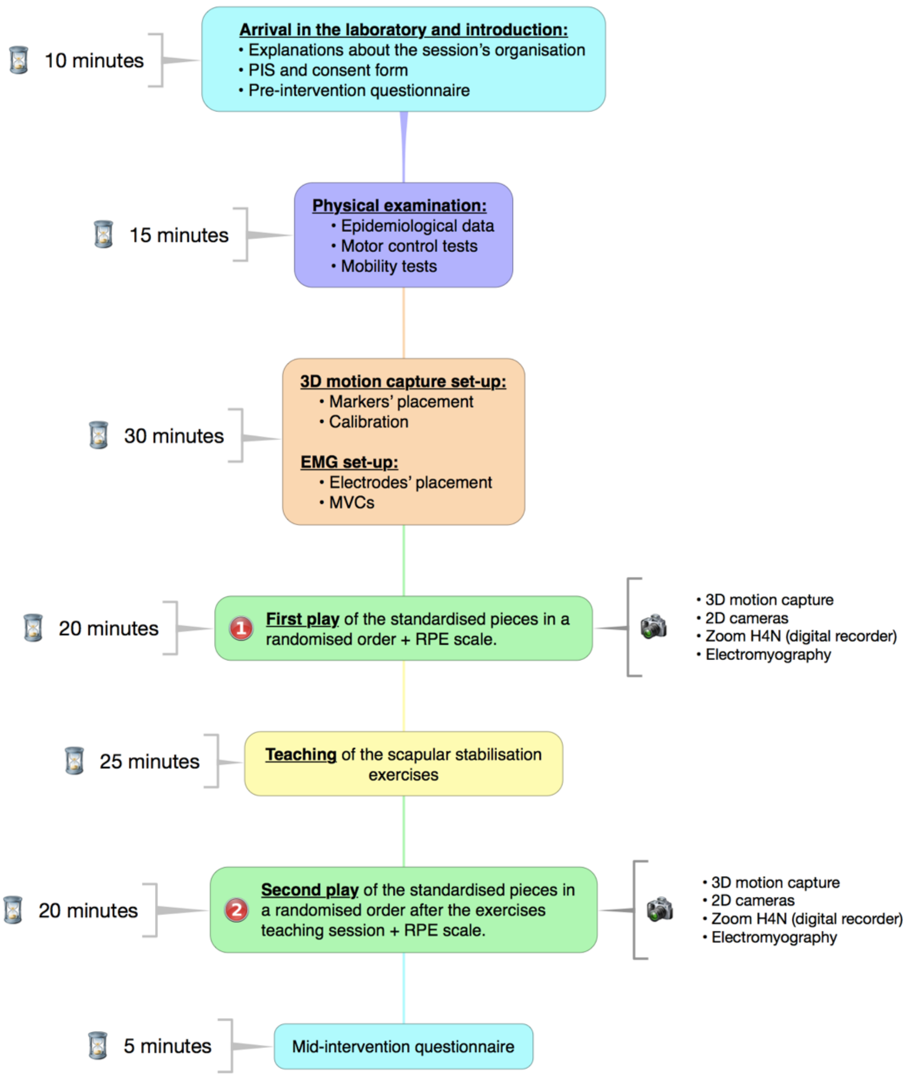


Figure S.1: Overview of the first session protocol

In between the two sessions, all upper string players would have been asked to perform the scapular stabilisation exercises five times a week, for 8 weeks and about 15 minutes before playing. Every fortnight, an e-mail would have been sent from the main researcher to the participant to know how much the exercises was performed on the past two weeks. If participants do not feel comfortable with the exercises and want to have a second session to learn more about how performing them, the main researcher would have provided them time slots to manage a second teaching session of the exercises. Explicitly explained videotapes of the exercises would also have been available for all participants. For the first two weeks of the protocol, participants would have been advised to look at the exercises videos before performing them to be sure they would perform them well. Eight weeks after the first session, the second one would have been conducted as described in Figure S.2.

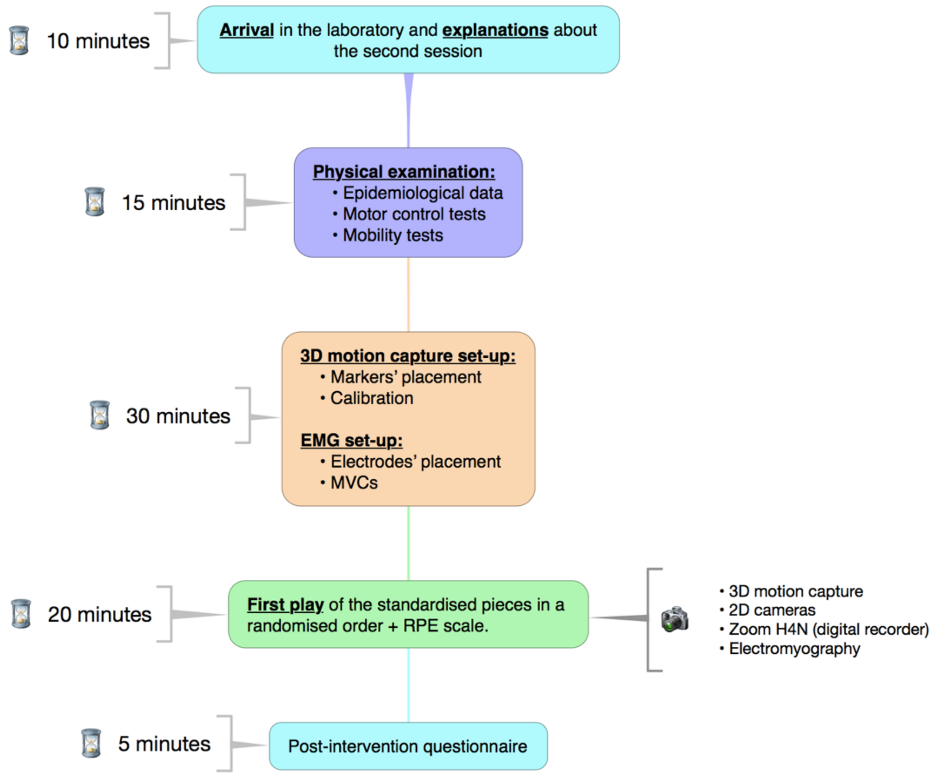


Figure S.2: Overview of the second session protocol

Standardised play

Upper strings players would have been asked to play in a random order 45-seconds excerpts from different standardised pieces previously used in violinists in the literature (McCrary et al., 2016):

- Praeludium and Allegro, Kreisler: provides the analysis of full and forceful right elbow flexion and extension (bars 1-22, crotchet = 108 bpm);
- Etude 7 for solo violin, Kreutzer: provides the analysis of fast notes and full right shoulder abduction and adduction (bars 9-26, crotchet = 108 bpm);
- 1er Air Varié, Beriot: provides the analysis of *piano* notes and limited right elbow movements in flexion/extension (bars 9-24, quaver = 92 bpm);

- Sonata for Violin and Piano, Ravel: provides the analysis of quick changes in right elbow flexion/extension and right wrist radial/ulnar deviations (marks 9-11, quaver = 160 bpm);
- Ave Maria, Bach/Gounod: provides the analysis of slow and controlled movement of the bow with full right elbow flexion/extension (bars 5-15, crotchet = 60 bpm).

A metronome (Android application) was used in order to standardise tempo (Baadjou et al., 2017; McCrary et al., 2016).

3D motion capture procedure

A six-degrees of freedom full body marker set would have been used and 62 retro-reflective markers were tracked by 12 motion capture cameras (120Hz, VICON Motion Systems, Oxford, UK). Participants would have been asked to wear sport or tight clothes to facilitate the motion analysis. Reflective markers would have been placed on the upper string players' body as described in Figure S.3. A head band with six reflective markers would have been used to track the head movements. Moreover, to facilitate the observations of scapular movements, an acromion marker cluster would have been used (Warner et al., 2015; Lempereur et al., 2014).

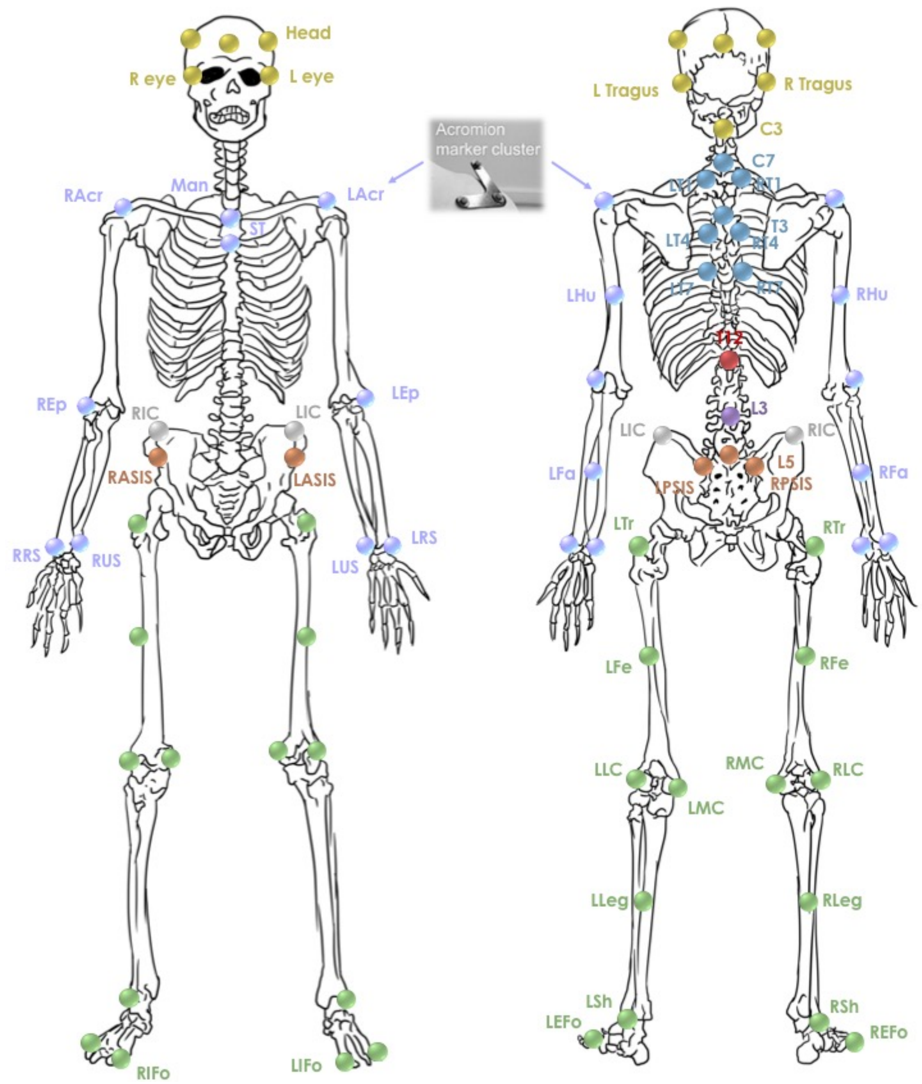


Figure S.3: Markers' placement model and acromion marker cluster (Warner et al., 2015)

2D motion capture and recorder procedure

Three 2D-cameras were placed to videotape the musician's performance from the anterior, posterior and lateral views. All standardised pieces and scales were recorded using a Zoom H4N Handy Portable Digital Recorder (Zoom, Tokyo, Japan).

Surface electromyography

The activation of spine and shoulder muscles would have been measured using surface electromyography (EMG). The recorded muscles would have been bilaterally the upper (UT), middle (MT) and lower trapezius (LT) (Rousseau et al., 2019 and previous work; Afsharipour et al., 2016; Rickert et al., 2013) and the serratus anterior (SA) (Rousseau et al., 2019 and previous work).

SENIAM (Hermens et al., 2000) guidelines would have been followed regarding the shoulder electrodes' placement and Criswell (2010) for the other electrode placement. Placement of electrodes are described in Table S.1. Ground electrode would have been placed on C7 spinous process. Firstly, the skin was prepared thanks to alcohol. Two Ag/AgCl surface electrodes would have been placed 2 cm apart in parallel with the muscle fibers of each selected muscles, in violin play position in order to avoid skin sliding, particularly for the serratus anterior. Electrodes would have been connected to wireless EMG sensors (Biopac). Maximal volunteer contractions (MVC) would have been conducted for shoulder muscles (Ginn et al., 2011). MVC procedures for each muscles are fully described in. Each procedure has been performed three times within 20 second rest period.

Table S.1: EMG electrodes placement and MVCs procedure

Muscles	Surface electrode locations	MVCs procedure
Upper trapezius	Halfway between the acromion and C7 spinous process (Hermens et al., 2000).	Sitting, 5 standardised shoulder movements will be performed (Ginn et al., 2011): - abduction at 90° with internal rotation; - internal rotation in 90° abduction; - flexion at 125° with scapula resistance; - horizontal adduction at 90° flexion; - extension at 30° abduction
Middle trapezius	Halfway between the scapular medial border and the spine at T3-level (Hermens et al., 2000).	
Lower trapezius	Lower third of the distance between the scapular trigonum spinea and T8 spinous process (Hermens et al., 2000).	
Serratus anterior	While the participant held the play position, laterally over the seven rib, in line with the muscles fibers (Hackett et al., 2014; Holtermann et al., 2010).	

Synchronisation of all recordings

Using a controlled device producing both light and sound, 3D and 2D motion captures as well as audio recording would have been synchronised, as well as EMG recordings.

Adjudication of audio recordings

Musicians would have been asked to rate their own performance (at least one month after the second session), as well as at least two external experts. Firstly, musicians and experts would have been asked to point out the fragment in which performance was better (Baadjou et al., 2017). Then they would have been asked to rate both performances based on the scale developed by McCrary et al. (2016) in Appendix N.

Experts would have been experienced and professional upper string players with at least 10 years of experience as teacher (to be used to the procedure of grades) (Baadjou et al., 2017; McCrary et al., 2016; Ackermann et al., 2002).
As much as possible, face-to-face meeting would have been conducted with musicians and experts when they would have been asked to listen to two fragments (same musician, same standard piece) in a randomised order (Baadjou et al., 2017). When face-to-face meeting would not have been possible, audio records would have been sent to the experts and musicians in a randomised order and with numbers in order to refer to the right record after adjudication.

Physical examination
A standardised physical assessment would have been performed with upper string players to investigate:

- Anthropometrics: height, weight (Ackermann & Driscoll, 2010),
- Shoulder mobility: Apley Scratch Test (Ackermann & Driscoll, 2010),
- Scapular motor control:
    - Wall push-ups (Madsen et al., 2011),
    - Distance acromion-wall (Struyf et al., 2009),
    - Scapular dyskinesia test (McClure et al., 2009).

The assessment is fully described in Table S.2.

Table S.2: Physical assessment for upper string players

Test		**Procedure**	**Outcomes**	**Reference**
Anthropo-metrics	Height	Tape measure	Height in cm	Ackmermann & Driscoll, 2010
	Weight	Scale measure	Weight in kg	Ackmermann & Driscoll, 2010
Mobility	Modified Apley's	Standing, participant is asked to grab his hands together behind the head and the back. Note ability and any pain.	Distance in cm	
	Apley's 1 (hands behind head)	**Standing**, participant is asked to take his/her hand behind the head and reach down as far as he/she can along the spine with the tip of the middle finger. Measure distance T1 – fingertip, note any pain.	Distance in cm	Kendall et al., 2005
	Apley's 2 (hands behind back)	**Standing**, participant is asked to take his/her hand backwards and reach up as far as he/she can along the spine, sliding the wrist. Measure T1 – radial styloid process, note any pain.	Distance in cm	Kendall et al., 2005
Motor control	Wall push-up	Facing and standing 70 cm away from the wall Marked the subject's individual spot on the wall to place their hands during the wall push-up. Three repetitions of each movement were done for every test, and the final assessment was made during the third repetition. Note any winging or dysrhythmia.	Correct/Not	Madsen et al., 2011

	Distance wall-acromion: relaxed shoulders	Horizontal distance between posterior border of the acromion and the wall, back facing to the wall, participant asked to relax his/her shoulder.	Distance in cm	Struyf et al., 2009
	Distance wall-acromion: relaxed shoulders	Horizontal distance between posterior border of the acromion and the wall, back facing to the wall, participant asked to retract his/her shoulder.	Distance in cm	
	Scapular dyskinesia test: abduction	**Standing**, performance of 5 repetitions of bilateral, active and weighted shoulder flexion and abduction. Dumbbells: - 1.4 kg if < 68,1 kg - 2,3 kg if > 68,1 kg	P/S/O on the left and right	McClure et al., 2009

Description of the exercises

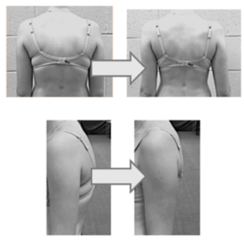
The exercises musicians would have been asked to perform were specifically designed to target scapular stabilisers, based on upper string players' movements while playing or described in general population (Rousseau et al., 2019 and previous work; Mottram et al., 2009).

Four exercises would have been taught to the musicians:

- X1: Bilateral shoulder exercise (with Theraband®, without instrument) (Rousseau et al., 2019 and previous work);
- X2: Bilateral shoulder exercise (with Theraband®, with instrument)
- X3: Scapular orientation exercise (without instrument) (Rousseau et al., 2019 and previous work; Mottram et al., 2009)
- X4: Scapular orientation exercise (with instrument) (based on Mottram et al., 2009).

Exercises instructions are described in Table S.3.

Table S.3: Exercises instructions

Exercise	**Starting position**	**Instructions**	**Picture**
X1: Bilateral shoulder exercise without instrument	Arms placed in the standard initial violin play position without violin (heel of the bow on the strings, left handfirst position), Theraband® between both wrists.	Stretch the elastic by spreading your wrists with a movement of your right upper limb, in position of playing the violin, feeling your shoulder blade muscles and opening your chest.	
X2: Bilateral shoulder exercise with instrument	Arms placed in the standard initial violin play position with the violin (heel of the bow on the strings, left handfirst position), Theraband® between both wrists.	Stretch the elastic while bowing, on a C-major scale up and down, feeling your shoulder blade muscles and opening your chest.	
X3: Scapular orientation exercise without instrument	Relaxed and comfortable position of the shoulders and the whole body.	Make your shoulder blades slightly down and closer, with opening your chest and feeling your shoulder blade muscles.	
X4: Scapular orientation exercise with instrument	Relaxed and comfortable position of the shoulders and the whole body, but while holding the instrument and the bow.	Make your shoulder blades slightly down and closer while playing C-major scale up and down, with opening your chest and feeling your shoulder blade muscles.	

In X1 and X2, resistance of the elastic would have been chosen to be standard among all participants (Theraband® color: green). The length of the elastic would have been chosen based on a standard position: the elastic should be in its slackest position when upper string players maintain on the left, the first position on the strings and the right, the heel part of the bow touching the strings. During 8 weeks, for each session, participants would have been asked to perform the exercises as described below:

- X1 and X3 (without instrument): holding the position for 15 seconds, 10 times with 10 seconds rest in between;
- X2 and X4 (with instrument): 10 C-major scales up and down with 10 seconds rest in between.

Between each exercises' series, participants would have been asked to rest 1 minute.

Questionnaires and scales

The Injury Risk Factors Questionnaire for Musicians (IRFQM) would have been used to investigate several elements in individuals such as individual characteristics, reported disorders, pain or injury and their management, physical activity, workload, life habits, psychological health, etc. (cf Chapter 4). To rate their perceived exertion while playing, musicians would have been asked to use the Borg scale (Borg, 1998), which has often been used in musicians to quantify performance exertion and particularly in upper string musicians (Schemann et al., 2018; McCrary et al., 2016; Chan et al., 2014; Chan et al., 2000). The scale is fully described in Appendix N.

Pre and post-intervention questionnaires were developed to investigate violinists' and violists' subjective feelings and perceptions about the exercises, the way they have been taught and performed, as well as their value to their performance. These questionnaires are fully transcribed below.

Pre-intervention questionnaire

1. What made you interested in volunteering for this study?
2. What do you understand the normal shoulder blade position to be?
3. What effect do you think controlling the shoulder blade movements may have on playing your instrument? Please indicate by circling the number that best represents how this affects you:

(-5 = Worst possible effect) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Best possible effect)

4. Have you ever done specific shoulder blade exercises before? If yes, please specify what kind of exercises, why and with whom:

Mid-intervention questionnaire

1. What effect did the shoulder blade exercises have on your playing immediately afterwards?

(-5 = Worst possible effect) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Best possible effect)

- On your overall perceived playing capacity
- On your posture
- On your ease of movement
- On your music sound
- On your confidence
- On your technique

2. After the 10-weeks protocol, what effect do you think the shoulder blade exercises will on your playing immediately afterwards?

(-5 = Worst possible effect) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Best possible effect)

- On your overall perceived playing capacity
- On your posture
- On your ease of movement
- On your music sound
- On your confidence
- On your technique

3. How well did you feel you could perform the exercises as explained and shown?

(-5 = Not at all) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Greatest possible ability to perform)

4. Are there any other comments that you would like to add about your experience?

Post-intervention questionnaire

1. What effect did the shoulder blade muscle exercises have on your playing after this 10-weeks protocol?

(-5 = Worst possible effect) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Best possible effect)

- On your overall perceived playing capacity
- On your posture
- On your ease of movement
- On your music sound
- On your confidence
- On your technique

2. How well did you feel you could perform the exercises as explained and shown?

(-5 = Not at all) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Greatest possible ability to perform)

3. How well did you feel you could do the exercises three times a week, at the prescribed dose?

(-5 = Not at all) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Greatest possible ability to do)

4. How likely would you be to continue doing this shoulder blade muscle exercises like these as “daily life” exercises?

(-5 = Not at all) -5 -4 -3 -2 -1 0 1 2 3 4 5 (5 = Greatest possible likelihood)

5. Could you order the exercises from the most useful to the less one?

   Exercises’ numbers will be shown on pictures.

   - ☐ X1
   - ☐ X2
   - ☐ X3
   - ☐ X4

6. According to your own answer in question 5, why have you rated this exercise as the most useful for you?
7. According to your own answer in question 5, why have you rated this exercise as the less useful for you?