OVERALL ANTHROPOMETRIC MEASUREMENTS AND PIANO DESIGN DIMENSIONS: THE EXISTENCE OF MISMATCH AS A POTENTIAL RISK FACTOR OF PIANISTS' PLAYING-RELATED MUSCULOSKELETAL DISORDERS

WONG ZHAO WEN

UNIVERSITI SAINS MALAYSIA

2025

OVERALL ANTHROPOMETRIC MEASUREMENTS AND PIANO DESIGN DIMENSIONS: THE EXISTENCE OF MISMATCH AS A POTENTIAL RISK FACTOR OF PIANISTS' PLAYING-RELATED MUSCULOSKELETAL DISORDERS

by

WONG ZHAO WEN

Thesis submitted in fulfilment of the requirements
for the degree of
Doctor of Philosophy

May 2025

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to Dr Johan Awang bin Othman (main supervisor) for his continuous support, inexhaustible patience and valuable critiques of this research work. Without his tremendous understanding in the past few years, it would be impossible for me to complete my study.

I would also like to thank Dr Mohd Najib Abdullah Sani (co-supervisor) for giving me professional guidance and valuable support for the successful completion of this thesis. His insightful comments and constructive recommendations are very much appreciated.

Sincere thanks also to the Universiti Sains Malaysia and the School of the Arts for welcoming me among their students.

My appreciation also goes out to my family and friends for their unwavering support and encouragement throughout my study. I am particularly grateful to my husband for his invaluable support and constant encouragement.

Last but not least, this thesis is the outcome of my years of learning, so I am thankful for all the ups and downs throughout the whole journey of my postgraduate studies because, without it, I would not have stumbled across my strength to complete this thesis.

Sincerely,

Wong Zhao Wen

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF APPENDICES

UKURAN ANTROPOMETRIK KESELURUHAN DAN DIMENSI REKA BENTUK PIANO: KETIDAKSEPADANAN YANG WUJUD SEBAGAI SATU FAKTOR POTENSI RISIKO PRMDS ANTARA PEMAIN-PEMAIN PIANO

ABSTRAK

Ahli-ahli muzik dan pemain-pemain piano mengalami risiko dan gangguan muskuloskeletal yang berkaitan dengan pekerjaan mereka (PRMDs). Walaupun kecederaan yang dialami oleh ahli-ahli muzik tidak semestinya mengancam nyawa mereka, tetapi kecederaan ringan mungkin bertambah teruk jika tidak mendapat rawatan dengan segera, justeru menjadi punca pengakhiran kerjaya ahli-ahli muzik. Salah satu cara untuk mengelakkan kecederaan adalah melalui pemahaman ergonomik instrumen bagi mencapai tahap permainan instrumen yang menyihatkan. Maka, adalah amat penting bagi pemain-pemain piano untuk memahami interaksi antara pemain piano dan piano, termasuk faktor-faktor yang mempengaruhi interaksi tersebut. Walaupun kajian yang lepas telah menyimpulkan bahawa ketidakpadanan antara saiz tangan pemain piano dan saiz papan kekunci merupakan faktor risiko yang menyumbang kepada PRMDs dalam kalangan pemain-pemain piano, namun, tiada kajian sebelum ini yang mengkaji tentang ketidakpadanan antara ukuran antropometrik keseluruhan pemain piano dan dimensi reka bentuk piano dari aspek ergonomik sebagai salah satu faktor yang menyebabkan PRMDs dalam kalangan pemain-pemain piano. Oleh itu, masalah yang dicadangkan oleh kajian ini untuk ditangani adalah tekanan fizikal yang disebabkan oleh ketidakpadanan antara ukuran antropometrik keseluruhan pemain piano dan dimensi reka bentuk piano. Reka bentuk kajian yang digunakan dalam penyelidikan ini adalah kaedah campuran konvergen kerana keberkesanannya untuk mendapatkan data yang relevan dan pandangan yang menyeluruh tentang ketidakpadanan antara ukuran antropometrik keseluruhan pemain piano dan dimensi reka bentuk piano dari aspek ergonomik. Sampel bagi kajian ini terdiri daripada empat orang pemain piano peringkat pengajian tinggi yang terdiri daripada pelajar jurusan piano pada peringkat sarjana muda yang sedang mengikuti trek persembahan dari Universiti Sains Malaysia, Pusat

Pengajian Seni, Bahagian Muzik. Maka, salah satu kepentingan kajian ini adalah untuk mengisi jurang penyelidikan yang dinyatakan di atas dengan mencadangkan ketidakpadanan antara ukuran antropometrik keseluruhan pemain piano dan dimensi reka bentuk piano dari aspek ergonomik sebagai salah satu faktor yang menyebabkan PRMDs dalam kalangan pemain-pemain piano, berdasarkan kaji selidik tentang hubungan antara kewujudan simptom PRMDs yang berkaitan dengan ketidakpadanan dan postur keseluruhan pemain piano. Sehingga kini, tiada senarai semak *Rapid Upper Limb Assessment* (RULA) sedia ada yang bersesuaian dengan konteks permainan piano tanpa sebarang pengubahsuaian. Oleh itu, salah satu kepentingan kajian ini adalah untuk menilai postur pemain piano dengan menggunakan senarai semak *Rapid Upper Limb Assessment* yang telah diubah suai bagi pemain piano (RULA-p) dan direka khusus untuk kajian ini. Keseluruhannya, penemuan dalam kajian ini bertujuan untuk mengembangkan lagi literatur yang sedia ada tentang isu-isu PRMDs dalam kalangan pemain-pemain piano dan juga menyumbang kepada pemahaman ergonomik instrumen bagi mencapai tahap permainan instrumen yang menyihatkan. Hasil kajian ini menunjukkan bahawa ketidakpadanan antara ukuran antropometrik keseluruhan pemain piano dan dimensi reka bentuk piano merupakan satu faktor yang menyebabkan PRMDs dalam kalangan pemain-pemain piano, terutamanya ketidakpadanan antara ketinggian siku pemain piano pada posisi duduk dan ketinggian kekunci piano yang membawa kepada simptom PRMDs dalam kalangan remain-pemain piano pada bahagian bahu dan leher.

OVERALL ANTHROPOMETRIC MEASUREMENTS AND PIANO DESIGN DIMENSIONS: THE EXISTENCE OF MISMATCH AS A POTENTIAL RISK FACTOR OF PIANISTS' PLAYING-RELATED MUSCULOSKELETAL DISORDERS

ABSTRACT

Musicians and pianists are subject to occupational disorders and are at risk of injuries from playing-related musculoskeletal disorders (PRMDs). Although injuries to musicians are not necessarily life-threatening, they might potentially end a musician's career, as these injuries can lead to permanent damage, especially if left untreated. Since one of the ways to prevent injuries is to understand the ergonomics of the instrument to achieve healthful playing, it is critical for pianists to understand the interaction between the pianist and the piano, including the factors that affect this interaction. Although past studies have concluded that the mismatch between pianists' hand size and keyboard size is a risk factor contributing to the pianists' PRMDs, none of the previous studies looked into the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect as a potential risk factor for pianists' PRMDs. Hence, the problem that this research proposes to address is the physical stress that is caused by the mismatch between pianists' overall anthropometric measurements and piano design dimensions. This study adopted a convergent mixed methods research design due to its usefulness in obtaining relevant data and gaining comprehensive insights into the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect. The sample of this study consists of a total of four tertiary level pianists, which only include undergraduate piano major students who are currently undertaking the recital track at the Music Department of the School of the Arts, Universiti Sains Malaysia. Therefore, one of the significance of this study is to fill in the above research gap by proposing the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect as a potential risk factor for

pianists' PRMDs, based on the examination of the relation between the occurrence of the symptoms of PRMDs associated with the existence of mismatch and pianists' overall posture. There is also no existing Rapid Upper Limb Assessment (RULA) checklist that exactly fits into the context of piano playing, at least not without some modifications. Hence, another novelty of this study is to assess the pianists' posture with a modified Rapid Upper Limb Assessment for pianists (RULA-p) specifically designed for this study. Overall, the findings are intended to contribute to the understanding of the ergonomics of healthful playing and to further expand the existing literature on pianists' PRMDs. Based on the results of this study, the mismatch between pianists' overall anthropometric measurements and piano design dimensions is a potential risk factor for pianists' PRMDs, particularly with regard to the mismatch between pianist's sitting elbow height and piano key height, which will potentially lead to symptoms of pianists' PRMDs in the shoulder and neck areas.

CHAPTER 1

INTRODUCTION

1.1 Introduction

An inappropriate dimensional match between a person's body and his or her workspace may lead to short- and long-term severe consequences. The mismatch between human anthropometric measurements and machine dimensions is one of the causes of physical stress, such as pain and discomfort, leading to musculoskeletal disorders and cumulative trauma. The mismatch between a player and an instrument can lead to various problems, as a musician's anatomy is not always suitable for a particular musical instrument. Mismatch exists when 'one-size-fits-all' furniture is used by users of different sizes. Since a 'one-size-fits-all' keyboard size has been the standard in present-day piano making, performing, teaching, and learning processes, pianists are highly susceptible to a higher level of ergonomic risk than other musicians. Therefore, the problem that this research proposes to address is the physical stress caused by the mismatch between pianists' overall anthropometric measurements and piano design dimensions. The purpose of this study is to propose mismatch between pianists' overall anthropometric measurements and piano design dimensions as a potential risk factor for pianists' PRMDs by examining the relation between the occurrence of the symptoms of PRMDs associated with the existence of mismatch and pianists' overall posture, based on the identification of the types of mismatch, as well as the assessment of the pianists' overall posture while playing on the piano.

This chapter begins with the background of the study and presents the statement of the problem. After establishing the research objectives and research questions, the methodology adopted for this study, as well as the research scope, is presented. Finally, the research significance is presented, followed by the definition of key terms.

1.2 Background to the Study

Musculoskeletal disorders are injuries that affect the human body, including muscles, tendons, ligaments, nerves and blood vessels (da Costa & Vieira, 2010; Ekpenyong & Inyang, 2014; Hagglund & Jacobs, 1996; Hayes, Cockrell, & Smith, 2009; Kulin & Reaston, 2011; Punnett & Wegman, 2004; Tinubu, Mbada, Oyeyemi, & Fabunmi, 2010). Musculoskeletal disorders also include injuries to the bones, joints, cartilage and spinal discs (da Costa & Vieira, 2010; Graham, 2002; Hayes et al., 2009; Kulin & Reaston, 2011). Musculoskeletal disorders can result from a single or cumulative injury that causes pain in any part of the human body, such as the neck, shoulders, upper and lower back, arms, wrists, hands, hips, knees and feet (Graham, 2002; Hayes et al., 2009).

Injuries caused by work that affect the human body are known as work-related musculoskeletal disorders (WRMDs) (Ekpenyong & Inyang, 2014; Hagberg, 1996; Ozdemir, Tutus, Akgun, & Kilcik, 2019). A musician is an occupation that involves playing musical instruments (Bragge, Bialocerkowski, & McMeeken, 2006b; Brandfonbrener, 1986; Lederman, 2002; Mishra, 2017; Oikawa, Tsubota, Chikenji, Chin, & Aoki, 2011; Paarup, Baelum, Holm, Manniche, & Wedderkopp, 2011; Park, Guptill, & Sumsion, 2007). It is worth noting that musicians are susceptible to occupational disorders (Caldron et al., 1986; Rozmaryn, 1993). Similar to other occupations, a musician is at risk of suffering from WRMDs (Caldron et al., 1986; Foxman & Burgel, 2006; Guptill & Golem, 2008; Knishkowy & Lederman, 1986; Zaza, 1998). Therefore, in the context of music, work-related musculoskeletal disorders (WRMDs) are referred to as playing-related musculoskeletal disorders (PRMDs) (Bragge, Bialocerkowski, & McMeeken, 2006a).

Some common causes of musicians' physical injury are:

(i) excessive or increased in muscle tension (Brandfonbrener, 2006; Dick et al., 2013; Dommerholt, 2009; Hagglund & Jacobs, 1996; Kava, Larson, Stiller, & Maher,

2010);

(ii) poor or awkward posture (Brandfonbrener, 2006; Dick et al., 2013; Dommerholt, 2009; Foxman & Burgel, 2006; Knishkowy & Lederman, 1986);

(iii) repetitive movement (Dommerholt, 2009; Foxman & Burgel, 2006; Guptill & Zaza, 2010; Hagglund & Jacobs, 1996; Knishkowy & Lederman, 1986);

(iv) long practice time (Dick et al., 2013; Fry, 1986a; Furuya, Nakahara, Aoki, & Kinoshita, 2006; Guptill & Zaza, 2010; Hagglund & Jacobs, 1996; Knishkowy & Lederman, 1986; Oikawa et al., 2011; Rozmaryn, 1993); and

(v) the intensity of playing that exceeded the physical demands (Dick et al., 2013; Hagglund & Jacobs, 1996; Rozmaryn, 1993).

Clara Schumann, compelled to increase her public performances to support her large family, began experiencing pain in her right arm, initially brief but progressively more persistent, requiring longer rest periods. While tackling the demanding works of Johannes Brahms, particularly his first piano concerto, the pain became chronic, forcing her to cease performing for over a year (Eckart Altenmüller, 2010). Similarly, at age 20, Alexander Scriabin developed an overuse injury in his right hand while striving to enhance the quality of his piano touch. Although rest, a reduced repertoire, and a greater focus on composition aided his recovery, he remained concerned about the endurance of his hand (Altenmüller, 2015). More recently, Lang Lang faced an extended period of inactivity due to an injury to his left arm. In 2017, he announced inflammation in his left arm, attributing the injury to what he described as “a stupid practice” of Ravel’s left-hand concerto, which led him to cancel several months of performances (The Straits Times, 2018).

Young musicians are willing to endure the pain they suffer from playing (Britsch, 2005; Hagglund & Jacobs, 1996; Lockwood, 1988; Park et al., 2007). Mark (1999) and Rosety-Rodriguez et al. (2015) claimed that the majority of injuries do not end a musician’s professional career. However, these injuries can restrict repertoire choices or

even lead to the cancellation of concerts and tours (Mark, 1999; Rosety-Rodriguez et al., 2015). Musicians' injuries may not be life-threatening (Zaza, Charles, & Muszynski, 1998), but they can be career-threatening if they are severe enough (Blackie, Stone, & Tiernan, 1999). In addition, Rozmaryn (1993) claimed that minor injuries could potentially end a musician's career because these injuries can cause permanent damage (Rosety-Rodriguez et al., 2015), especially if they are left untreated (Britsch, 2005; Rosety-Rodriguez et al., 2015). However, this tragic situation is avoidable as the injuries are preventable (Mark, 1999).

Musicians are high-powered athletes (Rozmaryn, 1993), and piano playing is similar to athletic activity (Ling, Loo, & Hamedon, 2018). Piano playing at an elite level (i.e. tertiary, college, conservatory or professional) (Bragge et al., 2006a, 2006b) requires agility and physical strength (Fry, 1988, 1989) to achieve high-intensity practice, speed and accuracy, and to cope with the stress of competition (Bragge et al., 2006a). While pianists (i.e. professional and non-professional) are at risk of developing PRMDs (Allsop & Ackland, 2010), pianists are also among the musicians with a high occurrence of PRMDs (Bragge et al., 2006b; Cayea & Manchester, 1998; Dommerholt, 2009; Hagglund & Jacobs, 1996; Knishkowy & Lederman, 1986; Zaza & Farewell, 1997). Over-practice (Heming, 2004), incorrect piano technique (Parry, 2003), and physical limitations such as small hands (de Smet, Ghyselen, & Lysens, 1998; Farias et al., 2002; Sakai, Liu, Su, Bishop, & An, 2006) and insufficient stamina (Parry, 2003) are some of the factors that lead to pianists' PRMDs (Ling, Loo, & Hamedon, 2016; Ling et al., 2018).

One of the ways to prevent injury is to understand the ergonomics of the instrument to achieve healthful playing (Blackie et al., 1999; Potter & Jones, 1995). Ergonomics is the study of the interaction between humans and machines, including the factors that affect that interaction (Bridger, 2003; Corlett & Clark, 2009). A mismatch results in potential physical stress such as pain and discomfort (Parvez, Rahman, & Tasnim, 2019). Therefore, the mismatch between the human anthropometric measurements

and the machine dimensions is also a significant factor leading to musculoskeletal disorders and cumulative trauma (Adegoke, Jegede, Olagbegi, Nadasan, & Christie, 2019; Bridger, 2003; Imrhan, Nguyen, & Nguyen, 1993; Parvez et al., 2019; Prado-León, Avila-Chaurand, & González-Muñoz, 2001).

In general, the physical mismatch between the musician and the instrument is a contributing factor to PRMDs (Dawson, 2006). Physical size (Pak & Chesky, 2001; Yuen, Clements, Sundar, & Ramalingam, 2021), as well as body habitus (Brandfonbrener, 2000) and anthropometry (Ranelli, Straker, & Smith, 2008), are risk factors for musicians' PRMDs (Brandfonbrener, 2000; Pak & Chesky, 2001; Yuen et al., 2021). According to Zinn (1990), body size and habitus describe an individual's physical characteristics, including the physique, general bearing and body build.

The mismatch between pianists' physical attributes and the piano is a risk factor that contributes to pianists' PRMDs (Chi, Halaki, & Ackermann, 2020). Pianists with physical limitations of smaller hand sizes are more likely to experience pain due to the mismatch between the hand size and the piano keys width (Yoshimura & Chesky, 2009). Pianists with a smaller stature and small hands are at a disadvantage and are prone to PRMDs on heavy action pianos (Sakai, 1992; Winspur, 2003), as heavy action pianos require considerable power from the pianist (Winspur, 2003).

Mismatch exists when 'one-size-fits-all' furniture is used by users of different sizes (Brewer, Davis, Dunning, & Succop, 2009). Because instruments that vary in size (Winspur, 2003), a musician's anatomy may not always be suitable for a certain musical instrument (Parry & Winspur, 1998; Sakai, 2007). There are therefore many opportunities for a mismatch between the musician and the instrument (Winspur, 2003), which can lead to various problems (Parry & Winspur, 1998; Sakai, 2007). As a 'one-size-fits-all' keyboard size has been the standard in the present-day piano making, performing, teaching and learning process (Booker & Boyle, 2011; Chi et al., 2020), pianists are highly susceptible to a higher level of ergonomic risk than other musicians

(Ozdemir et al., 2019).

The adjustable piano stool, a key advancement for musicians seeking comfort and precision, became widely popular in the 19th century. As pianos grew larger during the Victorian era (circa 1837–1901), the need for adaptable seating that provided stability and ergonomic support became clear. Early stools were simple, but over time they began to include height adjustments. The first models used a screw mechanism, allowing pianists to raise or lower the seat for improved comfort and better access to the keys and pedals. This evolution in stool design paralleled developments in piano technology and a growing emphasis on ergonomics. Today, modern adjustable stools continue this legacy, offering a variety of height and seating angle adjustments to help pianists of all sizes maintain optimal posture. This shift from fixed-height benches, which often caused discomfort and poor posture, greatly improved both comfort and performance, allowing musicians to find the ideal height for proper alignment and technique (Hidrau, 2024; Shaughnessy, 2024).

While the key consideration for piano bench height is ensuring the hands are at a comfortable playing height, sitting too low can still force the pianist to raise their elbows and shoulders, causing strain and increasing the risk of repetitive strain injuries. As increased awareness of ergonomic risks will reduce the incidence of musculoskeletal disorders (Ozdemir et al., 2019; Robertson, Huang, O'Neill, & Schleifer, 2008), it is necessary for musicians to understand the ergonomics of healthful playing in order to prevent injury (Blackie et al., 1999; Potter & Jones, 1995).

> Inadequate instrument set-ups and sizes that mismatch the player's physical attributes is frequently cited as one of the risk factors contributing to the development of PRMDs in violin and piano performers. ... For pianists, a "one-size-fits-all" keyboard has been the available industry standard with respect to the size of the keyboard in modern piano manufacturing, teaching and performing. (Chi et al., 2020, p. 103143-1)

From the statements cited above, past studies have concluded that the mismatch between pianists' hand size and keyboard size is a risk factor contributing to the pianists' PRMDs. However, to the best of the authors' knowledge, the mismatch between pianists' overall anthropometric measurements and piano design dimensions has not previously been presented in the literature as a potential risk factor contributing to the pianists' PRMDs. Furthermore, none of the existing studies relate pianists' postures to the mismatch between pianists' overall anthropometric measurements and piano design dimensions. It is therefore essential to study the relationship between a person's body posture and the workspace from an ergonomic aspect to reduce musculoskeletal disorders (Adegoke et al., 2019). The same should be applied in the context of piano playing.

1.3 Statement of Problem

Past studies of pianists' PRMDs have mainly focused on prevalence (Bragge et al., 2006a; Bragge, Bialocerkowski, & McMeeken, 2008; Furuya et al., 2006; Shields & Dockrell, 2000; Zaza, 1998), risk factors (Bragge et al., 2006a, 2008), piano technique (Allsop & Ackland, 2010; Wristen, 2000), hand size (de Smet et al., 1998; Sakai et al., 2006), wrist position (Oikawa et al., 2011), playing time (Bruno, Lorusso, & L'Abbate, 2008), psychological stress (Yoshie, Kudo, Murakoshi, & Ohtsuki, 2009), injury prevention (Guptill & Zaza, 2010; Wristen, 2000) and awareness (Ling et al., 2016).

PRMDs are caused by a myriad of factors, which involve the relationship between musicians and the instrument they play (Foxman & Burgel, 2006; Winspur, 2003). It is therefore necessary for musicians to understand the ergonomics of healthful playing in injury prevention (Blackie et al., 1999; Potter & Jones, 1995). In the context of music playing, ergonomics focuses on studying the relationship between the musician and the instrument (Foxman & Burgel, 2006).

While previous literature has studied the relation between hand size and piano performance variables (Chi et al., 2020), none of these studies have looked into the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect (e.g. piano bench height, piano key height, the vertical distance from the surface of the piano bench to the underside of the elbow) as a potential risk factor for pianists' PRMDs.

As the mismatch between the pianist's physical attributes and the piano is one of the risk factors contributing to pianists' PRMDs (Chi et al., 2020), it is important that studies include ergonomic factors as one of the risk factors causing PRMDs (Chan et al., 2000; Heming, 2004). Therefore, the problem that this research proposes to address is the physical stress that is caused by the mismatch between pianists' overall anthropometric measurements and piano design dimensions.

1.4 Research Objectives

Based on the problem discussed above, this study has the following research objectives, which focus on looking into the existence of the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect:

(i) To identify the types of mismatch between pianists' overall anthropometric measurements and piano design dimensions that exist from an ergonomic aspect.

(ii) To assess the pianists' overall posture while playing on the piano.

(iii) To examine the relation between the occurrence of the symptoms of PRMDs associated with the existence of mismatch and pianists' overall posture.

(iv) To propose mismatch between pianists' overall anthropometric measurements and piano design dimensions as a potential risk factor for pianists' PRMDs.

An expert in the field of Environmental Health and Occupational Health was consulted in formulating the above research objectives.

1.5 Research Questions

Based on the research objectives listed above, the research questions for this study are as follows:

(i) What are the types of mismatch between pianists' overall anthropometric measurements and piano design dimensions that exist from an ergonomic aspect?

(ii) How to assess the pianists' overall posture while playing on the piano?

(iii) What is the relation between the occurrence of symptoms of PRMDs, the existence of mismatches, and pianists' overall posture?

(iv) How does a mismatch between between pianists' anthropometric measurements and piano design dimensions poses a potential risk factor of pianists' PRMDs?

1.6 Methodology

This study adopted a non-experimental mixed methods research approach, which involves the collection and integration of both quantitative data and qualitative data to provide additional insights (Creswell & Creswell, 2018b). As each method has its strengths and weaknesses, the mixed methods approach (formerly known as the multiple methods approach) was initially developed to neutralise the weaknesses of both quantitative and qualitative data (Creswell & Creswell, 2018b). A mixed methods design is particularly useful because the combined strengths of both quantitative and qualitative data can provide a better and more insightful understanding of the research problem (Creswell & Creswell, 2018b). Therefore, this study adopted a convergent mixed methods research design. As both quantitative and qualitative data in this study have the same emphasis, therefore, the notation for this study is: QUAN + QUAL.

The choice of a convergent mixed methods design for this study is primarily due to its usefulness in obtaining relevant data and gaining comprehensive insights into the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect.

1.7 Research Scope

Pianists are one of the musicians with a high occurrence of PRMDs (Bragge et al., 2006b; Cayea & Manchester, 1998; Dommerholt, 2009; Hagglund & Jacobs, 1996; Knishkowy & Lederman, 1986; Zaza & Farewell, 1997). Piano playing at an elite level (i.e. tertiary, college, conservatory or professional) (Bragge et al., 2006a, 2006b) requires agility and physical strength (Fry, 1988, 1989) to achieve high-intensity practice, speed and accuracy, as well as the stress of competition (Bragge et al., 2006a; Ling et al., 2018).

In addition, a sudden increase in practice time is one of the factors for injury development (Fry, 1987; Newmark & Lederman, 1987; Storm, 2006), which is typical of tertiary music students (Fry, 1987). Tertiary level pianists include undergraduate and postgraduate piano major students (Savvidou, Willis, Li, & Skubic, 2015). Therefore, the population for this study is the tertiary level pianists, which include undergraduate and postgraduate piano major students from the Music Department of the School of the Arts, Universiti Sains Malaysia.

This study will adopt a non-probability purposive sampling method (Chua, 2016a), which is similar to Cerveró, Ruiz, Sanchis, and Ros's (2018) study that focused on identifying postural errors among clarinettists. Therefore, the sample of this study consists of a total of four tertiary level pianists, which only include undergraduate piano major students who are currently undertaking the recital track at the Music Department of the School of the Arts, Universiti Sains Malaysia.

The purpose of this convergent mixed methods study was to investigate the existence of the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect and to propose it as a potential risk factor for pianists' PRMDs, based on the examination of the relation between the occurrence of the symptoms of PRMDs associated with the existence of mismatch and pianists' overall posture by identifying the types of mismatch, as well as the assessment of the pianists' overall posture while playing on the piano. As the primary focus of this study is on the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect, which causes pianists' physical stress, it should be emphasised that it is not the intention of this study to focus on the intervention or prevention of pianists' PRMDs.

1.8 Research Significance

In music discipline, musicians including pianists are susceptible to musculoskeletal injuries (Bruno et al., 2008; Sheibani-Rad, Wolfe, & Jupiter, 2013). Although there are some studies that have addressed this matter, past studies have not looked into the aspect of the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect, leading to pianist's PRMDs. Therefore, one of the significance of this study is to identify the existence of the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect, which could be a potential risk factor for the pianists' physical stress. Systematically address this matter can improves piano teaching and learning, as well as performing.

While past studies have focused on the prevalence and risk factors of pianists' PRMDs, as well as the importance of PRMDs prevention, they have not informed on the factors contributing to the pianists' PRMDs in relation to the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect. Therefore, one of the significance of this study is to fill in the

above research gap by proposing the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect as a potential risk factor for pianists' PRMDs, based on the examination of the relation between the occurrence of the symptoms of PRMDs associated with the existence of mismatch and pianists' overall posture.

Although the RULA assessment checklist is widely used in various industries, there is no existing checklist that exactly fits into the context of piano playing, at least not without some modifications. Therefore, one of the novelties of this study is to assess the pianists' posture with a modified Rapid Upper Limb Assessment for pianists (RULA-p) specifically designed for this study. Overall, the findings are intended to further expand the existing literature on pianists' PRMDs, which will contribute to the understanding of the ergonomics of healthful playing.

1.9 Definition of Key Terms

The term 'Playing-related Musculoskeletal Disorders', abbreviated to 'PRMDs', is used in this study as a generic term for a range of musculoskeletal problems. Common PRMDs include carpal tunnel syndrome, tendinitis, focal dystonia and other conditions (Zaza, 1998).

1.10 Organisation of Thesis

This thesis followed the IMRaD (Introduction-Method-Result-and-Discussion) structure of a scientific research report, with some modifications to the outline and title. The IMRaD structure provides a clear and logical presentation of content for organising scientific research reports, which can be customised and personalised to one's requirements when necessary (Johannesson & Perjons, 2014). The structure adopted in this thesis extended the IMRaD by splitting the 'Introduction' section of the IMRaD form into two chapters–'Chapter 1: Introduction' and 'Chapter 2: Literature Review',

and combining the 'Result' and 'Discussion' sections of the IMRaD form into one chapter–'Chapter 4: Discussion', with an additional chapter–'Chapter 5: Conclusion' that reiterates the highlights of this study.

Firstly, 'Chapter 1: Introduction' provides a detailed description of the practical problems associated with the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect, by giving an overview of mismatch and PRMDs in musicians and pianists, followed by the identification of the research problems, the formulation of the research objectives and the research questions. This chapter also briefly discusses the methodology and defines the scope of this study. The relevance and contribution of this study is also clearly stated in this chapter. Finally, this chapter concludes with the definition of key terms and the structure of the rest of the thesis.

'Chapter 2: Literature Review' provides in-depth knowledge of the risk factors for PRMDs in musicians and pianists through various relevant sources of literature (e.g. scientific journal articles, theses, books, proceedings and conference paper). This chapter also explores the relationship between posture and ergonomics, which is essential to understanding the mismatch between musician and instrument, as well as the mismatch between pianist and piano. This chapter also explores aspects of pianists' awkward posture in relation to the mismatch between pianist and piano. To ensure the credibility, authenticity, and accuracy of the documents, the literature review is based on books and academic publications that have been peer-reviewed by well-established publications, journals and conferences (Johannesson & Perjons, 2014). According to Gregor and Hevner (2013), a detailed and thorough literature review should include descriptive and prescriptive knowledge relevant to the decision problem being addressed, as well as prior and existing studies with similar aims, which may have different labels. The extensive and comprehensive literature study related to the decision problems helps to conclude this chapter by identifying the existing research gap related to this study. The theoretical and conceptual framework of this study has

also been included in this chapter.

'Chapter 3: Methodology' describes and justifies the research design, which was validated by an expert in the field of Environmental Health and Occupational Health. In addition, this chapter provides the rationale for adopting the Rapid Upper Limb Assessment (RULA) as an appropriate posture assessment tool and explains the process of using RULA. This chapter also identifies the limitations of the existing RULA approach in assessing pianists' posture, followed by the proposal of the modified Rapid Upper Limb Assessment for pianists (RULA-p). This chapter begins with a discussion of the preliminary study, which aims to test and refine the survey instrument in preparation for a full-scale study investigating the relationship between pianists' anthropometric measurements and piano design dimensions. This chapter includes the process of data collection, the sampling method, and the inclusion and exclusion criteria. The rationale for the small sample size ($n = 4$) was also included. This chapter also explains the procedures for collecting anthropometric measurements and piano design dimensions, followed by the four mismatch equations of pianists' anthropometric measurements and piano design dimensions used in this study. In addition to discussing the process of observing the subjects in this study, this chapter also discusses and develops the necessary questions for the pre- and post-observation interviews. This chapter ends with the elaboration of ways of analysing and interpreting the data collected from the subjects.

'Chapter 4: Results and Analysis' presents the findings of the preliminary study, as well as the results of the pre-observation and the post-observation interviews, including all necessary measurements. These measurements were then applied to the mismatch equations to determine the existence of mismatches between the subjects' anthropometric measurements and piano design dimensions. The final RULA-p scores were obtained based on the observations of all subjects. These RULA-p scores were then validated for all subjects in order to achieve higher precision and accuracy.

Finally, ‘Chapter 5: Discussion and Conclusion’ reiterates the highlights and the novelties of this study in order to bridge the knowledge gap. This chapter is the central chapter of this thesis and provides a discussion of the findings, which includes the integration of the three main components of this study (i.e. the mismatch equations, the final RULA-p scores (validated) and the interview results), followed by a separate section which answers all the research questions raised from the beginning of the thesis and concludes. According to Bem (2004), it is crucial to provide a concluding chapter that ties the entire research together, with a summary that goes back to generalities as far as possible. This chapter also reflects on the limitations of the current research that require further improvement. Thus, some recommendations for future research are provided in order to extend and improve the scope of studies on similar research problems.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

'Chapter 2: Literature Review' provides an extensive and comprehensive literature study covering PRMDs in musicians and pianists and their risk factors, followed by posture and ergonomics, and pianists' awkward posture in relation to mismatch. This chapter ends with research gaps and theoretical and conceptual frameworks.

'Section 2.1: Introduction' provides an overview of 'Chapter 2: Literature Review'.

'Section 2.2: PRMDs in Musicians and Pianists' provides an overview of the background to PRMDs in musicians and pianists to emphasise the prevalence of PRMDs among them.

'Section 2.3: Risk Factors of PRMDs' summarises the risk factors for PRMDs to provide a better understanding of PRMDs in musicians and pianists.

'Section 2.4: Posture and Ergonomics' discusses the relationship between a person's posture and their workspace from an ergonomic aspect. An overview of the mismatch between musicians and instruments, as well as the mismatch between pianists and piano, is provided in separate subsections to inform the research problem of this study on the physical stress caused by the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect.

As the issues of the mismatch between the pianist and the piano is often addressed through the principles of ergonomics (Yoshimura & Chesky, 2009), 'Section 2.5: Pianists' Awkward Posture in Relation to Mismatch' further elaborates on the two postural problems (i.e. excessive kyphotic posture and elevated shoulders) that commonly oc-

cur in pianists' in relation to the mismatch between pianists' overall anthropometric measurements and piano design dimensions from an ergonomic aspect.

'Section 2.6: Research Gaps' identifies the existing knowledge gaps related to this study.

'Section 2.7: Theoretical Framework' and 'Section 2.8: Conceptual Framework' illustrate the theoretical and conceptual framework of this study.

'Section 2.9: Conclusion' concludes this chapter.

2.2 PRMDs in Musicians and Pianists

According to Bruno et al. (2008), musicians who play at a professional level are similar to athletes. Performing artists, such as musicians, are often compared to athletes (Brandfonbrener, 1986; Dick et al., 2013). It is common for musicians to perform at high speed for a long duration (Brandfonbrener, 1991; Quarrier, 1993), requiring physical endurance (Brandfonbrener, 1991). Because both musicians and athletes perform activities that require strength, flexibility, coordination and agility (Quarrier, 1993), they are susceptible to musculoskeletal injuries (Bruno et al., 2008; Sheibani-Rad et al., 2013). Therefore, PRMDs are common among musicians (Allsop & Ackland, 2010; Mishra, 2017; Paarup et al., 2011; Savvidou et al., 2015; Storm, 2006; Zaza, 1998).

PRMDs are not limited to professional musicians; student musicians, particularly those at the tertiary level, also face this challenge (Miao, Musib, & Selvarajah, 2024). While much of the literature focuses on professional musicians, college student musicians are also highly vulnerable. Extensive research indicates that PRMDs affect most musicians at some point in their careers, with prevalence rates for pianists ranging from 26% to 93% (Miao, Musib, & Selvarajah, 2023). In Miao et al.'s (2023) study, all 12 participants were student pianists who had not yet entered a professional career, yet

PRMDs had already influenced their career planning and job choices due to physical limitations (Miao et al., 2023). Beyond physical pain and discomfort, PRMDs can have profound psychological effects, including loss of self-confidence and uncertainty about one's identity as a pianist. These issues significantly impact young student pianists' career development and life choices (Miao et al., 2023). A major contributing factor is the lack of PRMD prevention courses in higher education, which results in limited knowledge and awareness of PRMDs among student pianists (Ling et al., 2018; Miao, 2024).

Piano playing requires agility and physical strength (Fry, 1988, 1989) to achieve high-intensity practice, speed and accuracy, and the stress of competition (Bragge et al., 2006a; Ling et al., 2018), all of which are similar to athletic activity (Ling et al., 2018). This is particularly true for piano playing at an elite level (i.e. tertiary, college, conservatory or professional) (Bragge et al., 2006a, 2006b). Therefore, pianists are among the musicians with a high occurrence of PRMDs (Bragge et al., 2006b; Cayea & Manchester, 1998; Dommerholt, 2009; Hagglund & Jacobs, 1996; Knishkowy & Lederman, 1986; Zaza & Farewell, 1997).

2.3 Risk Factors of PRMDs

Pianists' playing-related health problems have been noted since around 1830, about a century after the invention of the piano (Yoshimura & Chesky, 2009), with "pianist's cramp" being a well-known issue for Robert Schumann (Altenmüller, 2005), and later recognised in medical journals by the late 19th century (Poore, 1887).

Both professional and non-professional pianists are at risk of developing PRMDs (Allsop & Ackland, 2010). Various risk factors that lead to pianists' PRMDs include: (i) long hours of practice; (ii) sudden increase in practice time; (iii) excessive muscle tension; (iv) improper playing techniques; (v) physical limitations (e.g. hand size and small build); and (vi) awkward postures.

2.3.1 Long Hours of Practice

Musicians are similar to athletes in that an increase in practice time increases the risk of injury (Dick et al., 2013). Excessive practice (Brandfonbrener, 2003; Toledo et al., 2004) and continuous repetition of practice can be harmful (Rozmaryn, 1993) because repeated use of the body in a particular position, pushing it to the extreme and beyond a comfortable state, leads to physiological stress (Savvidou et al., 2015). An increase in physiological stress can lead to excessive muscle tension, which is common in the development of PRMD (Brandfonbrener, 2003).

Foxman and Burgel (2006) cited Hoppmann's (2001) study with the title 'Instrumental Musicians' Hazards', which claimed that a sudden increase in practice time was the most important risk factor for PRMDs. In addition, a sudden increase in practice time can cause difficulties for musicians, especially music students (Blackie et al., 1999). Musicians' practice time increases as they prepare for their juries, examinations, auditions, concerts and recitals (Ackermann, Adams, & Marshall, 2002; Blackie et al., 1999; Brandfonbrener, 2003; Fry, 1986a).

Pianists spend long hours in practising (Belmarsh & Jardin, 1996; Blanco-Piñeiro, Díaz-Pereira, & Vidal, 2017). According to Kreutz, Ginsborg, and Williamon (2008), musicians who spend long hours practicing to develop and maintain their skills often put heavy strain on their musculoskeletal system (Kreutz et al., 2008). While Pak and Chesky (2001) and de Smet et al. (1998) found no correlation between practice hours and pianists' PRMDs, Fry, Ross, and Rutherford (1988) and Shields and Dockrell (2000) claimed otherwise. Shields and Dockrell's (2000) study suggested a positive correlation between practice time and pianists' PRMDs and Fry et al. (1988) concurred that there was a strong correlation between practice duration and the symptoms of PRMDs. As longer practice hours are associated with a high risk of PRMDs in musicians (Fry, 1986a, 1986b, 1986c; Shields & Dockrell, 2000), long hours of practice is one of the risk factors contributing to pianists' PRMDs (Allsop & Ackland, 2010; Brandfonbrener,

2003; Parry, 2003).

2.3.2 Piano Techniques

According to Sakai (2002), certain piano techniques require a specific hand movement. For example, the wide-hand position (Belmarsh & Jardin, 1996) when playing an octave is used in a similar way when playing chords (Sakai, 2002). According to Sakai (1992) and Belmarsh and Jardin (1996), regular practice using wide-hand-positioned techniques with the abduction of the thumb and the small finger for octaves or chords increases the risk of developing hand pain. Sakai (2002) also asserted that hyperabduction of the thumb and the little finger, which is required to strike the key with each fingertip when playing octaves and chords, causes hand pain and other symptoms in pianists. Hochberg, Leffert, and Heller's (1983) study also showed that playing octaves is one of the piano techniques that would lead to muscle injury. Therefore, there is a correlation between playing techniques that require pianists to maintain a large hand span (i.e. octaves and chords) and injury (Wristen, 2000).

Improper piano playing technique, such as pressing the fingers too hard on the keyboard (Ling et al., 2018), playing loudly with high force (Wolf, Keane, Brandt, & Hillberry, 1993; Yoshimura, Paul, Aerts, & Chesky, 2006), using an excessive muscle force to press the keys (Dawson, 2006) and exaggerated technique (i.e. an overly percussive approach to the keyboard) (Parry, 2003) can lead to pianists' PRMDs. In addition, the repetitive application of dynamic force from practising chords with *fortissimo*[1] will also lead to pianists' PRMDs, particularly in the hand/finger, wrist, forearm and elbow (Furuya et al., 2006). Shields and Dockrell (2000) showed that 73% of the subjects experienced pain with at least one of the piano techniques, which include chords, *fortissimo*, double octaves or *presto*[2]. Piano techniques, such as octaves, chords (Sakai, 1992, 2002; Sakai et al., 2006; Yoshimura et al., 2006) and *fortissimo* (Oikawa

[1] *fortissimo* (It.), Very loud (abbreviation *ff*) (Kennedy & Kennedy, 2007).

[2] *presto* (It.), Quick. *prestezza*, quickness; *prestamente*, quickly; *prestissimo*, very quick; *prestissimamente*, very quickly (Kennedy & Kennedy, 2007).

et al., 2011), are therefore some of the technical demands that not only increase the risk but are also responsible for pianists' PRMDs, particularly in the hand and forearm area.

2.3.3 Physical Limitations

In general, physical size (Pak & Chesky, 2001; Yuen et al., 2021), body habitus (Brandfonbrener, 2000) and anthropometry (Ranelli et al., 2008) are risk factors for musicians' PRMDs. Body size and habitus describe the physical characteristics of an individual, including the physique, general bearing and body build (Zinn, 1990). Physical limitations such as small hand size are also one of the risk factors for discomfort (Lai et al., 2015), hand pain (de Smet et al., 1998; Pak & Chesky, 2001; Sakai, 1992; Yoshimura et al., 2006) and injury (Chi et al., 2020; de Smet et al., 1998; Ling et al., 2018; Sakai, 1992).

Pianists' anthropometric characteristics (Grieco et al., 1989), physical size and strength (Brandfonbrener, 2000, 2003; Shamoto, 2013), muscular structure (Grieco et al., 1989) and physical condition (Brandfonbrener, 2000; Shamoto, 2013) are risk factors for pianists' PRMDs (Brandfonbrener, 2000; Grieco et al., 1989; Shamoto, 2013). Studies by Yoshimura et al. (2006), Yoshimura, Fjellman-Wiklund, Paul, Aerts, and Chesky (2008) and Yoshimura and Chesky (2009) showed a negative correlation between hand size and pain. In addition, de Smet et al.'s (1998) study concurred that pianists with smaller hands are prone to PRMDs.

According to Grieco et al. (1989), pianists with smaller build and lower muscle strength require more effort from the shoulder and trunk to sustain the movement of the fingers. In addition, pianists with a smaller hands size (Ling et al., 2016) require a larger abduction in between the fingers to perform certain piano techniques (de Smet et al., 1998; Lai et al., 2015). For example, small-handed pianists will have difficulty playing octaves or chords (Sakai, 1992), especially those techniques that involve a wide-hand position, requiring them to spread their fingers excessively (Lai et al., 2015). Stretching

the finger span of a small hand can potentially cause severe or even permanent damage to the joints and soft tissues (Brandfonbrener, 2003). Belmarsh and Jardin (1996) concurred that playing with a wide-hand position is more difficult for a pianist with an anthropometrically smaller hand. Therefore, a larger abduction angle between the thumb and the little finger puts more stress on the hand of a small-handed pianist compared to a large-handed pianist (Ling et al., 2018; Oikawa et al., 2011; Sakai, 2002; Sakai et al., 2006).

Relatively speaking, female pianists have smaller hands than men (Yoshimura & Chesky, 2009). As small-handed pianists are highly susceptible to injury (Ling et al., 2018; Yoshimura et al., 2006), thus, female pianists are likely to have a higher prevalence of PRMDs (Pak & Chesky, 2001). In response, manufacturers like Yamaha and Steinbuhler have created narrower keyboards, though Yamaha discontinued these models in 2003 after 14 years due to low demand (Yoshimura & Chesky, 2009). Despite the fact that female musicians spend less time practising than their male counterparts, female musicians are still subject to PRMDs (Zetterberg, Backlund, Karlsson, Werner, & Olsson, 1998). Sakai (1992) claimed that the results of piano techniques that lead to hand and forearm pain might be due to the small hand span of the subjects (i.e. Japanese pianists), which was concurred by Shields and Dockrell (2000). On the contrary, Furuya et al.'s (2006) study stated that hand size was neither a major nor a direct causal factor of PRMDs in Japanese female pianists. Therefore, further studies should be conducted to justify the findings.

2.3.4 Awkward Postures

'Posture' is a term used to define the position of different parts of the body (Jaffar, Abdul-Tharim, Mohd-Kamar, & Lop, 2011) at rest or during activity (Shamoto, 2013; Twomey & Taylor, 1994). Musicians often suffered from postural related problems (Winspur & Parry, 1997). Postural stress in musicians originated from prolonged sitting (Foxman & Burgel, 2006) and awkward postures when playing an instrument

(Dawson, 2006; Foxman & Burgel, 2006). According to Ranelli et al. (2008), musicians adopted awkward postures due to the influence of the physical characteristics of musical instruments. In addition, Winspur and Parry (1997) added that the most common problems related to playing technique for string and keyboard instruments are also related to postures.

Awkward posture generally leads to musculoskeletal disorders (Ansari & Sheikh, 2014). Excessive bending or twisting of any joint in the body out of a comfortable range of motion is the cause of awkward posture (Jaffar et al., 2011). Faulty alignment (Kendall et al., 2005), poor alignment (Shamoto, 2013) or awkward posture (Jaffar et al., 2011) will inflict excessive stress and strain on bones, joints, ligaments and muscles (Kendall et al., 2005), causing them to work harder (Jaffar et al., 2011). Therefore, awkward posture is one of the risk factors for PRMDs in musicians (Foxman & Burgel, 2006; Ranelli et al., 2008) and pianists (Mark, 1999; Parry, 2003; Shamoto, 2013; Wood, 2014).

2.4 Posture and Ergonomics

A person's working posture is restricted and dependent on the relationship between the dimensions of the person's body and the dimensions of his or her workspace (Pheasant, 2003a, 2003b). Pheasant and Haslegrave (2006) categorised the relationship between a person's body and workspace into physical connections (i.e. seat, worktop and floor) and visual connections (i.e. location of the display and gaze direction). Ergonomically, 'posture' is defined as the relative orientation of the body parts in space (Pheasant, 2003b). According to Bridger (2003), ergonomics is about the interaction between human and machine, including the factors that affect that interaction.

2.4.1 Mismatch between Human and Workspace

The work surface height can cause pain in the back, neck and shoulder region, as testified by the people who have experienced such pain at work (Sanders & McCormick, 1993). A working surface that is too high for a short person is just as unpleasant as one that is too low for a tall person (Pheasant, 2003a). An inappropriate dimensional match between a person's body and his or her workspace may lead to short- and long-term severe consequences (Pheasant, 2003b).

2.4.2 Mismatch between Musicians and Instrument

In the early stages of musical instrument development, ergonomic design was not considered a priority, as instruments were primarily designed for sound production (Bayraktarkatal, n.d.; Ozdemir et al., 2019). However, the absence of ergonomic principles in design can lead to musculoskeletal discomfort for musicians (Bayraktarkatal, n.d.; Ozdemir et al., 2019).

General individual anatomical differences and improper positioning are some of the variables for musicians' PRMDs (Hagglund & Jacobs, 1996). The physical mismatch between the musician and the instrument comes under the heading of awkward posture (Dawson, 2006). The physical characteristics of musicians (e.g. short or long stature, arm length and hand size) can create a disproportionate challenge between the musician and the instrument, increasing the risk of injury (Brandfonbrener, 2006).

The mismatch between player and instrument can lead to various problems, as a musician's anatomy is not always suitable for a particular musical instrument (Parry & Winspur, 1998; Sakai, 2007). In general, the mismatch between the human anthropometric measurements and the machine dimensions is one of the causes of physical stress, such as pain and discomfort (Parvez et al., 2019) leading to musculoskeletal disorders and cumulative trauma (Adegoke et al., 2019; Bridger, 2003; Imrhan et al.,