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The prevalence of playing-related musculoskeletal disorders in relation to piano players' playing techniques and practising strategies

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ABSTRACT: This study focused on the motor skills and practice strategies employed by piano players in relation to playing-related musculoskeletal disorders (PRMDs). A questionnaire was designed by the researchers to investigate the prevalence of PRMDs among both professional and non-professional piano players. A pilot study was conducted to assess the test-retest reliability of the instrument, which was high (r = .92). Respondents (N = 505) completed the self-administered questionnaire, with 42.4% reporting PRMDs. A higher proportion of professional musicians (71.9%) reported PRMDs (p < .05) in comparison with 38.1% of respondents who were not professional musicians. Respondents who played with elevated shoulders and maintained a neutral wrist posture were also likely to report PRMDs. Professional pianists were more likely than non-professional players to report PRMDs, while among those who experienced PRMDs, respondents who defined themselves as teachers reported more severe symptoms than did players. Respondents who had played the piano for longest, who practised for the most hours and most regularly were most likely to report PRMDs. There was no significant effect of players' hand span on the occurrence of PRMDs. PRMDs seemed to arise when overuse was compounded by misuse and/or adverse playing conditions, and so we concluded that PRMDs do not have one or more simple causes, but are the product of many interacting factors.

KEYWORDS: Injury, wrist, shoulder, hand span, keyboard, overuse.

Pianists' musculoskeletal complaints commonly include tendonitis, overuse syndrome, carpal tunnel syndrome at the wrist and radial nerve compression at the elbow (Harding, Brandt, & Hillberry, 1989). Both professional pianists and non-professional piano players are at risk of playing-related musculoskeletal disorders (PRMDs), which include mainly soft tissue (muscle, ligament and tendon) conditions related to mechanical strain, but may also involve bone, cartilage and nerves, with such symptoms being experienced as pain and loss of function that relate specifically to piano playing. Factors that may contribute to the incidence of PRMDs appear to include biomechanical inefficiency of wrist, finger, elbow and shoulder postures and movements, extremely long hours of practice, and insufficient regard for the characteristics of and structural differences between individual pianos.

Lippmann (1991) argues that 'overuse' is a simplistic label that ignores various other possible correctable causes of malfunction in the playing of a musical instrument. A diagnosis of overuse may imply the need for therapeutic rest, which may cause unwarranted disuse that remains second best to appropriate use in otherwise healthy players who have developed malfunction from misuse (Winspur, 2003).

Motor skills are fundamental to playing the piano. The motor demands of arm, hand and finger movements are enormous in piano performance. Despite this, the piano syllabus of the Australian Music Examinations Board Ltd. (2008) does not emphasize the motor skills (e.g., economy of movement) involved in the performance although it does specify that speed of playing, evenness of sound, and quality of touch should be demonstrated during the examination. Yet an individual's performance cannot be evaluated on the basis of the motor skills that were used at a particular moment to achieve a goal, but only on the musical results of the action. This may reflect the fact that we are not sure what kind of motor skill or movement technique is the most energy-efficient, and if these techniques change when players produce different amounts of force or when playing different pianos. Furthermore, little evidence exists to suggest healthy practice strategies that allow optimum training without giving rise to PRMDs. The term 'playing techniques' is used in this paper to refer to the pianist's postures and movements of the wrists, fingers, elbows and shoulders rather than chords, scales and various pianistic skills performed by the pianist, which are called 'piano techniques'.

Different kinds of postures and movements are required for three commonly-used techniques: (1) the traditional playing technique (Altenmüller, Wiesendanger, & Kesselring, 2006; Brée, 1997 – see Figure 1a), (2) the weight playing technique (Breithaupt, 1909; Hmelnitsky & Nettheim, 1987) (see Figure 1b), and (3) the Levinskaya system (Gerig, 1974; Levinskaya, 1930: a combination of both Figures 1a and 1b). The traditional playing technique (involving wrist postures ranging from neutral to flexed) was developed during the clavichord and harpsichord period. It was also used on early models of piano and has been applied continuously through to the present day; pianists still use it to play the acoustic piano and other keyboard instruments. The weight playing technique (involving wrist postures ranging from neutral to extended) was developed when greater speed and force were needed to produce a powerful sound on the nineteenth-century piano, with its more sophisticated mechanical structure, and in response to the development of new piano techniques and repertoires. The Levinskaya system was intended to incorporate the best features of traditional and weight playing techniques (involving flexed and extended wrist postures), so as to meet the demands of further developments in the piano literature accom-

modated by the twentieth-century acoustic piano. Given that pianists are likely to play a variety of keyboard instruments, with different kinds of mechanism and individual characteristics, they need to be able to adapt their motor skills and movement techniques accordingly.

Figure 1a. Neutral and flexed wrist postures.

Figure 1b. Extended wrist posture.

There is a dearth of scientific information concerning the frequency of PRMDs associated with the use of the traditional and weight playing techniques, and the Levinskaya system. Consequently, educators cannot offer evidence-based recommendations regarding piano playing techniques for the prevention of PRMDs at the present time.

Statement of the problem

Bartolomeo Cristofori invented the first generation of pianos in the eighteenth-century (Crombie, 1995). These were used in drawing rooms for audiences of a few aristocrats. Over the course of a hundred years, between 1750 and 1850, piano manufacturers sought more power, more volume, a greater dynamic range, and a wider compass of pitches (Altenmüller et al., 2006). The contemporary concert grand piano can project sound to an audience of three to four thousand people in a concert hall. The touch-weight of each key varies from approximately 34g for an eighteenth-century piano (Sadie & Tyrrell, 2001) to 52g for twentieth-century acoustic pianos (Crombie, 1995). Much of the music that was composed in earlier times for a variety of keyboard instruments is now performed on modern

acoustic pianos. There is no published advice to pianists on how to use different or more economical movements in order to adapt their playing, so that music composed for an instrument with one kind of action can be performed on an instrument with a different kind of action, and/or a heavier touch-weight.

Despite the long history of piano playing, some pianists – even professionals – may be ignorant of the fact that playing can cause serious physical injuries. Research has shown that many pianists inadvertently subject themselves to cumulative trauma through potentially harmful playing techniques. These include long hours of unbroken practice, inappropriate wrist postures and repetitive movements causing musculoskeletal disorders, exacerbated by performance anxiety (Blackie, Stone, & Tiernan, 1999). Some musicians develop physical handicaps that impact on all aspects of their lives (Scourfield, 1999). In some cases PRMDs are so severe that they threaten or even end some players' careers prematurely.

There are now specialized clinics for the occupational health problems of performing artists in many cities, including London, Hanover, New York, Boston, and San Francisco. As well as increased access to medical intervention for musicians, a dialogue between physicians who are experts in musicians' medicine and teachers of performance has opened up. One issue for pianists is that piano teaching is saturated in tradition: teachers teach the way they and their teachers were taught (Lister-Sink, 1994), typically on a one-to-one basis (Kennell, 2002). An exception to this is the development of electronic keyboard classes since the twentieth-century (Shender, 1998) in which students are taught in large groups by a single teacher (Enoch, 1974). In such classes it may not be possible to ensure that all students use appropriate playing techniques, which may increase the risk of PRMDs. Brandfonbrener (1991) argues that although PRMDs are more strongly associated with some schools of playing than others, it is rare for PRMDs to have a single origin. In order to identify the root of the problem of PRMDs it is therefore necessary to find out how pianists were taught as beginners.

Lippmann (1991) suggests that PRMDs in professional and non-professional pianists and piano teachers are related to misuse of the body, in relation to practice habits including motor skills and movement techniques. Because PRMDs are complex and have multi-factorial etiologies, they cannot be resolved by musicians or physicians alone (Spaulding, 1988). It is essential to develop multidisciplinary approaches in order to provide pianists with programmes that will help them avoid PRMDs. Such programmes involve encouragement to develop healthy practice habits, the promotion of energy-efficient biomechanical motor skills and the early use of effective treatment when necessary. In this way the incidence of PRMDs in pianists may ultimately be reduced.

Purpose of the study

The purpose of this study was to gather and analyze information about professional pianists and non-professional players' practice strategies and playing techniques, and their association with incidence of PRMDs. The theoretical framework illustrated in Figure 2 indicates that there are three major sources of risk for PRMDs: misuse (Lippman, 1991), overuse (Winspur, 2003; Worksafe Australia, 1994), and playing conditions (Winspur & Parry, 1998). The study employed a questionnaire comprising items designed to elicit information regarding misuse and overuse. It also investigated respondents' awareness of PRMDs and the

strategies they report using to prevent and treat such problems. We anticipate that the study may also promote awareness of PRMDs, and hope that the findings will encourage educators to incorporate programmes designed to prevent PRMDs into curricula for piano pedagogy.

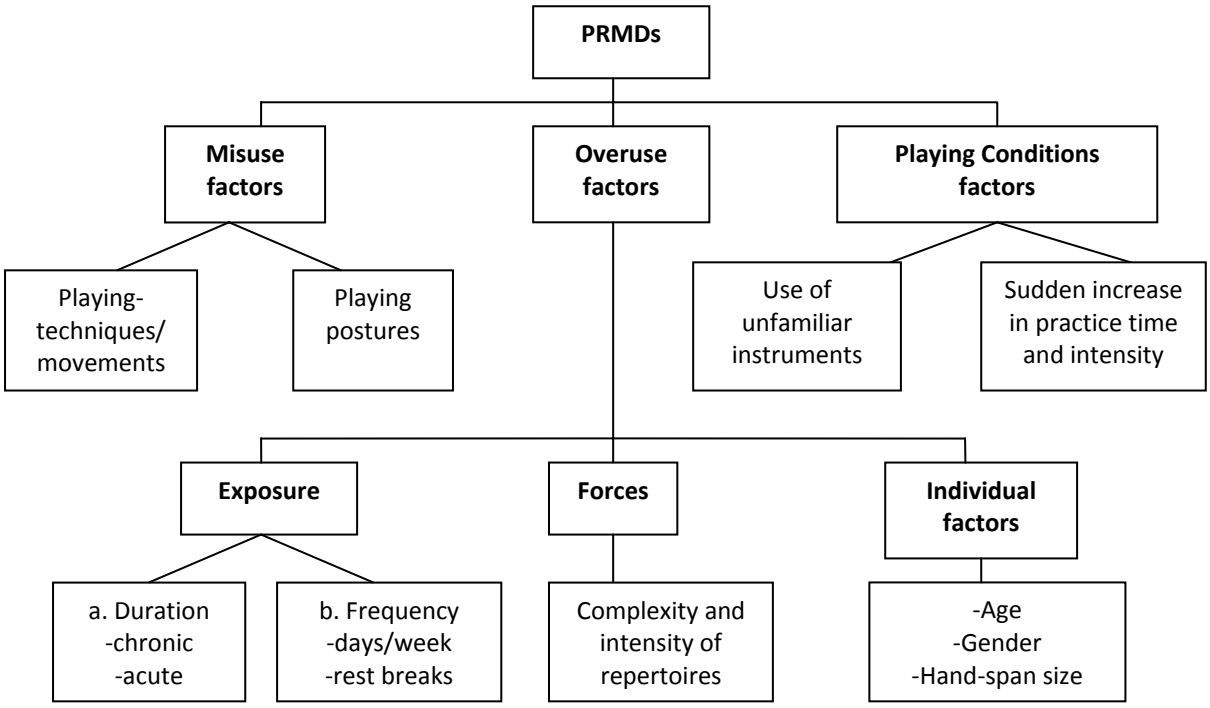

Figure 2. The theoretical framework. Factors potentially associated with PRMDs are classified as misuse, overuse, or related to playing conditions. The questionnaire explored respondents' exposure to misuse and overuse factors as possible risks for developing a playing-related injury.

Definitions of terms

The following terms, although commonly used in the biomechanics literature, may not be familiar to the present audience. Closed- and open-kinetic chains describe the relationship and interactions between parts of the human body and the environment, such as those that occur when someone is playing the piano. When both ends of an extremity are supported, movement at one joint within the chain produces predictable movement at all other joints (Prentice, 2001). This is called a closed-kinetic chain and it occurs, for example, when the weight of the arm is shared between the shoulder and the keyboard when the keys are depressed by the fingers, as in the weight playing technique described above. When only one end of an extremity is supported, the distal segment of extremity is mobile and movement occurring in other segments within the chain is not necessarily predictable (Prentice, 2001). This is known as an open-kinetic chain and occurs when the arm is suspended over the keyboard and the weight of the upper limb is supported by the shoulder alone. This is the situation when the neutral wrist posture is used in the traditional playing technique described above, and in the neutral technique described in the first paragraph of the Results section.

METHOD

Pilot study

A pilot study was undertaken to gather feedback on the items comprising the questionnaire (see Appendix), as well as to establish test-retest reliability. The questionnaire was completed on three occasions, each separated by two weeks, involving professional and non-professional players (n = 14) aged between 10 and 87 years. The questionnaire proved to be reliable, with a high correlation (r = .92; p < .01). All 33 questions were retained for the main study. Only minor amendments were made to the questionnaire subsequently; these involved a change in the order of some items and altering some of the wording to minimize ambiguity.

Respondents

Five hundred and eighty copies of the questionnaire were distributed, of which 505 were returned for analysis. The survey was completed by players from 12 to 89 years of age who had played the piano for two years or more, and for whom piano was the major instrument or second instrument. The sample comprised 154 male and 351 female players. Respondents defined themselves as professional musicians (17 males and 47 females) or not professional musicians (137 males and 304 females). They also defined themselves as teachers (n = 50), performers (n = 21), or 'players' (n = 434). To ensure that data were non-identifiable during analysis, the last page of the questionnaire, which contained personal details, was detached before data entry.

The majority of respondents (n = 500) were living in the Perth metropolitan area and country regions of Western Australia, while a small number (n = 5) lived in other states in Australia. Respondents were recruited from government and non-government high schools, as well as university staff and students. Respondents were also sought from the community, with questionnaires returned by members of the West Australian Music Teachers' Association and candidates at examinations conducted by the Australian Music Examinations Board of Western Australia. Approval for the study was granted by the Human Ethics Committee of the University of Western Australia and parental or guardian consent was obtained for those respondents who were under 16 years of age.

Instrument

The self-administered questionnaire, *An Investigation of Professional and Non-Professional Piano Players' Playing Postures and Techniques,* was designed by the researchers (see Appendix). It comprised a total of 33 questions and took 5-12 minutes to complete. Questions 1-10 addressed the respondent's history of playing, practice habits and occupation. Questions 11, 12 and 14 used photographs to identify various playing techniques. Question 13 requested respondents to record the maximum stretch of their hand span as measured from the tip of digit five to the tip of the thumb (see Appendix). A measurement of ≤20 cm was categorized as a *small*, and ≥20.1 cm as a *large* hand span. Other authors have categorized hand size (i.e. not necessarily hand span) differently and somewhat arbitrarily; for example, Wristen, Jung, Wismer, and Hallbeck (2006) classified large hand span as being >22

cm; however, the view of the present authors was that a 20 cm hand span allows the player to carry out the task of playing octaves and chords comfortably. This method equates the morphology of hand span with a measurement that is directly related to the playing action. Questions 15-26 covered the respondent's history of PRMDs, and Questions 27-33 related to personal information.

Data analysis

Pearson Chi-square tests were used to assess the significance of association between PRMDs and, separately, the use of particular playing techniques, occupation (performer, teacher, player), status (professional, non-professional) level of playing, age, gender, as well as practice strategies. Significance was accepted at $p < .05$. Univariate ANOVAs, with post-hoc Tukey's HSD tests where required, were also used to identify differences in the severity of PRMD symptoms experienced by respondents who reported suffering from PRMDs. Finally, a series of two-factor ANOVAs was used to identify the effects of level of playing, age, sex and occupation on the number of respondents reporting PRMDs who used different practice strategies. For these multiple ANOVA comparisons, a full Bonferroni correction was not used as this method is known to be too conservative. Instead, a significance level of $p < .01$ was used (following the suggestion of Smith, Lloyd, & Wood, 2004) allowing for multiple comparisons with a large sample size to be made without increasing the risk of Type II errors.

RESULTS

Of the 505 respondents, 42.4% (n = 214) reported experiencing PRMDs. In the following paragraphs the number of responses available for analysis varies slightly from 505, due to minor errors or omissions made by the respondents, and are indicated in each section. In addition to the three playing techniques described in the Introduction (traditional, weight-playing and Levinskaya system) a fourth technique was reported by a large proportion of respondents: neutral (i.e. use of a neutral wrist posture).

Playing techniques

Wrist postures: There was a significant relationship between playing techniques and reported PRMDs (χ^2 [3, 503] = 16.57, $p < .01$). A total of 349 respondents reported using neutral wrist postures, of whom 47.0% experienced PRMDs. One hundred and eight used traditional, neutral to flexed wrist postures, of whom 30.6% experienced PRMDs. Forty-one reported using the weight-playing technique involving neutral to extended wrist postures, of whom 26.8% experienced PRMDs. Only five players reported using the Levinskaya system, of whom four reported PRMDs.

Shoulder postures: A significantly higher proportion (52.5%) of the 99 respondents who reported using an elevated shoulder posture also reported PRMDs, compared with the 40.1% of the 394 players who reported using a non-elevated shoulder posture and experienced PRMDs (χ^2 [1, 493] = 5.42, $p < .05$).

Elbow postures: The majority of respondents (a total of 397) reported using a bent rather than straight elbow posture. There was no significant association between elbow posture and experience of PRMDs (χ^2 [1, 500] = 3.47, $p > .05$).

Finger postures: Similarly, the majority of respondents (a total of 437) reported using curved rather than flat finger postures. There was no significant association between finger postures and experience of PRMDs (χ^2 [1, 491] = 2.34, $p > .05$).

Occupation and status

Questionnaire respondents reported their occupations as follows: performers (*n* = 21), teachers (*n* = 50) and players (*n* = 434). There was a significant association between group and PRMDs (χ^2 [2, 505] = 21.55, $p < .05$) such that 68.0% of the teachers, 66.7% of the performers, but only 38.2% of the non-professional players reported experiencing PRMDs.

The degree of discomfort was rated on a scale from 0 (none) to 4 (very severe). Among those respondents who reported PRMDs (*n* = 214), a one-way ANOVA revealed a significant difference in the degree of discomfort (*F* [2, 211] = 4.64, $p < .01$) experienced by the three groups. Post-hoc Tukey's HSD showed that teachers (*M* = 2.60) experienced significantly more discomfort than players (*M* = 2.10; $p < .01$), but there were no significant differences between performers (*M* = 2.55) and teachers or performers and players.

Respondents reported themselves to be professional musicians (*n* = 64) or not professional musicians (*n* = 441). Forty-six professional musicians (71.9%) reported that they sustained PRMDs, whereas only 168 non-professional respondents (38.1%) experienced PRMDs. Not only was there a significantly higher incidence of PRMDs in the professional group (χ^2 [1, 505] = 26.12, $p < .05$), but they also experienced a significantly greater degree of discomfort (*M* = 2.52) than the non-professional group (*M* = 2.08) (independent samples *t* [214] = 2.80, $p < .01$ [two-tailed]).

Practice strategies

Number and length of breaks during practice: There was a significant relationship between the number of practice breaks taken by respondents and presence of PRMDs (χ^2 [3, 505] = 21.94, $p < .05$), with a higher incidence of PRMDs among those who took two or more breaks during a practice session. Among pianists with PRMDs (*n* = 214), approximately half (50.5%) generally took breaks of between 3 and 60+ minutes during practice, while the remainder took no break from practice at all during their daily practice session. A two-way ANOVA revealed a significant main effect of professional status, but not of experiencing PRMDs, on the length of breaks (*F* [1, 501] = 29.95, $p < .01$), and a significant interaction between professional status and experience of PRMDs (*F* [4, 501] = 7.18, $p < .01$).Overall, the professional group took longer breaks than non-professionals (see Figure 3); however, professional players without PRMDs took longer breaks (*M* = 19.7 mins) than those who reported PRMDs (*M* = 11.8 mins). In contrast, the non-professional players without PRMDs took shorter breaks (*M* = 4.11 mins) than those with PRMDs (*M* = 6.48 mins).

Practice hours: For all respondents, a greater number of practice hours over seven days was associated with a higher incidence of PRMDs (χ^2 [3, 504] = 18.28, $p < .05$). The percentage of respondents reporting PRMDs who practised from one to five hours was 37.0%, from six to ten hours 49.5%, from 11 to 20 hours 65.8%, and from 21 to 40 hours 66.7%. As

shown in Figure 4, a three-way ANOVA revealed significant main effects of professional status on number of practice hours over seven days (F [1, 497] = 18.89, $p < .01$) and whether or not the player majored in piano (F [1, 497] = 32.90, $p < .01$).

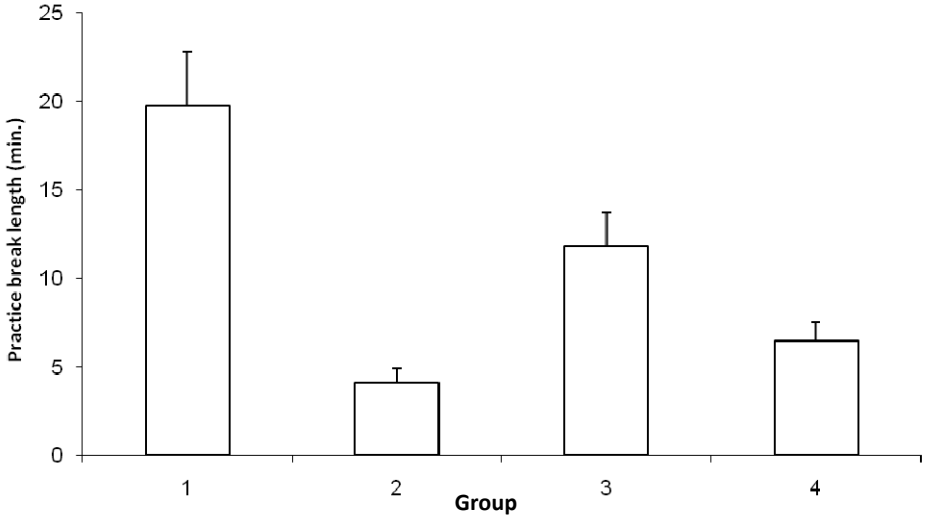

Figure 3. Mean and SE of practice break length for professional players without PRMDs [1] (n = 18) and with PRMDs [3] (n = 46), and non-professional players without PRMDs [2] (n = 273) and with PRMDs [4] (n = 168).

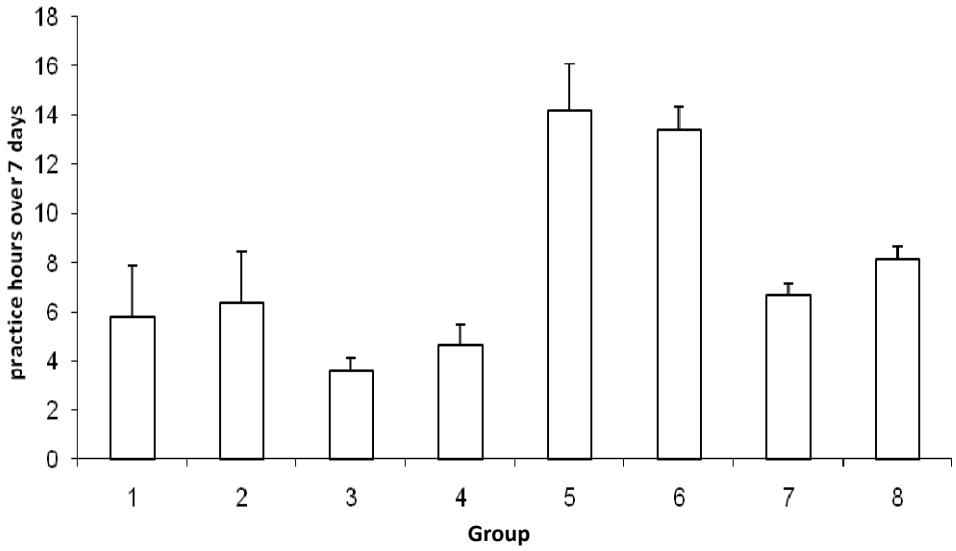

Figure 4. Practice hours over seven days (Mean and SE) for professional and non-professional players, with and without PRMDs, and with respect to whether piano was their non-major (n = 184) or major instrument (n = 320): Groups 1 and 2 = professional players, with piano as the non-major instrument, without and with PRMDs respectively; Groups 3 and 4 = non-professional players, with piano as the non-major instrument, without and with PRMDs respectively; Groups 5 and 6 = professional players, with piano as the major instrument, without and with PRMDs respectively; Groups 7 and 8 = non-professional players, with piano as the major instrument, without and with PRMDs respectively.

Professional musicians with piano as their major instrument practised for more hours over seven days (*M* = 13.7 hours) compared with non-professionals (*M* = 7.5 hours). Similarly, professional musicians with piano as their second instrument practised more hours over seven days (*M* = 6.1 hours) compared with non-professionals (*M* = 4.0 hours). There was no main effect of experience of PRMDs on practice hours, nor were there any significant interactions between professional status, whether or not the player majored in piano, and experience of PRMDs.

Years of playing

Respondents were divided into four groups based on the number of years of playing: 164 had played for two to five years, 250 had played for six to 15 years, 65 had played for 16-40 years and 26 had played for 41-60+ years. There was a significant relationship between years of playing and reported PRMDs (χ^2 [3, 505] = 35.74, $p < .01$), such that 26.8% of respondents who had played least longest reported PRMDs, as did 44.4% of those who had played for six to 15 years, 63.1% of those who had played for 16-40 years and 69.2% of those who had played for 41-89 years. Exposure to this activity is a function of both the number of years of playing and number of practice hours per week. An analysis of survey responses revealed no significant difference in the number of practice hours over seven days (F [1, 497] = 2.07) between the respondents with and without PRMDs (Figure 5).

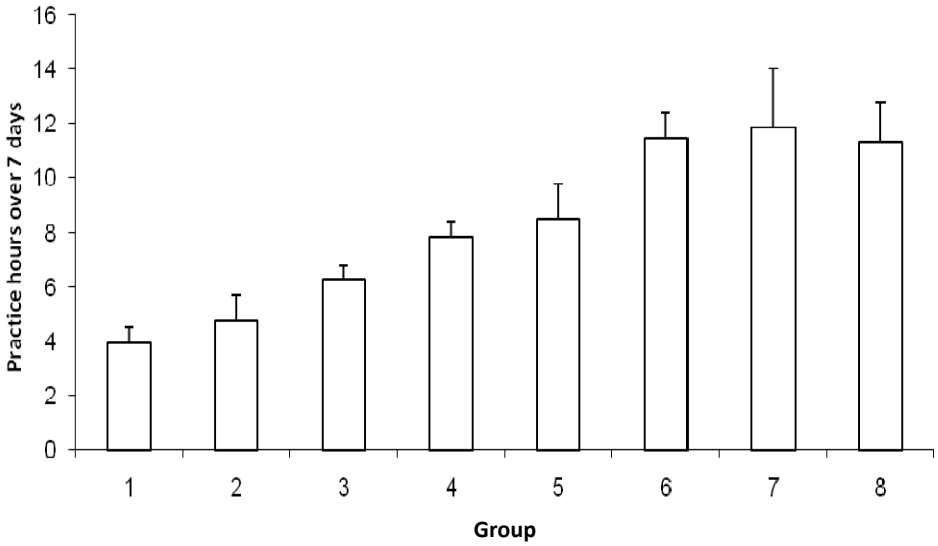

Figure 5. Practice hours over seven days (Mean and SE) for players with differing years of playing experience, both with and without PRMDs: Groups 1 and 2 = 2-5 years of playing experience (*n* = 164), without and with PRMDs respectively; Groups 3 and 4 = 6-15 years of playing experience (*n* = 250), without and with PRMDs respectively; Groups 5 and 6 = 16-40 years of playing experience (*n* = 65), without and with PRMDs respectively; Groups 7 and 8 = 41-60+ years of playing experience (*n* = 26), without and with PRMDs respectively.

Levels of playing, piano major and non-major

Respondents were asked to report the AMEB examination grades they had achieved, on the basis of which they were divided into three groups representing levels of playing. One hundred and seventy three had taken Grades 1-3, 163 had taken Grades 4-6 and 164 had taken Grades 7-8, associate, licentiate or tertiary diplomas. There was a significant association between level of playing and experience of PRMDs (χ^2 [2, 500] = 42.50, $p < .01$) such that 62.8% of the highest-level group reported PRMDs in comparison with 32.5% of the mid-level group and 31.8% of the lowest-level group. Respondents were also asked to say whether piano was their major or second instrument. The majority, 321, were piano majors, of whom a significantly higher percentage (48.9%) reported PRMDs, compared to those for whom piano was their second instrument (31.0%)(χ^2 [1, 505] = 15.40, $p < .01$).

Age and sex

Respondents were divided into three age groups. The majority, 372, were aged 12-20 years; 57 were 21-40 years old and 76 were 41-89 years old. There was a significant relationship between age and experience of PRMDs (χ^2 [2, 505] = 22.50, $p < .01$) such that 36.3% of the youngest group, 54.4 % of the middle group and 63.2% of the oldest group reported PRMDs. There was also a significant relationship between sex and experience of PRMDs (χ^2 [1, 505] = 5.75, $p < .05$) such that 45.9% of females but only 33.8% of males reported PRMDs.

Hand span

ANOVA yielded no main effect of hand span on experience of PRMDs (F [1, 504] = 2.6, $p > .05$).

Piano techniques

Concerning techniques, 96 respondents reported that PRMDs were associated with specific piano techniques and exercises; 59 respondents reported the occurrence of PRMDs when playing octaves, 27 when playing fast passages, 20 when playing chords, 20 when playing fortissimo, 13 when playing arpeggios, 11 when playing trills, 11 when playing scales, two when playing polyphonic music and one when playing pianissimo.

Locations and types of discomfort, and treatment options

Of the 214 respondents who reported PRMDs, 137 experienced discomfort in the wrist, hand or finger; 109 in the neck or shoulder, 80 in the back, 56 in the forearm or elbow and 12 in the upper arm. One hundred and forty reported pain, the most frequently reported symptom; 124 reported aching, 83 stiffness, 67 fatigue, 18 parasthaesia (i.e. pins and needles), 14 swelling, 13 spasms and nine numbness. Ninety-four respondents with PRMDs (43.9%) sought help, 57 from teachers, 22 from physiotherapists, 17 from medical doctors, 13 from chiropractors and nine from other practitioners. Of the remaining respondents with PRMDs, 111 did not seek any help, two were trying different playing postures and seven stopped playing altogether.

DISCUSSION

This study sought to gather and analyse questionnaire data from 505 professional pianists and non-professional players about their practice postures and strategies, and playing techniques, with respect to their experience with PRMDs. Respondents were of both sexes, with a wide range of ages and levels of experience. Factors associated with self-reported injuries were considered separately. Respondents who played with elevated shoulders and maintained a neutral wrist posture were likely to report PRMDs. Professional pianists were more likely than non-professional players to report PRMDs, while among those who experienced PRMDs respondents who defined themselves as teachers reported more severe symptoms than did players. Respondents who had played the piano for longest, who practised for the most hours and most regularly were most likely to report PRMDs. Non-professional players who took longer and more frequent breaks from practice were also more likely to report PRMDs. Perhaps this was in response to their reported musculoskeletal disorder. Conversely, professional players who took longer and more frequent breaks from practice were less likely to report PRMDs, so this may have been a successful strategy used to prevent these disorders from occurring. Hand span was not associated with experience of PRMDs.

Misuse factors

While four of the five respondents who reported using the Levinskaya system experienced PRMDs, and it would be worth investigating whether this is typical, there were too few such respondents in this study to draw any conclusions from this finding. Of respondents using the other playing techniques, a significantly greater percentage of players adopting the neutral (i.e., open-kinetic chain) wrist posture reported PRMDs than did those who used the wrist postures typical of weight playing (i.e., closed-kinetic chain) and traditional playing (i.e., both closed- and open-kinetic chain).

Pianists who use the extended wrist postures typical of closed kinetic-chain, weight playing may experience fewer PRMDs because they are working with, rather than against gravitational force. The use of flexion at the distal phalanges produces gripping forces to maximize control of tone quality while allowing the arm to relax. According to Savage (1988) this minimizes passive tension in the extensor tendons of the forearm. The result is that these are shortened, so active tension in the flexor tendons is also reduced, thus helping the pianist avoid the risk of early fatigue (Llobet & Odam, 2007) and in addition enable the fingers to produce greater force. Li (2002) found that wrist position had a significant effect on the force produced by individual fingers and overall, with the greatest force produced by the fingers when the wrist was extended (lowered) by 20˚ with an ulnar deviation of 5^{o}. In short, if the wrist is in a position such that the pianist does not have to work so hard, he or she may be less likely to experience PRMDs.

Players' wrists not only allow flexion-extension motion, but also abduction-adduction motion. As the pianist's hands move up and down the keyboard (from left to right and vice versa) he or she has constantly to adjust the angle of wrist to keys. According to the literature on ergonomics, it is much less risky to maintain the wrist in a neutral position, activating the muscles as little as possible, than to use flexed, extended, adducted or abducted positions (Chaffin & Andersson, 1984). However, this demands constant co-contraction of the

forearm musculature to stabilize the wrist joint, which may greatly reduce the speed of piano playing when movements are required in more than one direction. Moreover the pianist needs to activate the forearm muscles and tendons when accelerating and decelerating, which uses more energy and can therefore cause fatigue (Prentice, 2001). This may also increase the risk of PRMDs. Circular movements of the wrist and elbow require less energy (Wristen, 2000) and enable more efficient use of the hands and fingers when playing the piano.

According to Hagberg, Thiringer, and Brandström (2005), pain in the neck and shoulder are the musculoskeletal disorders most often associated with instrumental practice. In the present study, players who reported playing with elevated shoulders were more likely than those who played with non-elevated shoulders to experience PRMDs. This finding is congruent with the ergonomics literature on overuse injuries, showing that the greater the degree of arm abduction and shoulder elevation the more energy is expended (Chaffin & Andersson, 1984). Specifically, respondents reported pain in the neck. This can result from tension in the upper trapezius muscles, which reduces the functional capacity of the fingers, hands and forearms and – as in other manual handling tasks – can lead to premature fatigue (Chaffin & Andersson, 1984; Winspur & Parry, 1998; Worksafe Australia, 1994). Respondents reported that they were often unaware of practising or performing with elevated shoulders, especially when they were experiencing external pressures such as an excessive workload compounded with internal pressures such as stage fright. While Marley and Wehrman (1992) showed that extending the elbow can produce a stronger grip, no significant association was found in the present study between elbow posture and the reporting of PRMDs.

Overuse factors

Several factors that may underlie PRMDs relating to overuse were identified in the theoretical framework shown in Figure 2, including exposure to the risk of injury and the force needed when playing as well as individual characteristics. Significantly more performers and teachers suffered PRMDs than did respondents who identified themselves as players, and of all those who experienced PRMDs, the performers and teachers described them as being more severe than did the players. This supports the claim that imbalance between high work demands and lack of autonomy in the work environment may cause negative stress that can increase the risk of ill health (Lim & Altenmüller, 2003).

With professional and non-professional players pooled for analysis, 42.4% of the respondents reported PRMDs. This result was lower than the finding of Chong and Chesky (2001), where 59% of those surveyed experienced PRMDs. Chong and Chesky reported the responses of 455 keyboard players ranging in age from 14 to 69 years and including keyboard instrumentalists, and jazz and classical musicians. In the present study PRMDs were reported by 71.9% of the professional pianists surveyed who, compared with other respondents, played the piano for more years and practised more hours each week. It would be difficult, however, to persuade professional pianists to reduce their hours of practice so as to avoid PRMDs, since most pianists believe that longer hours of practice lead to higher standards of performance. Players who majored in piano and had achieved higher examination grades did more practice each week but were not more susceptible to PRMDs. Thus

exposure to risk – playing the piano – may contribute to PRMDs, as suggested in Figure 2, but other factors are also important.

This study demonstrated that a significantly higher proportion of players who practised more than 11 hours each week reported PRMDs in comparison with those who practised for fewer than ten hours each week. In research undertaken by Grieco (1989) 60% of participants reported that PRMDs developed within or after two hours' practice, when participants practised every day. Yet quantity of practice alone is unlikely to cause PRMDs (Figure 4). Participants defining themselves as professional musicians took longer breaks from practice than non-professionals, although professional musicians with PRMDs took shorter breaks than professionals without PRMDs. On the other hand non-professional musicians with PRMDs took longer breaks than non-professionals without them, suggesting that they were forced by their symptoms to do so and that many non-professional players may not recognize that breaks can prevent PRMDs (Figure 3).

A higher proportion of respondents with more than 16 years' experience of playing reported PRMDs than those with fewer than 15 years' experience of playing. More respondents who had taken examinations at Grade 7 and above reported PRMDs than those who had taken examinations at lower grades. However players who had taken examinations at the higher grades also needed to practise for more hours each week to meet the demands of the repertoire and consequent difficulty of the piano techniques required. Thus risk for PRMDs appears to be a function of exposure (number of hours of practice) combined with task demands (complexity and physical demands of playing). However, when practice hours over seven days were analyzed within years of playing groups and PRMDs (Figure 5), no significant difference was revealed between the groups with and without PRMDs ($p > .01$). Therefore, those without PRMDs may have better playing techniques and, despite the fact that they have been exposed to a similar level of activity, they may not 'misuse' their musculoskeletal system by adopting poor postures and/or inefficient playing techniques.

In contrast to the findings of Chong and Chesky (2001), who showed a trend for younger players to be more likely to report PRMDs than older players, the present study showed that the likelihood of reporting PRMDs rose with age. On the other hand the present study confirms existing findings for sex (Chong & Chesky, 2001; Lim & Altenmüller, 2003; Fjellman-Wiklund, Brulin, & Sundelin, 2003): more females than males reported PRMDs. Females did not, however, undertake more practice each week. While Tubian (2005) found that players with hand spans >22 cm were more likely to report PRMDs the present study confirmed Ong (1992) in finding no significant association between hand span and experience of PRMDs.

Association between PRMDs and certain piano techniques

Respondents who reported PRMDs were most likely to attribute them to the playing of octaves, supporting Sakai's (1992) finding that players experienced pain in the wrists, fingers and hands when playing double octaves. Near maximal abduction of two or more fingers, together with the flexion of all phalangeal joints to produce force could cause high tension in the mechanical systems of hands and wrists. Thus PRMDs may be caused by using an inefficient technique to exert force when playing repeated octaves and octave-chords, as well as failing to take sufficient breaks during practice.

Common symptoms and seeking help when PRMDs occurred

Respondents who reported PRMDs typically experienced pain and aching in the wrist, hands and fingers (cf Sakai, 2007). Fewer than half (94 out of a total 214) sought help – the majority from their teachers, although teachers were the most likely, of the three groups surveyed, to experience PRMDs themselves. It may well be the case that Brandfonbrener's (1991) concerns are justified: players lack confidence in medical practitioners and are therefore reluctant, when injured, to seek medical help in the early stages of PRMDs, which can cause difficulties in evaluating and eradicating the problem.

Experienced piano teachers may know that certain playing postures should be used to prevent possible strain arising from the use of particular piano techniques. They may not be sufficiently familiar with anatomy to understand how they work mechanically, or why they are more efficient in terms of saving energy (Llobet & Odam, 2007). Piano teachers may recommend methods for preventing and managing PRMDs based on their own experience, rather than research-based evidence. After all, music education curricula (in Australia, at least) do not require piano teachers to understand or even recognise PRMDs. For these reasons, most teachers have only a limited ability to advise injured players effectively. Medical practitioners and physiotherapists may be able to treat symptoms but, unless they know how players can employ motor skills to perform specific piano techniques with maximum economy, they are ill-equipped to offer practical advice for preventing further injuries.

Limitations of the study

Some limitations must be acknowledged. As usual in survey research, the data reflect respondents' subjective perceptions rather than objective observations of their practice. In the present study these included definitions and descriptions of playing postures. Also, it was not possible to investigate a further potential factor underlying PRMDs: the differences between various models of piano used in daily practice.

CONCLUSION

This study surveyed a large sample of piano players with a wide age-range and varying levels of expertise and experience, in order to test a theoretical model proposing that PRMDs are caused by factors relating to misuse, overuse and individual characteristics. Analysis of numbers of respondents with and without PRMDs reporting use of each of the factors independently (and in some cases together) suggests that PRMDs are associated with particular playing techniques and postures (misuse), frequency and duration of practice, which may be related to level of playing (overuse) as well as age, sex and occupation although not hand span (individual characteristics). We can thus conclude that PRMDs do not have one or more simple causes but are the product of many interacting factors.

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