
PIANIST HAND SPANS: GENDER AND ETHNIC DIFFERENCES AND IMPLICATIONS FOR PIANO PLAYING

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Hand span data was collected from 473 adult pianists and analysed using descriptive and inferential statistical methods, focusing on differences according to gender, ethnicity and level of acclaim. For comparative purposes, similar data was collected from 216 non-pianist university students and 49 children and teenagers. Gender differences are consistent with those found in earlier studies and ethnic differences are also significant but smaller in magnitude. Highly acclaimed solo performers tend to have bigger hand spans than others. 'Small hands' are defined in terms of hand span metrics, allowing estimates of the proportions of pianists with 'small hands'. The conclusion is that the current 'standard' piano keyboard is too large ergonomically for a majority of pianists.

1.0 INTRODUCTION

Pianists are often heard to comment on the size of their hands or those of other pianists. They may say that they have 'small hands' or 'large hands'. 'Small hands' are generally seen to be a disadvantage when playing the piano while 'large hands' are seen to be an advantage. But what do we actually mean by 'small hands' or 'large hands'? What hand size dimensions are relevant to playing the piano comfortably and how can these be linked to the pain and injury that affects a significant proportion of pianists? What proportion of pianists, and indeed members of the population at large, have 'small hands'?

Unlike many other musical instruments, most notably stringed instruments, pianos effectively come with the same sized keyboard. The key question this paper addresses is whether the current one-sized 'standard' or 'conventional' keyboard is ergonomically suited to the varying hand sizes of the general piano playing population.

Until the late nineteenth century, piano keyboards were available in different sizes and generally had smaller key widths than today. The current piano keyboard was standardised in the 1880s, based on what suited male virtuosos of the time, such as Liszt (Parakilas et.al., 1999; summarised by Booker & Boyle, 2011). The belief that the 1880s 'standard' keyboard size is somehow 'sacred', that it suits all pianists and that it cannot be varied for either musical or technological reasons, has rarely been questioned since that time.

However, today, the 'one size fits all' approach is increasingly being challenged, mainly due to growing evidence from performing arts health research coupled with the recent availability of ESPKs (ergonomically-scaled piano keyboards) with narrower keys. Such keyboards effectively give 'larger' hands to pianists who otherwise experience enormous frustration and risk pain and injury from attempting advanced repertoire with 'small

hands' on the standard keyboard. Pianists who experience such keyboards finally understand the barriers caused by having hands too small for the conventional piano keyboard. The need for ESPKs to become widely available is supported by evidence from health professionals who are concerned about the high level of pain and injury among pianists and from the direct experience of teachers and their students who have noted a wide range of benefits when using ESPKs.

Within the general population it is clear that there is significant variation in hand size. In this paper we provide statistical data to quantify this variation among pianists and non-pianists. A definition of 'small hands' is proposed, drawing on research from various fields and other evidence. We conclude that only a minority of adult pianists have 'large hands', providing them with a significant advantage on the current keyboard in terms of ease of playing, speed of learning, pianistic accomplishment, range of accessible repertoire and reduced risk of pain and injury. Further, we conclude that the large majority of people (considering children as well as adults) who have 'small hands' are disadvantaged on the current keyboard and that they would benefit significantly from having access to pianos with narrower keys (ESPKs).

2.0 STUDIES OF HAND SIZE

2.1 Previous studies of hand size

Hand size, as with other body characteristics such as weight and height, varies greatly among the human population. The science of anthropometry, which deals with the measurement of the human individual, has traditionally been used in anthropology to correlate physical features with racial and psychological traits. Today, anthropometry plays an important role in industrial and clothing design, ergonomics and architecture. Much of the published anthropometrical data has been collected from specific populations, such as defence force personnel or industrial workers, and used to analyse physical requirements for specific tasks undertaken by those groups.

Measurements of the human body are normally categorised on the basis of gender and ethnicity. Published data (for example, Pheasant 1988; Garrett, 1971) confirm what is obvious for most physical characteristics – that there are variations between ethnic groups and that males are generally bigger than females. General observation is sufficient for one to realise that males have larger hands than females. From measurements of many different features of the human hand in the US Army (Garrett, 1971), depending on the characteristic measured, differences between males and females generally range between 10% and 20%.

The authors have only found two previous statistical studies that relate specifically to pianists' hand spans and which looked at gender differences.

The most comprehensive set of data on hand size and other characteristics of pianists dates back to the 1980s (Wagner, 1988). He measured 20 characteristics in hand size and joint mobility for professional pianists, teachers and tertiary level students, and found significantly higher mean values in males than females for virtually all hand size variables. His measurements included active finger spans (i.e. maximum stretch when the hand is spread out unaided on a flat surface) between the fingers, including the thumb. Active finger spans can be directly related to a pianist's capacity to play various intervals and chords.

Steinbuhler (2004) measured pianists' active thumb to fifth finger span at a music teachers' convention in the US. The data have been displayed visually since that time¹ but were not analysed quantitatively until research by two of the authors in 2009 (Boyle & Boyle).

A third data set, held by the University of North Texas (UNT), has been discussed by Yoshimura and Chesky (2009) but gender differences were not reported. They commented on the extensive range of hand spans among nearly 400 UNT music students, with the difference between the smallest and the largest being 4 inches (10 cm) – more than the width of four piano keys!

Several writers have noted that pianists of Asian ethnicity have smaller hands than those of Caucasian origin (e.g. Sakai, 1992, 2008) but no data relating to ethnic differences among pianists were found by the authors.

2.2 *Previous research by the authors*

The authors have previously undertaken research and reviewed published data and literature relating to hand spans and piano playing, including:-

- Analysis of Steinbuhler's (2004) data (Boyle & Boyle, 2009).
- Investigation of the relationship between active hand spans (based on Steinbuhler and Wagner) and the capacity to reach certain intervals on the conventional piano keyboard (Boyle & Boyle, 2009).
- Review of literature on the relationship between pain and injury and hand size, and perceptions of pianists using ESPKs (Boyle & Boyle, 2009; Booker & Boyle, 2011).
- Survey of the experiences of adult pianists who play ESPKs (Boyle, 2012).

¹ www.steinbuhler.com/html/our_research.html
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- Summary of results of major international piano competitions; history of the piano keyboard; analysis of the 'barriers' to change (Booker & Boyle, 2011).
- Exploration of the biomechanical and physiological factors relevant to hand size/keyboard size (Boyle, 2013).

2.3 *The authors' study of hand size - aims and methodology*

In 2011 the authors began collecting hand span measurements from pianists. The principal intention was to gather sufficient data to make objective statements about hand spans for pianists overall and about differences based on gender and ethnicity. The data would enable direct comparison of results with those reported by Steinbuhler and Wagner. An assessment was also made of the 'status' of each pianist, based on their demonstrated success as a performer, to see if there was a possible relationship between pianists' level of accomplishment and hand span. Smaller databases were also developed for children and teenagers, and for non-pianist university students, mainly for comparative purposes.

The authors focused primarily on active hand span measurements, in particular:

- The 1-5 spans for left and right hands, defined as the distance from the outside tip of the thumb to the outside tip of the little finger when the hand is at maximum stretch on a flat surface.
- The 2-5 spans for left and right hands, defined as the distance from the outside tip of the index finger to the outside tip of the little finger when the hand is at maximum stretch on a flat surface.

It is essential to note that these two-dimensional metrics do not equate directly to comfortable piano playing – obviously, it is not possible to play with a hand stretched flat along the keyboard. However, the metrics were chosen in order to achieve consistency in measurement from one person to the next, and to allow comparison of results with those from previous studies.

The following table provides a summary of equivalent hand span stretches on a flat surface in terms of white keys covered on a standard keyboard, measured from the outside edges of the white keys.

	Number of white keys							
	5	6	7	8	9	10	11	12
Inches	4.6	5.5	6.5	7.4	8.3	9.3	10.2	11.1
Centimetres	11.7	14	16.5	18.8	21.2	23.5	25.9	28.3

The table can be used to put the authors' hand span data into context, reflecting the wide range of hand spans encountered among pianists. But as noted the measures do

not equate to comfortable playing (i.e. without any tension). For example, the table shows that a span of 7.4 inches corresponds to the width of eight keys but a pianist with that span will not be able to play the octave interval with any comfort. In Section 7.2 we include a discussion of the minimum 1-5 and 2-5 spans required for comfortable playing.

The data collection process and the results of the subsequent statistical analysis are summarised in this paper. The results are then examined in a wider context of information from other sources, including performing arts medicine, biomechanics, piano competition results and commentary from pianists about their experiences with ESPKs.

To draw conclusions about 'all pianists' world-wide one would need to randomly select a sample from that group. Clearly this is unrealistic. Even sampling from pianists in a particular country, state or city is impracticable. Hence, like the studies mentioned above, the surveys undertaken by the authors were based on judgement sampling. However, for much of the following analysis, it is assumed that each survey group can be treated as an acceptable random sample.

Wagner (1988) collected many hand, wrist and arm measurements to a high level of accuracy including spans between all fingers, hand widths and breadths, and passive mobility measures. His measurement processes were time-consuming and required specialised equipment. The authors decided on a relatively quick and simple data gathering process involving just four hand span measurements, active thumb to fifth finger and second to fifth finger spans for both left and right hands. Three databases were developed.

The *Adult Pianist* database is the principal database and the main focus of the analysis in this paper. It includes hand span measurements from 473 pianists, all of whom were aged 18 years or over.

The *Young Pianist* database involves data from 49 children and teenagers between the ages of 6 and 17. Most of these children and teenagers were students of one of the authors, Erica Booker.

The *Business Student* database involves data collected as class-room exercises by two business statistics academics at Monash and Deakin Universities (in Melbourne, Australia). In collaboration with the authors, they collected hand span and other pertinent data from their students for use in their teaching of introductory business statistics during 2013 and 2014.

The following data were gathered for the Adult Pianist and the Young Pianist databases:-

1. Name
2. Gender
3. Handedness [Left or Right or Ambidextrous]
4. For left and right hands separately – active thumb to fifth finger and second to fifth finger spans [cm or inches]
5. Ethnic background [Caucasian, Asian, Other/Mixed]
6. Any other musical instrument they play/have played.

Additional information sought for the Young Pianist database included age, date of measurement and approximate AMEB level².

For the Adult Pianist database, no strict acceptance criteria were adopted to define 'pianist' except that each participant had had piano lessons for at least a few years at some stage in their life. The authors made their own judgement of the status ('level of acclaim') of each pianist, based largely on published biographies. The three categories adopted: 'International', 'National' and 'Regional/Amateur', are explained further in section 3.5. Names were recorded on a confidential basis as a cross-check to ensure the same pianist had not been included twice. Measurements were made in either centimetres or inches using measuring tapes, rulers or a printed copy of Steinbuhler's 'Hand Gauge'³. In nearly all cases measurements were undertaken by the authors but for approximately 30 Monash university piano students included in the Adult Pianist database, hand spans were self-measured using a measuring sheet with verbal instructions from one of the authors.

Those surveyed for the Adult Pianist database were mainly Australian pianists encountered during the three-year period (2011-14) and included piano teachers and academics attending piano pedagogy conferences and seminars, piano students at university or undertaking private lessons, plus piano playing acquaintances known to the authors. Several visiting professional performers were included in this database of 473, plus a small number of piano students and teachers whom the authors met in the USA and UK. The vast majority of pianists surveyed for the Adult Pianist database had reached a reasonably high level of proficiency: piano professionals (teachers, performers), those undertaking tertiary level classical piano studies or committed amateurs learning from a teacher and/or involved in public performances.

The Business Student database was developed to provide the authors with a non-pianist data set for comparative purposes. During tutorials, students recorded their own data on a single-page A4 form which included a printed 'measuring gauge' marked in centimetres

² AMEB – Australian Music Examinations Board

³ www.steinbuhler.com/html/handsizepage.html

(copy in Appendix 1). Hand spans were self-measured under the direction of tutors and the A4 survey forms passed on to the authors for data entry. Names were not collected. As many of these students were not pianists, a question was included as to whether they had ever learnt the piano, and if so, whether they were still playing. (The completed Excel database was subsequently used by the academics for their teaching purposes as a practical example of statistics.)

Measurements for all three data sources were entered into Excel databases. Hand span measurements in equivalent inches or centimetres were generated, and ratios of 1-5 (thumb to fifth finger) versus 2-5 (second to fifth finger) active spans were calculated.

While none of the three databases were based around strict random sample selection of respondents, the authors have treated each database as being a random sample for each group surveyed. All three data sets were analysed with statistical software using both descriptive and inferential methods.

The results described in the following section (3) relate to the 473 pianists in the Adult Pianist database. Analysis of the Business Students and Young Pianists databases are described in sections 4 and 5 respectively.

3.0 SURVEY OF ADULT PIANISTS – ANALYSIS AND RESULTS

Left hand and right hand measurements of the 473 surveyed in the Adult Pianist database were initially compared to see if there was any significant difference between their left and right hand spans. The analysis indicated that, while it was uncommon for individual pianists to have exactly the same measurements in both hands⁴, when considered as a group, the statistical patterns revealed for right hand measurements were emulated for the left hand. Accordingly, the authors made the decision to analyse just the right hand 1-5 and 2-5 span results. Thus, the results described here focus on right hand data only, with the exception of the analysis of left-right differences for cellists and guitarists (section 3.8). Note also that Wagner (1988) found very little difference between the left and right hands in most of his active hand span measures. [Analysis by the authors of the smaller 1-5 span of each person (i.e. using the smaller of their right and left hand spans) showed the statistical summary measures to be only marginally smaller than for the right hand 1-5 span measures.]

Left-handed respondents in the survey were outnumbered by right-handed respondents by a factor of 11 to 1. The general prevalence of left-handed people in the population is

⁴ L-R differences of between 0.1 and 0.3 inches were common; in some cases the differences were greater.

10%.⁵ A comparison of hand spans between left-handed and right-handed respondents showed no significant differences in size between the two groups.

For the remainder of this paper:

- '1-5 span' means right hand active span from the outside tip of the thumb to the outside tip of the fifth finger
- '2-5 span' means right hand active span from the outside tip of the second finger to the outside tip of the fifth finger
- 'active span' means the maximum unaided stretch when the hand is spread out on a flat surface.

3.1 *All adult pianists as a group*

How much variation in hand spans is there among pianists?

Key statistical summary measures were calculated for all 473 respondents in order to understand the group overall. These are summarised in Table 1 in Appendix 2.⁶ These results show that there is significant variation in hand spans between pianists. The key results to note are:

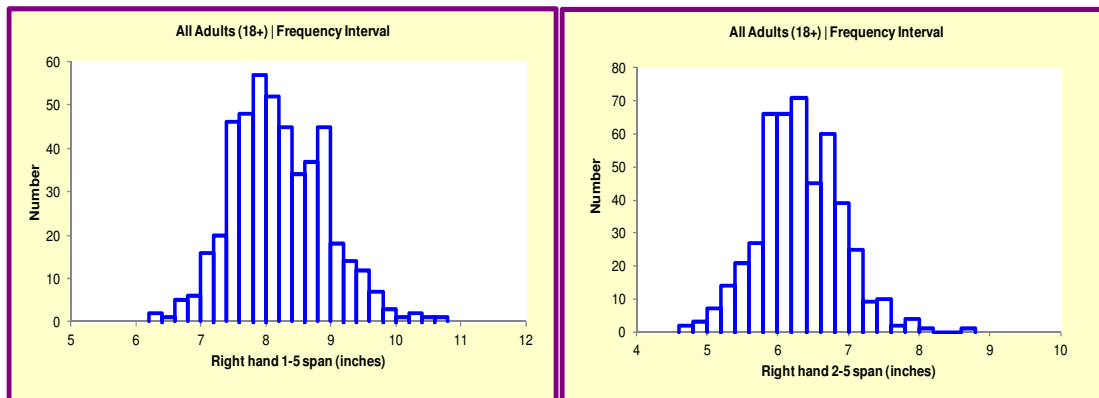
- The very large range from 6.4 to 10.8 inches (16.3 to 27.4 cm) for 1-5 spans. This means that the respondent with the largest hand (a male) can span 4.4 inches (11.2 cm) more than respondent with the smallest hand (a female). This is equivalent to about four and a half white keys on the standard keyboard.
- The very large range from 4.7 to 8.6 inches (11.9 to 21.9 cm) for 2-5 spans. This distance of 3.9 inches (10 cm) is equivalent to approximately four white keys on the standard keyboard. Again, the largest 2-5 span belongs to a male and the smallest to a female but they were not the same two people as for the 1-5 span.
- The average overall (using the arithmetic mean) is 8.2 inches (21 cm) for the 1-5 span while the median (or middle value when the data are ranked in ascending order) is the same at 8.2 inches (21 cm). The mean is 6.4 inches (16.2 cm) for the 2-5 span with a median of 6.3 inches (16.0 cm). However, there is significant variation either side of the means.

Figures 1 and 2 group all hand spans into 0.2 inch classes or groups within the Adult Pianists database.

⁵ Wikipedia, 2014

⁶ A note on rounding: generally summary statistics are given to one decimal place, while some other measures, for example, standard deviations and the difference between two means, are given to two decimal places. Any apparent anomalies will be due to rounding.

Figure 1: Adult pianists – 1-5 spans **Figure 2: Adult pianists – 2-5 spans**



The significant ranges for both hand span measures, as discussed above, are highlighted by these graphs. However, the graphs also highlight the bimodal nature of the two distributions, with two peaks, or high points, in each graph (at approximately 8 and 9 inches in Figure 1 and at approximately 6.4 and 6.6 inches in Figure 2).

Note that the results in Table 1 and Figures 1 and 2 do not differentiate between males and females or between varying ethnic backgrounds. These factors are taken into account in the following sub-sections and it is demonstrated that the first, and taller, peak in each graph is attributable to the smaller hands of females while the second peak, to the right, is due to the larger hands of males. (The 'female' peaks are taller because almost twice as many females (314) as males (159) were surveyed but the same bimodal shape would occur if the graphs plotted the percentage rather than the number in each interval.)

3.2 Gender differences

Do male pianists have hand spans significantly larger than females?

Analysing males and females separately gives the statistics for the 1-5 spans shown in Table 2 (Appendix 2). While there are approximately twice as many females as males, it is the summary measures which are important. These results show that male pianist 1-5 hand spans tend to be significantly larger than for females. The key results to note from Table 2 are:

- The arithmetic mean, the median and the quartiles all indicate a difference of about 1 inch (2.5 cm) in favour of males. This difference is slightly more than the width of one white piano key.

- The smallest male span of 7.8 inches (19.7 cm) is close to the female average value of 7.9 inches (20.1 cm) meaning that close to 100% of males surveyed have hands bigger than the average female.
- In the sample group, 75% of males have 1-5 spans 8.5 inches (21.6 cm) or greater (using the first quartile) while 75% of females have 1-5 spans of 8.3 inches (21 cm) or less (using the third quartile). Furthermore, the data show that 83.7% of males have hand spans bigger than 8.3 inches, meaning the top 83.7% of males outrank the bottom 75% of females.
- Results of a two-tail hypothesis test (assuming random sampling), indicate that this gender difference between arithmetic means is significant at the 5% level, with a p-value of 0.0000.
- And we can be 95% confident that the average male 1-5 span is at least 0.88 inches (2.2 cm) bigger than the average female span and the difference could be as much as 1.09 inches (2.8 cm).

The table also shows significant variation within each gender, the range from minimum to maximum span being 3 inches (7.7 cm) for males and 3.1 inches (7.9 cm) for females. This is a significant finding in its own right, and highly relevant to the discussion later in this paper.

The disparity between males and females is clearly illustrated in the two frequency curves shown in Figure 3, and also in the column chart (Figure 4) which groups 1-5 spans into four size categories.

Figure 3: Adult pianists – RH 1-5 span by gender, frequency curve

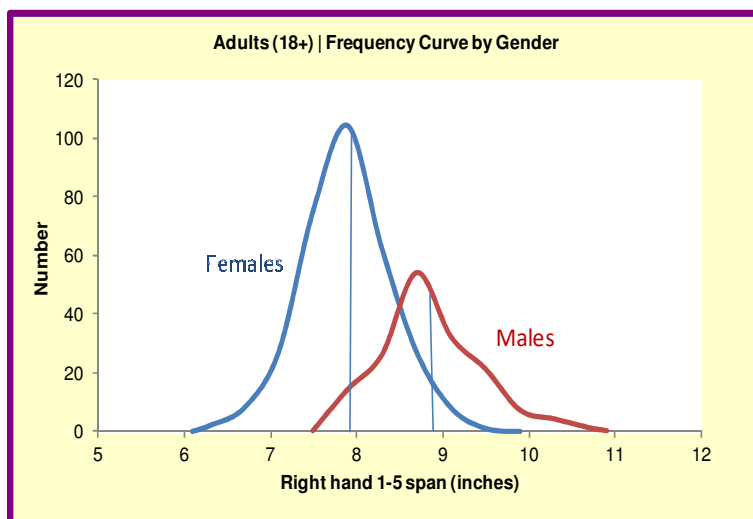
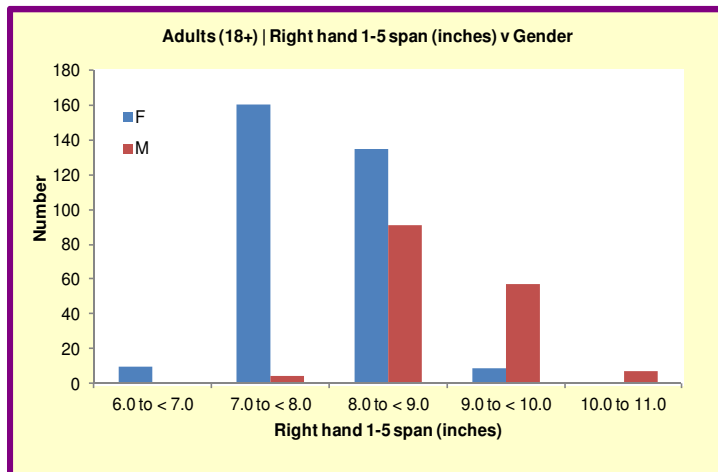


Figure 4: Adult pianists – RH 1-5 span by gender, column chart



The key factors to note are:

- Males are generally located to the right of females, that is, towards the larger hand spans.
- The vertical line in Figure 3 shows that only a very small minority of men (2.0% of all males in the sample) have 1-5 spans below the female mean of 7.9 inches (20.1 cm).
- Conversely, the figure shows only a very small minority of women have 1-5 spans above the male mean of 8.9 inches (22.6 cm).

Detailed cross-tabulations by gender are presented in Table 3 (Appendix 2). The preponderance of males in the larger hand span groups is again highlighted. The 'Percent of Columns' table shows that while only 2.5% of males have 1-5 spans less than 8 inches, 54.2% of females (3.2% plus 51.0%) have spans of less than 8 inches. Conversely, 40.2% of males (35.8% plus 4.4%) compared with only 2.9 % of females have 1-5 spans of 9 inches or more, with no females above 10 inches.

Summary statistics for 2-5 spans were also calculated for each gender and these are presented in Table 4 (Appendix 2). These results show also show that males tend to have significantly larger 2-5 spans than females. Key results to note are:

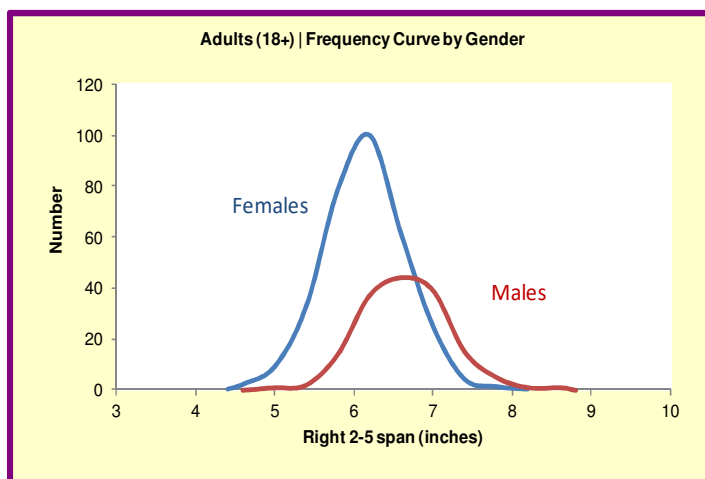
- Male 2-5 spans cover a greater range (3.6 inches, or 9.2 cm) than those of females (3.0 inches, or 7.6 cm).
- The gender difference in the average values is again apparent with a mean of 6.7 inches (17.0 cm) for males and a mean of 6.2 inches (15.7 cm) for females, a difference of 0.5 inches (about 1.3 cm).
- As expected, this difference is less in absolute terms than for the 1-5 span.

- Results of a two-tail hypothesis test indicate that this gender difference in the two means is significant at the 5% level, with a p-value of 0.0000.
- And we can be 95% confident that the average male 2-5 span is at least 0.42 inches (1.07 cm) bigger than the average female span and that the difference could be as much as 0.62 inches (1.57 cm).

The table also shows significant variation within each gender. In particular, note that the male 2-5 span range of 3.6 inches (9.2 cm) is greater than the male 1-5 span range of 3.0 inches (7.7 cm) as shown in Table 2.

The gender differences for the 2-5 span are illustrated in the two frequency curves shown in Figure 5. While the disparity between males and females is not as great for the 1-5 span, the graph clearly shows males located to the right. Further analysis of the data show that 73% of females have 2-5 spans less than 6.5 inches (16.5 cm), while 65% of males have 2-5 spans of 6.5 inches or more.

Figure 5: Adult pianists – RH 2-5 span by gender

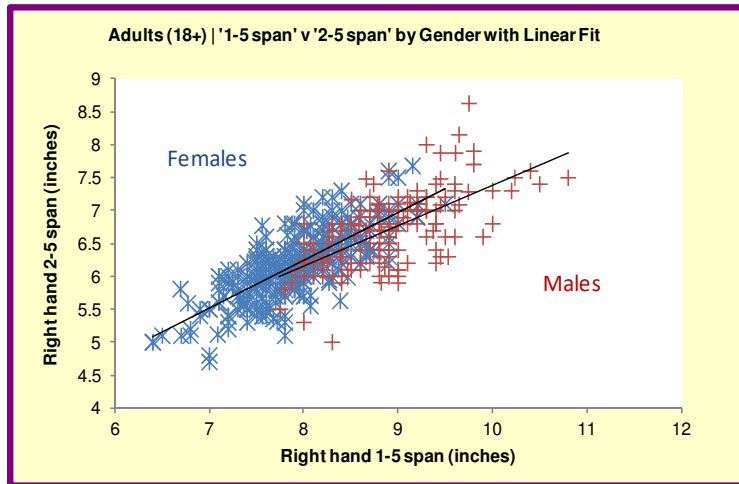


The relative flexibility of the second to fifth fingers in relation to total (thumb to fifth finger) active hand span was assessed by calculating the ratio of 2-5 versus 1-5 values. Table 5 (Appendix 2) shows these ratios for males and females separately. Key points to note are:

- The mean 2-5:1-5 ratio for females (0.78) is higher than for males (0.75).
- This difference in the two sample means is significant at the 5% level with a p-value of 0.0000.
- These results point to greater relative flexibility between non-thumb digits among females, although this small statistical difference is of doubtful practical significance.

Figure 6 shows separate regression analysis plots of 1-5 versus 2-5 hand spans for males and for females.

Figure 6: Adult pianists – RH 1-5 span versus 2-5 span by gender



As would be expected, in both cases, the bigger the 1-5 span, generally the bigger the 2-5 span. The relationship is stronger for females with an R^2 value of 0.56, compared with an R^2 of 0.39 for males. The bigger hands of males are demonstrated by the scatter of points noticeably to the right of the scatter for females.

3.3 Ethnic differences by gender

Do hand spans vary according to ethnic background?

Of the 473 pianists surveyed, 124 were categorised as Asian and 332 as Caucasian. The Asian category includes those originating from north-eastern Asia, south-eastern Asia or southern Asia (Indian subcontinent, Sri Lanka). The Caucasian category includes those identifying themselves to be of European or Middle Eastern/North African descent. The majority of the Asian group were of Chinese ethnicity while the majority of the Caucasian group had European ancestry.

Because of the very small sample size, those identified as southern African were omitted from this analysis of ethnic differences. Those of mixed Asian/Caucasian descent were also omitted from this analysis. After omitting 17 respondents, the remaining 456 were categorised as follows:

	Female	Male	Total
Asian	87	37	124
Caucasian	216	116	332
Total	303	153	456

Analysis of the Adult Pianist database (males and females combined) showed that the adult Caucasians in the group have, on average, 1-5 spans 0.3 inches (7 cm) larger than the adult Asians. The Caucasians have a bigger range, having both the smallest and largest spans. The results clearly show that hand spans do vary according to ethnic background.

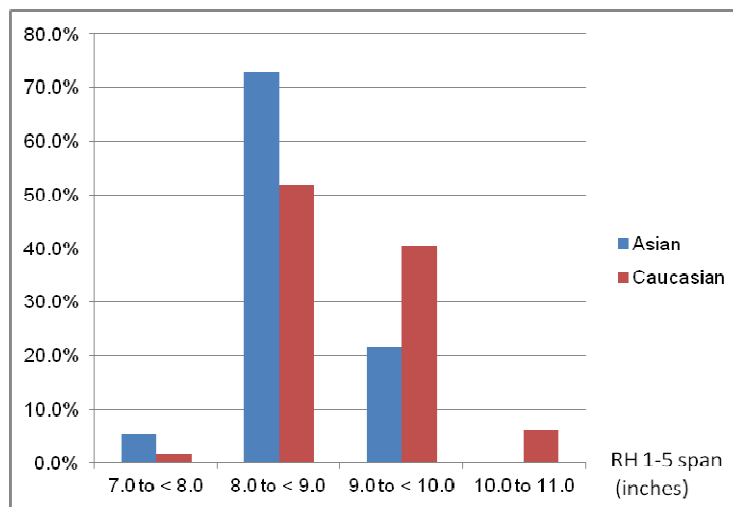
Considering each gender separately, is it still the case that Caucasians have bigger hands than Asians?

For this analysis, the database was first split by gender and then by ethnicity (Caucasian versus Asian). Summary measures for the 1-5 and 2-5 spans of Asian and Caucasian males are compared in Tables 6 and 7 (Appendix 2). These results show that 1-5 hand spans for Caucasian males tend to be significantly larger than for Asian males, while there is no significant difference in 2-5 spans. Key points to note are:

- For male 1-5 spans, arithmetic means are 9.0 inches (22.8 cm) for Caucasians and 8.7 inches (22.0 cm) for Asians, a difference of 0.3 inches (0.8 cm).
- The difference in the two sample means is significant at the 5% level, with a p-value of 0.0033.
- And we can be 95% confident that the average Caucasian male 1-5 span is at least 0.11 inches (0.27 cm) bigger than the average Asian male span and the difference could be as much as 0.52 inches (1.3 cm).
- In the case of 2-5 spans however, Asians have a slight advantage, but the difference is small and not statistically significant.
- The range of hand spans is much greater among Caucasians, being most pronounced for the 1-5 spans which show maxima of 10.8 inches (27.4 cm) for Caucasians and 9.4 inches (24.0 cm) for Asians.

Figure 7 is a column chart which groups 1-5 values for males into four hand span categories. The frequencies in each hand span group are expressed in terms of *percentage* splits for each ethnic group, thereby accounting for the different numbers in each of the two groups. It clearly shows the tendency for Caucasian male hands to be bigger, with the greater proportion of Asian male 1-5 spans below 9 inches and no spans above 10 inches.

Figure 7: Adult pianists – Male RH 1-5 span by ethnicity (percent)

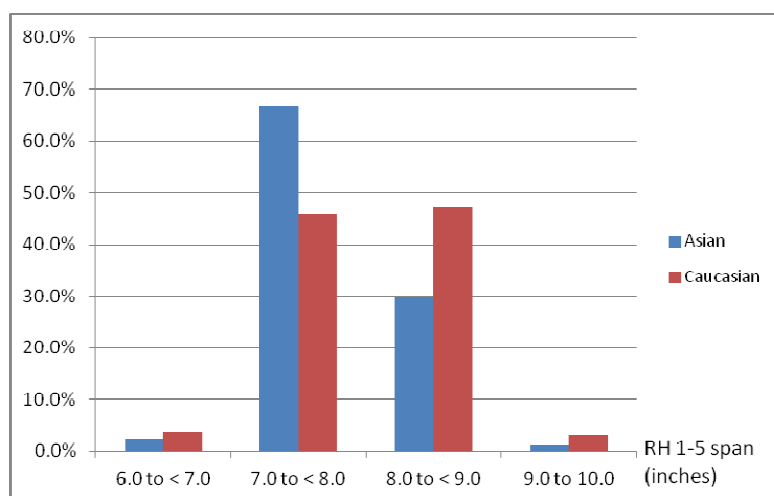


The same analysis by ethnicity was repeated for females. Summary measures for the 1-5 and 2-5 spans of Asian and Caucasian females are compared in Tables 8 and 9 (Appendix 2). These results show that 1-5 hand spans for Caucasian females tend to be significantly larger than for Asian females (though not as large a difference as for males), while there is no significant difference in 2-5 spans between Caucasian and Asian females. Key points to note are:

- For female 1-5 spans, arithmetic means are 8.0 inches (20.2 cm) for Caucasians and 7.8 inches (19.8 cm) for Asians, a difference of 0.2 inches (0.4 cm) in favour of Caucasians.
- The difference in the two sample means is significant at the 5% level, with a p-value of 0.0127.
- And we can be 95% confident that the average Caucasian female 1-5 span is at least 0.04 inches (0.1 cm) bigger than the average Asian female span and the difference could be as much as 0.30 inches (0.76 cm).
- Looking at 2-5 spans, the mean and median results are the same for both female groups.
- Once again, the range of values for both 1-5 and 2-5 spans is much greater for Caucasians than for Asians.

Figure 8 illustrates these results in a column chart like that used above for males. It clearly shows the greater proportion of Asian females with 1-5 spans of less than 8 inches (20.2 cm), indicating the Caucasian females tend to have bigger 1-5 spans than Asian females.

Figure 8: Adult pianists – Female RH 1-5 spans by ethnicity (percent)



The greater range of hand spans among Caucasians, whether male or female, (as illustrated in Tables 6 to 9) is worth further investigation but beyond the scope of this paper. The dataset seems to indicate that for both males and females, the very smallest hands and the very largest hands are more likely to belong to those with a Caucasian background.

The ratio of 2-5 to 1-5 spans is higher among Asians. (This follows logically from their 1-5 spans being smaller than Caucasians but their 2-5 spans being very similar.) The mean ratio for Asian females is 0.80 compared to Caucasian females of 0.78. The mean ratio for Asian males is 0.78 compared to Caucasian males of 0.75. This difference is significant statistically at the 5% level for both males and females.

3.4 Gender differences within ethnic groups

For each ethnic group, how do hand spans vary according to gender?

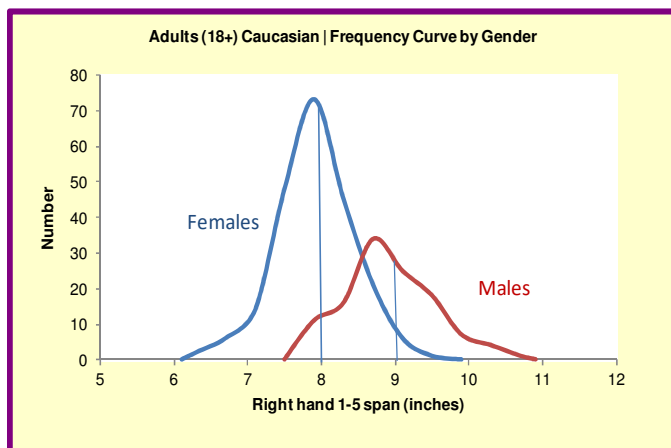
Tables 10 and 11 (Appendix 2) show gender differences in 1-5 and 2-5 spans for all Caucasians in the sample group broken down by gender. These results show that Caucasian male 1-5 hand spans tend to be significantly larger than for Caucasian females. Key points to note are:

- The gender differences in Caucasian hand spans are similar to those for all adult pianists (see section 3.2). In particular, Caucasian males have an average 1-5 span 1 inch (2.6 cm) greater than for Caucasian females.
- This difference in means is also statistically significant at the 5% level, with a p-value of 0.0000.

- And we can be 95% confident that the average Caucasian male 1-5 span is at least 0.90 inches (2.3 cm) bigger than the average Caucasian female span and the difference could be as much as 1.15 inches (2.9 cm).
- There is little difference between genders in the ranges for 1-5 spans, but for 2-5 spans, the range for males is significantly greater than for females.

The over-riding feature of the data is that Caucasian males as a group have significantly larger hands than Caucasian females, illustrated in Figure 9. The vertical lines indicate the mean (average) for each group and the graph clearly shows that the vast majority of Caucasian females have 1-5 spans less than the mean for Caucasian males, while the vast majority of Caucasian males have 1-5 spans greater than the mean for Caucasian females. In fact, 97% of Caucasian females have 1-5 spans below the mean for Caucasian males of 9.0 inches (22.8 cm), while only 1.7% of Caucasian males have 1-5 spans below the mean for Caucasian females of 8.0 inches (20.2 cm).

Figure 9: Adult pianists – Caucasian RH 1-5 span by gender



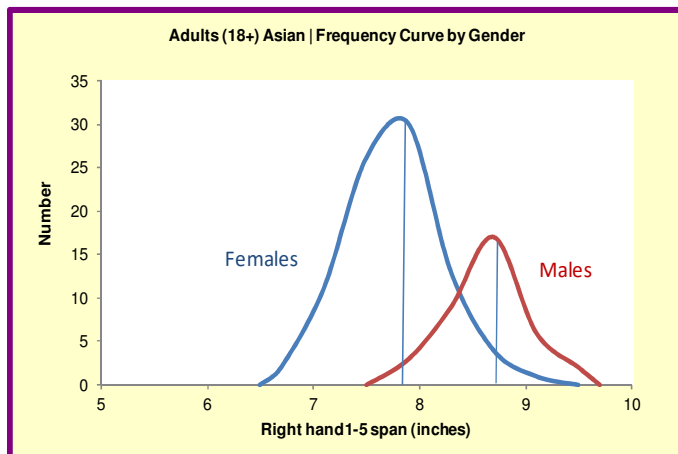
Tables 12 and 13 (Appendix 2) show gender differences in 1-5 and 2-5 spans for all Asians in the sample group. These results show that Asian male 1-5 hand spans tend to be significantly larger than for Asian females. Key points to note are:

- The gender differences in Asian hand spans are similar to those for all adult pianists (see section 3.2). In particular, Asian males have an average 1-5 span 0.9 inches (2.2 cm) greater than for Asian females.
- This difference is also statistically significant at the 5% level, with a p-value of 0.0000.
- And we can be 95% confident that the average Asian male 1-5 hand span is at least 0.71 inches (1.8 cm) bigger than the average Asian female span and the difference could be as much as 1.05 inches (2.7 cm).

- The range of values for 1-5 spans is greater for Asian females than Asian males, but there is little gender difference in the range in the case of 2-5 spans. (This pattern differs from that for Caucasians where males have a bigger range than females.)

The overriding feature of the data is that, while it is not quite as pronounced as for Caucasians, Asian males as a group have significantly larger hands than Asian females, as illustrated in Figure 10. The vertical lines indicate the mean (average) for each group and the graph clearly shows that the vast majority of Asian females have 1-5 spans less than the mean for Asian males, while the vast majority of Asian males have 1-5 spans greater than the mean for Asian females. In fact, 98% of Asian females have 1-5 spans below the mean for Asian males of 8.7 inches (22.1 cm), while 97% of Asian males have 1-5 spans above the mean for Asian females of 7.8 inches (19.8 cm).

Figure 10: Adult pianists – Asian RH 1-5 span by gender



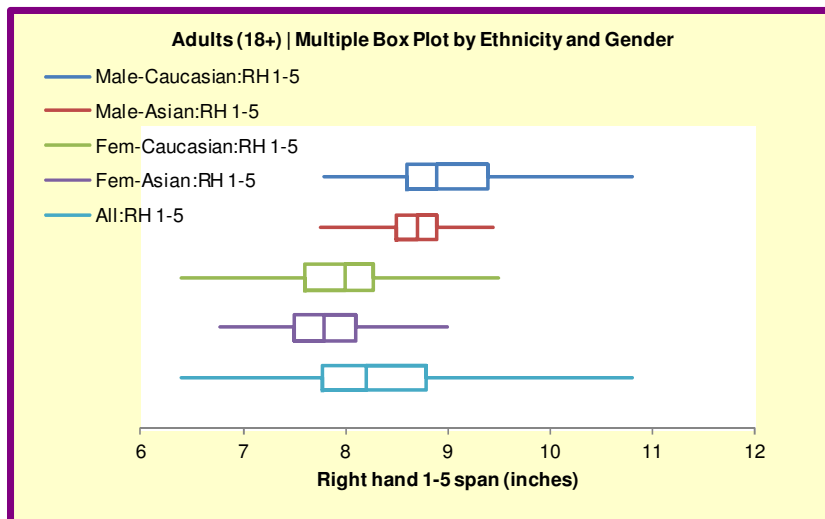
A key finding from the analysis by gender and ethnicity described in sections 3.2 to 3.4 is that gender differences in both 1-5 and 2-5 spans are much greater in magnitude than ethnic differences. To summarise:-

- Males generally have 1-5 spans about 1 inch (2.5 cm) greater than females. This still applies whether analysing Caucasians by gender or analysing Asians by gender.
- The difference between male Caucasian and male Asian 1-5 spans is considerably less, with Caucasians on average 0.3 inches (0.8 cm) larger, while the difference between Caucasian and Asian females is only 0.2 inches (0.5 cm).
- Male 2-5 spans are, on average, about 0.5 inches (1.3 cm) larger than females, regardless of ethnicity.

- The ethnic difference in 2-5 spans, both for males and for females, is very slight and was not found to be statistically significant in the authors' sample.

Figure 11 provides a useful means of comparing 1-5 spans for sub-groups of the Adult Pianists. The top box plot clearly shows the generally larger spans of the Caucasian males. Male Asians tend to have the next largest hands. Caucasian females have noticeably smaller hands, with female Asians smaller still. The bottom box plot includes all Caucasians and Asians together. Comparing the largest and smallest groups, the sample mean for Caucasian males exceeds the sample mean for Asian females by 1.19 inches (3 cm) – a width significantly greater than one white piano key.

Figure 11: Adult pianists – RH 1-5 span by ethnicity and gender



3.5 Hand span by level of acclaim

Do acclaimed pianists tend to have bigger hands?

Pianists in the Adult Pianist database were categorised according to 'level of acclaim' based on their success as a performer. Pianists with a certain level of acclaim were identified by the authors at two levels.

Firstly, those with an 'International' profile based on:-

- Long-standing solo performing career, including in major concert venues around the world, covering a wide range of repertoire
- Internationally acclaimed recordings covering a wide range of repertoire
- Prize-winner in major international piano competition(s).

Secondly, those with a 'National' profile based on:-

- Long-standing professional performing career in their home country, either as a soloist, accompanist or chamber musician
- Nationally acclaimed recordings
- Prize-winner in significant national competition(s).

The remaining pianists in the database were classed as 'Regional/Amateur' based on either:-

- The piano forming an important aspect of their adult lives, for example, as teachers, occasional performers (for example, in community fund-raising concerts) and/or as keen amateur recreational pianists, or
- The piano being part of their lives in the past, having learnt as a child or teenager but no longer playing regularly.

The issue of repertoire range for 'International' performers is considered relevant to hand span because repertoire from the Romantic and later periods tends to require a larger span than repertoire from the Baroque or Classical periods (see later discussion in section 7). Twelve pianists (10 male, 2 female) were identified as 'International', while 51 (30 male, 21 female) were identified as 'National'.

Considering all adult pianists together, summary statistics for the 1-5 spans of the three 'level of acclaim' groups are compared in Table 14 (Appendix 2). These results show that internationally acclaimed pianists tend to have bigger hands than the nationally acclaimed, who in turn have bigger hands than the remaining 'Regional/Amateur' pianists.

The key results to note for the Internationals versus the other groups are:

- The International group has a maximum 1-5 span of 10.8 inches (27.4 cm) while the minimum of 8.8 inches (22.4 cm) was close to the mean 1-5 span for all males of 8.9 (22.6 cm) inches (Table 2).
- The minimum 1-5 span for the International group is bigger by 1.6 inches (4.1 cm) than the minimum span for the National group and bigger by 2.4 inches (6.1 cm) than the minimum span for the Regional/Amateur group.
- The mean and median 1-5 spans for the International group are approximately 1.0 inch (2.5 cm) larger than those measures for the National group and 1.3 inches (3.3 cm) larger than for the Regional/Amateur group.
- All of the differences in means are significant at the 5% level.

- Further highlighting the significantly bigger hands of the internationally acclaimed group is that all 12 Internationals have 1-5 spans bigger than approximately 75% of Nationals and Regional/Amateurs combined (using the third quartiles).

The key results to note for the National group versus Regional/Amateur group are:

- The mean and median for the National group are about 0.3 of an inch (0.75 cm) larger than for the Regional/Amateur group.
- The two quartiles for the National group are also higher by 0.2 to 0.4 inches (0.5 to 1 cm).
- However, the range of values for the Regional/Amateur group is greater than for the National group, with the lowest minimum of all respondents but a maximum close to the maximum for the International group. This very wide range for the Regional/Amateur group is not surprising, given that it includes pianists from many walks of life, many of whom do not perform regularly any more.

Table 15 (Appendix 2) gives cross-tabulations of level of acclaim by three 1-5 span groups. Figure 11 illustrates the 'Percent of columns' information from Table 15 in the form of a frequency chart. The table and chart clearly show the increasing proportions of pianists of National and International status as hand span increases. Every acclaimed pianist in the International group has a right 1-5 span of 8.5 inches (21.6 cm) or more. And in fact, further analysis shows that 9 out of the 12 internationally acclaimed pianists have 1-5 spans of 9.3 inches (23.6 cm) or more. The table clearly illustrates the pattern of the higher the acclaim, the bigger the hand.

Figure 11: Adult pianists – RH 1-5 span by level of acclaim (percent)

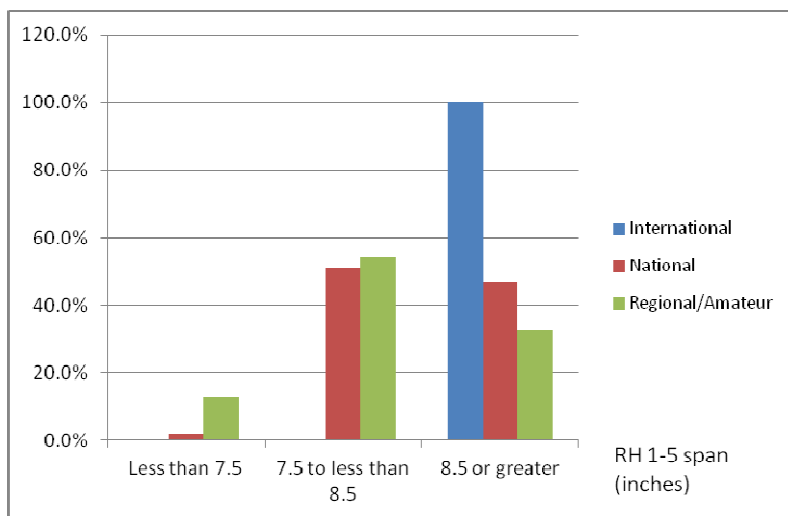


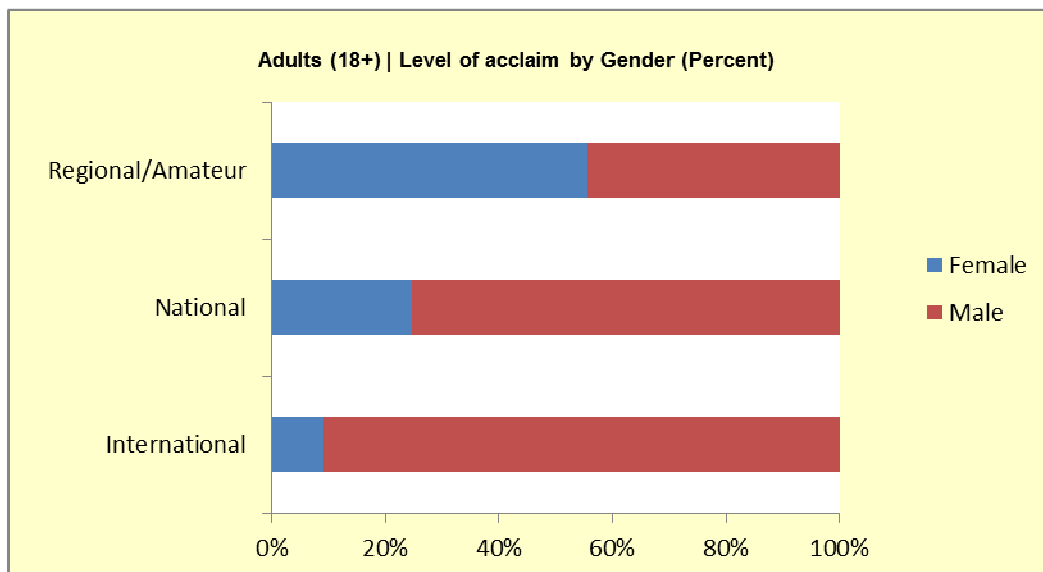
Table 16 (Appendix 2) presents the same summary statistics for the three 'level of acclaim' groups for 2-5 spans. Key findings from this analysis are:

- The differences in mean and median values between the three groups follow a similar pattern to the 1-5 spans. That is, Internationals' hands are larger than Nationals which are in turn, larger than Regional/Amateurs. However, the absolute differences are not as great as the 1-5 span differences.
- The difference between the means for International and National groups is significant at the 5% level, whereas the National – Regional/Amateur difference is significant at the 10% level.
- The range of values for the International group is only about half that of the National and Regional/Amateur groups.

3.6 Level of acclaim by gender

In order to investigate gender differences in pianists' status, Table 17 (Appendix 2) presents cross tabulations of 1-5 spans by gender versus level of acclaim. Figure 12 is a column chart illustrating the 'Percent of columns' cross tabulation which directly compares the relative proportions of males and females within each of the three 'level of acclaim' groups.

FIGURE 12: Adult pianists – Level of acclaim by gender (percent)



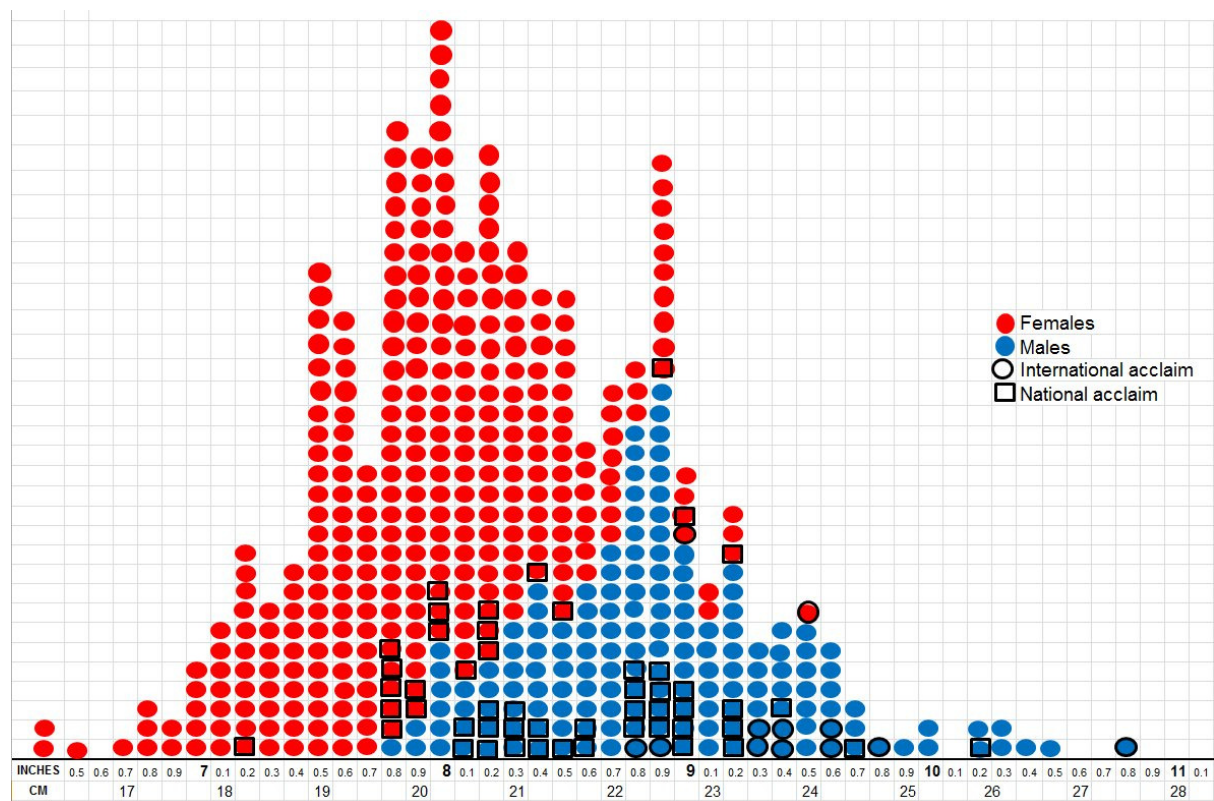
The proportions of Internationals, Nationals and others might not be representative of the population of adult pianists at large due to the sampling methods used, however, the results clearly show the higher proportions of males compared with females who have reached a National level of acclaim, and even more obviously, the relatively high proportion of males from this sample at the International level.

From an analysis of 1-5 spans by level of acclaim for each gender separately, the data show that:-

- For males, there is a significant difference (5% level) in hand spans between the Internationals and Nationals and also between the Internationals and Regional/Amateurs (in favour of Internationals in both cases). However, the difference in hand spans between the National and Regional/Amateur groups is not significant at the 10% level.
- As there were only two females in the International category, these were combined with the National group for analysis. The difference in 1-5 spans between this combined acclaimed group and the Regional/Amateur group was found to be significant at the 5% level (in favour of Internationals/Nationals).

Figure 13, a dot chart like that compiled by David Steinbuhler (2004), clearly illustrates the findings that Internationals tend to have significantly larger hands both overall and within each gender. It shows the complete set of right hand 1-5 active hand span data for all 473 adult pianists, with gender and level of acclaim illustrated by colour and marker.

Figure 13: Adult pianists – right hand 1-5 spans by gender and level of acclaim



This graph shows a number of noteworthy features, some of which have already been highlighted in earlier sub-sections:

- Males tend to be located towards the right, i.e., towards the larger 1-5 spans.
- The Internationally and Nationally acclaimed males are located in this top section.
- Females tend to be located towards the left, i.e., towards the smaller 1-5 spans.
- With one exception, the Internationally and Nationally acclaimed females are located in the top section of the female distribution, around the female average 1-5 span or higher. The two female Internationals are at 9.0 inches or higher.

Clearly, Figure 13 illustrates the authors' findings that internationally acclaimed pianists tend to have relatively large hand spans and as males tend to have larger hands, they dominate the ranks of internationally acclaimed pianists. (Refer to discussion in section 7.1.5.).

The lone female at the 'National' level in the authors' study who has a 1-5 span of only 7.2 inches (18.3 cm), later (in section 8) defined as 'very small' – is worthy of brief discussion. She is an extremely talented young pianist, who is greatly assisted by having an exceptionally wide 2-5 span for her hand size, in fact just within the 'large hands' 2-5 group according to the definitions in section 8. Her 2-5:1-5 ratio is approximately 0.85. She has an eclectic repertoire including Mozart, selected works of Beethoven, Ravel and late Brahms (Brahms and Ravel generally requiring significant modifications to the score), and many carefully chosen contemporary works. She often performs with other chamber musicians or orchestras. A pianist with her hand span of 7.2 inches would find it impossible to perform extended fast passages of octaves or octave-based chords due to the physical constraints (having to play octaves on the front edge of the white keys) and build-up of pain that would become apparent due to the extreme stretch required. A pianist with this span cannot play a ninth on the conventional keyboard.

3.7 Level of acclaim by ethnicity

Cross tabulations between level of acclaim and ethnicity have not been included here because the small sample did not enable conclusions to be drawn with any confidence.

3.8 Differences between left and right hands for cellists and guitarists

There is a common belief among musicians that maintaining extreme joint positions from playing an instrument and/or regular stretching exercises increases the flexibility in the corresponding joints. For example, cello players are often thought to have larger left hand than right hand spans.

To test this belief, one question in the authors' study asked each pianist which other instruments they had played, if any. For the purposes of comparison with the results of previous studies discussed below in section 6.3 (Kloeppe, 2000; Driscoll & Ackermann, 2012), those who nominated cello or guitar were compared with all other pianists in the sample. For all 473 pianists, the results indicate a difference between left and right hand 1-5 span of only 0.03 inches (0.08 cm) on average in favour of the left hand. For the 65 pianists who had played the cello and/or guitar the average difference was 0.05 inches in favour of the left. Looking at 2-5 span measures, the differences were slightly greater, with a 0.11 inch difference for cellists, 0.02 inches for guitarists and 0.06 inches for all other pianists, in favour of the left hand. These differences are all insignificant at the 10% level and in any case, are insignificant for piano playing in any practical sense. A similar analysis of left-right hand differences among violin and viola players also found no significant differences between this group and the adult pianists in general.

4.0 SURVEY OF BUSINESS STUDENTS – ANALYSIS AND COMPARISON WITH ADULT PIANISTS

How do hand spans of pianists compare to the hand spans of non-pianists?

The only data the authors were able to find on hand spans for the population at large date from the 1980s or earlier (see Section 6.5).

Given the lack of recent data, with the aid of two university academics the authors collected data from a number of non-pianists, namely students in business statistics subjects. The authors have assumed that this judgement sample can be treated as a random sample for analysis purposes.

Thus, as described in section 2.3, similar hand span data as for the adult pianists were gathered from business students at Deakin and Monash Universities. Some data collection problems surfaced. With the Adult Pianist database, respondents were generally closely supervised by one of the authors to ensure hands were properly stretched. However, the academics were only able to give instructions from the front of the class, hoping that students would make the measurements correctly and record them accurately.

As reliability was expected to be less than for the main Adult Pianist database, a thorough validation check of the student data was carried out by the authors prior to analysis. As a result, several records were omitted due to missing data or measurements that were not believable. For example, some students recorded identical values for their 1-5 and 2-5 spans while some other measurements were judged by the authors to be

abnormally small for adults. The measurements also show evidence of many students rounding up or down to the nearest centimetre even though the measuring template enabled them to measure to the nearest 2 millimetres.

Ultimately, data from 216 students were included in the analysis: 86 from Deakin University and 130 from Monash University. All were students enrolled in business courses, but while the gender and ethnic percentage mix may have been different to the general university student population, there is no reason to believe the various sub-groups in the sample differed from their larger sub-populations within the universities in terms of hand size.

4.1 Analysis by university and semester

At each university, data were collected over two semesters. Table 18 (Appendix 3) shows summary statistics for the 1-5 span measurements for all students in each semester at each university. The results indicate that students in the Deakin semester B group have significantly larger hand spans than for the other groups. It is noted that 89% of students in that group were Caucasian, whereas for the other three semester groups Asians dominated with 75%, 85% and 94% of respondents. (Results from the analysis of the Adult Pianist database discussed above indicate that Caucasians have larger hand spans than Asians.) Figure 14 illustrates the results in the form of box plots which highlight median and quartile values.

Figure 14: Business students – RH 1-5 span by campus/semester group

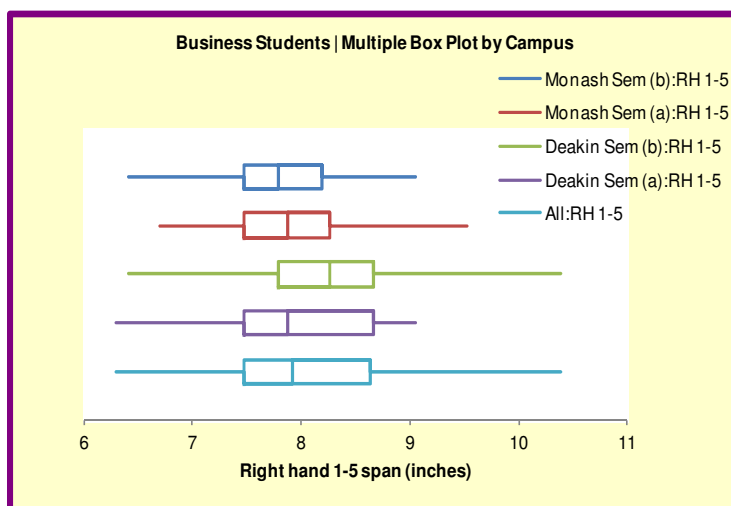


Table 19 (Appendix 3) shows summary statistics for the 2-5 span measurements. The results show very little difference between the four groups.

For further analysis, the four semester groups were combined to form a single Business Student database of 216 respondents. Key findings follow; comparisons with the Adult Pianist results are given in Section 4.6.

4.2 Gender differences

Gender differences were analysed in the same way as for the Adult Pianist database. In the Business Student database there were 123 males and 93 females in total. Table 20 (Appendix 3) shows summary statistics for 1-5 spans for males and females.

These results show that male Business Student 1-5 hand spans tend to be significantly larger than for females. Key findings from this analysis are:

- The arithmetic means are 8.3 inches (21.2 cm) for males and 7.6 inches (19.2 cm) for females.
- The difference in the two sample means of 0.76 inches (1.9 cm) is significant at the 5% level.
- And we can be 95% confident that the average male business student 1-5 span is at least 0.59 inches (1.5 cm) bigger than the average female 1-5 span and the difference could be as much as 0.93 inches (2.4 cm).

Figure 15 illustrates the results in the form of a frequency chart. The location of males towards the right highlights the difference between male and female 1-5 spans for the business student data, with females generally having smaller hands.

Figure 15: Business students – RH 1-5 span by gender

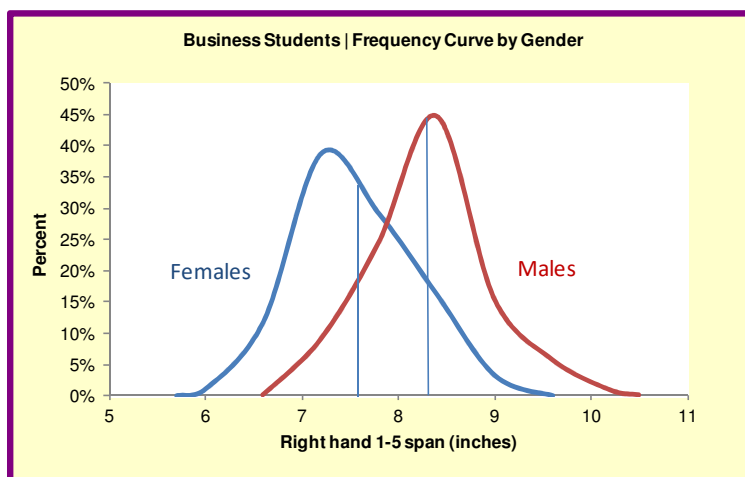


Table 21 (Appendix 3) shows similar summary statistics for 2-5 spans. Again, the conclusion is that males in the Business Student database have significantly bigger 2-5 spans than females.

4.3 Ethnic differences by gender

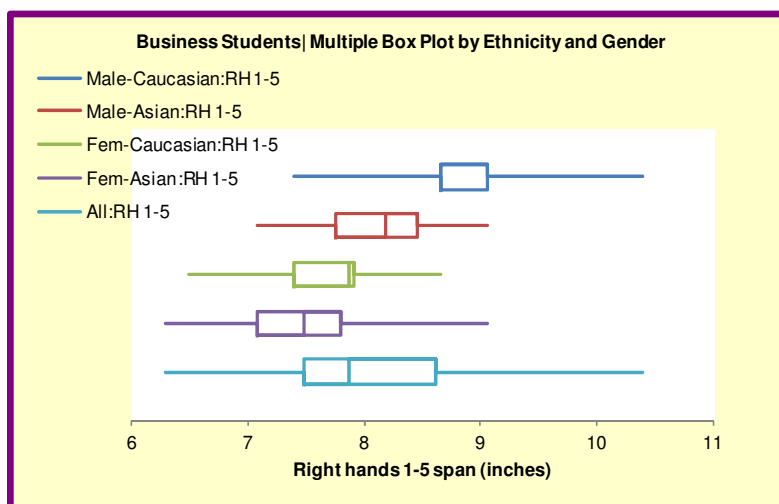
As for the Adult Pianist database, students were categorised as 'Asian', 'Caucasian' or 'other/mixed'. The eight respondents in the last category were not included in the analysis of ethnic differences in order to concentrate on the two major groups. Of the females, 56 were of Asian descent and 30 of Caucasian descent. For males, 79 were Asian and 42 Caucasian. Tables 22 and 23 (Appendix 3) compare 1-5 spans of Asians and Caucasians, for males and females separately.

These results show that Caucasian male and Caucasian female Business Students tend to have 1-5 hand spans significantly larger than their Asian gender counterparts. Key results to note are:

- Caucasian males have a sample mean 0.7 inches (1.8 cm) greater than their Asian counterparts.
- Caucasian females have a sample mean 0.28 inches (0.7 cm) greater than their Asian counterparts.
- These differences in the means are both significant at the 5% level.

Figure 16 is a multiple box plot that summarises the 1-5 span results for the four gender/ethnic groups. The top box plot clearly shows the generally larger 1-5 right spans of the Caucasian males in the Business Student database. Male Asians tend to have the next largest hands with Female Asians the smallest.

Figure 16: Business students – RH 1-5 span by ethnicity and gender



Further interesting results from this analysis are that:

- The sample mean for Caucasian males exceeds that for Asian females by 1.4 inches (3.5 cm). This difference is significant at the 5% level and we can be 95%

confident that, on average, Caucasian male 1-5 spans exceed Asian female 1-5 spans by at least 1.13 inches (2.9 cm) and by up to 1.58 inches (4 cm).

- The sample mean for Asian males exceeds that for Caucasian females by 0.4 inches (1.0 cm). This difference is significant at the 5% level and we can be 95% confident that, on average, Asian male 1-5 spans exceed Caucasian female 1-5 spans by at least by 0.16 inches (0.4 cm) and by up to 0.59 inches (1.5 cm).
- Caucasian males in the Student database have only marginally smaller hands on average than Caucasian males in the Adult Pianist database (0.2 inches or 0.51 cm less). However, Asian males in the Student database have noticeably smaller hands than Asian males in the Adult Pianist database (0.7 inches or 1.8 cm less).

Analysis of 2-5 spans shows that ethnic differences are not statistically significant, neither for females nor for males. While summary tables are not given, means and standard deviations are included in section 4.6 (Table 25).

4.4 *Pianists versus non-pianists*

Students were asked if they had ever learnt to play the piano and if so, whether or not they still played. Table 24 shows the results, grouped into the three classes.

	Total	%	No. of males	%	No. of females	%
Total number of responses	215	100%	123	100%	93	100%
Never learnt to play	128	59%	89	73%	39	42%
Learnt but no longer play	68	32%	24	20%	44	47%
Still play the piano	19	9%	9	7%	10	11%

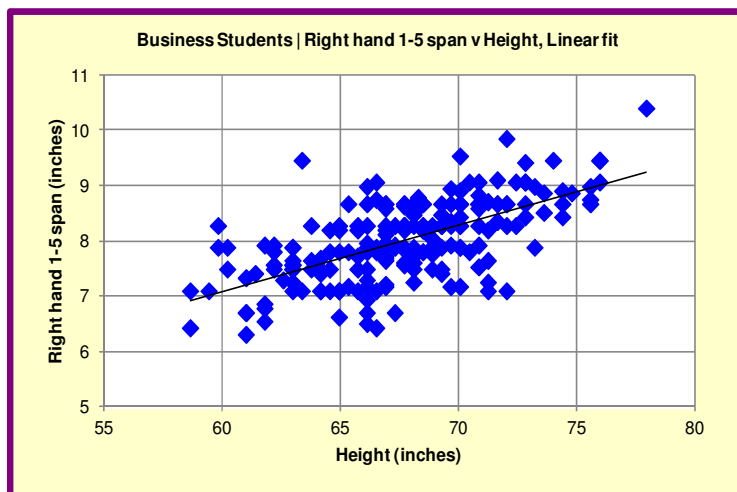
There are no noteworthy findings from statistical comparisons of the various groups. Detailed information, such as AMEB level reached, was not sought from the university students, as this was not suited to the data gathering process. It may be the case that many of those who learnt but no longer play had only reached a relatively elementary level. Those included in the Adult Pianist database were, on the other hand, virtually all pianists who would have reached a high level of accomplishment, being either teachers, university music students or professional or serious amateur performers. These results are discussed further in section 6.5 which deals with how pianists' hand spans might compare with non-pianists.

4.5 Height as a predictor of hand span

Do tall people tend to have bigger hands than short people?

In addition to hand span data, the Business Student survey also asked the students to record their heights. The regression analysis plot of height versus 1-5 span, for all students together, is shown in Figure 17.

FIGURE 17: Business students – RH 1-5 span versus height



This analysis indicates that there is a weak but clear relationship between a person's height and 1-5 hand span ($R^2=0.41$; $p=0.00$). Thus, in general we would conclude that although a person's height provides a guide to their 1-5 span, it is not a perfect predictor. For this data set we note the extreme example in the top left quadrant of a person with a large 1-5 span (>9 inches) but with a height of only 63 inches (160 cm). And from the bottom right quadrant we also note the many tall people with relatively small hands, often smaller than much shorter people. As discussed in section 7.2, it is quite common to hear people wrongly concluding that because a person is small that they must have a small hand span (and conversely).

4.6 Comparison with Adult Pianist database

The results of the Business Student database analysis can now be compared with that of the Adult Pianist database described in section 3.0. Table 25 (below) presents a selection of means and standard deviations for various sub-groups. Relevant p-values from two-tailed hypothesis tests are included for comparisons between the two databases. A p-value of 0.05 is the normal benchmark used to indicate a significant difference between arithmetic means, hence p-values below 0.05 indicate statistical significance at the 5% level. Values between 0.05 and 0.1 indicate significance at the 10% level. Differences in

the 2-5 spans between the Adult Pianists and the Business Students are less likely to be significant (indicated by high p-values) than differences in 1-5 spans (indicated by low p-values).

Note that the Business Students sample comprises a much higher proportion of males and also a higher proportion of Asians than the Adult Pianists sample.

Table 25: Comparison between hand spans of Adult Pianists and Business Students

		ADULT PIANIST DATABASE				BUSINESS STUDENT DATABASE					Test – diff. between means
		Arithmetic mean		Standard deviation			Arithmetic mean		Standard deviation		P value
	Sample	Inches	Cm	Inches	Cm	Sample	Inches	Cm	Inches	Cm	
All respondents 1-5 span*	473	8.2	21.0	0.71	1.81	216	8.0	20.3	0.72	1.82	0.0000
All respondents 2-5 span*	473	6.4	16.2	0.58	1.47	210	6.4	16.1	0.68	1.72	0.4371
Males 1-5 span	159	8.9	22.6	0.56	1.43	123	8.3	21.2	0.62	1.57	0.0000
Females 1-5 span	314	7.9	20.1	0.53	1.35	93	7.6	19.2	0.60	1.52	0.0000
Males 2-5 span	159	6.7	17.0	0.55	1.40	119	6.6	16.6	0.65	1.65	0.2761
Females 2-5 span	314	6.2	15.7	0.51	1.30	91	6.1	15.5	0.63	1.59	0.2209
Caucasian males 1-5 span	116	9.0	22.8	0.60	1.52	42	8.8	22.3	0.46	1.39	0.0637
Asian males 1-5 span	37	8.7	22.0	0.38	0.97	79	8.1	20.5	0.50	1.26	0.0000
Caucasian males 2-5 span	116	6.7	17.0	0.58	1.47	42	6.6	16.9	0.64	1.63	0.6341
Asian males 2-5 span	37	6.7	17.1	0.45	1.15	75	6.5	16.5	0.65	1.65	0.0427
Caucasian females 1-5 span	216	8.0	20.2	0.54	1.38	30	7.7	19.6	0.58	1.47	0.0278
Asian females 1-5 span	87	7.8	19.8	0.45	1.15	56	7.4	18.9	0.55	1.39	0.0000
Caucasian females 2-5 span	216	6.2	15.6	0.51	1.30	30	6.1	15.6	0.68	1.72	0.7055
Asian females 2-5 span	87	6.2	15.8	0.48	1.22	54	6.0	15.2	0.55	1.39	0.0132
'International' group 1-5 span	12	9.5	23.9	0.52	1.32		NA	NA	NA	NA	
'National' group 1-5 span	51	8.5	21.6	0.57	1.45		NA	NA	NA	NA	
'Regional/Amateur' 1-5 span	410	8.2	20.8	0.70	1.77		NA	NA	NA	NA	
'International' group 2-5 span	12	7.0	17.7	0.47	1.20		NA	NA	NA	NA	
'National' group 2-5 span	51	6.5	16.5	0.59	1.50		NA	NA	NA	NA	
'Regional/Amateur' 2-5 span	410	6.3	16.1	0.57	1.45		NA	NA	NA	NA	

*Note the different gender and ethnic mixes between the two groups. (NA = not applicable.)

Table 26 presents the mean RH 1-5 spans from all sample groups ranked in order, from largest to smallest.

Table 26: Adult pianists and Business students – Ranking of mean RH 1-5 spans		
Sample group	Inches	Centimetres
ADB – All Internationals 1-5 span	9.5	24.0
ADB - Caucasian males 1-5 span	9.0	22.8
ADB - Males 1-5 span	8.9	22.6
SDB - Caucasian males 1-5 span	8.8	22.3
ADB - Asian males 1-5 span	8.7	22.0
ADB – All Nationals 1-5 span	8.5	21.6
SDB - Males 1-5 span	8.3	21.2
ADB - All adults 1-5 span	8.2	21.0
ADB – All Regional/Amateurs 1-5	8.2	20.8
SDB - Asian males 1-5 span	8.1	20.5
SDB - All adults 1-5 span	8.0	20.3
ADB - Caucasian females 1-5 span	8.0	20.2
ADB - Females 1-5 span	7.9	20.1
ADB - Asian females 1-5 span	7.8	19.8
SDB - Caucasian females 1-5 span	7.7	19.6
SDB - Females 1-5 span	7.6	19.2
SDB - Asian females 1-5 span	7.4	18.9

ADB=Adult Pianist database SDB=Business Student database

Major points to note from Tables 25 and 26 are:

- The group with the biggest span is the internationally acclaimed pianists, followed by male Caucasians from the Adult Pianist database.
- The group with the smallest hands were Asian females from the Business Student database.
- Those in the Business Student database had lower means than their counterparts in the Adult Pianist database. This could partly be due to measurement problems where the students were not made to stretch as much, combined with how they recorded their own results. However it could also mean that pianists with larger hands tend to continue playing and reach a higher level.
- For the Adult Pianists, Caucasian males have an advantage of about 1.2 inches (3 cm) on average over Asian females. For the Business Students, this difference is even greater with Caucasian males having a 1.4 inch (3.6 cm) advantage over Asian females.
- The large difference in means (0.7 inches, 1.8 cm) between Caucasian and Asian males in the Business Student database is unlikely to reflect measurement issues only (see discussion in section 6.5).

For 2-5 spans for each gender, the differences between ethnic groups are relatively small or negligible.

The reasons why the mean hand spans of pianists might exceed those of non-pianists and the general adult population are discussed further in section 6.5. The two main possible reasons discussed there are: (1) the long term effect of playing the instrument and/or stretching exercises, and (2) those with larger hands finding the task relatively easier and achieving greater success than those with smaller hands, and hence being more likely to continue playing (i.e. self-selection). For the comparison between the two databases discussed here however, there is an additional factor which could also be relevant - the different data gathering processes. While pianists in the main Adult Pianist database were, in nearly all cases, measured directly by one of the authors, those in the Business Student database measured themselves under the direction of business statistics tutors. It is possible that the importance of stretching the hand to the maximum extent along the measuring device was not adequately communicated and/or some students did not listen intently or take the task seriously.

5.0 SURVEY OF YOUNG PIANISTS

The Young Pianist database with measurements from 49 children and teenagers (less than 18 years) was not analysed in great detail due to the small sample size and the non-representative make-up of ages, gender and ethnic background. There is also the added obvious complication that their hands were, in most cases, still growing, and growth rates will vary greatly among those of similar age.

Table 27 (Appendix 4) shows the students classified in three-year age groups broken down by RH 1-5 span. Their actual ages ranged from 6 to 17 years. The 1-5 spans ranged from 5.8 inches (14.7 cm) to 9.2 inches (23.4 cm). The youngest, a 6 year-old girl, had the smallest span while the biggest span belonged to a 15 year-old boy.

The table clearly shows the predictable pattern that older children tend to have bigger hands. This is illustrated graphically in Figure 18.

Figure 18: Young pianists – RH 1-5 span by age and gender

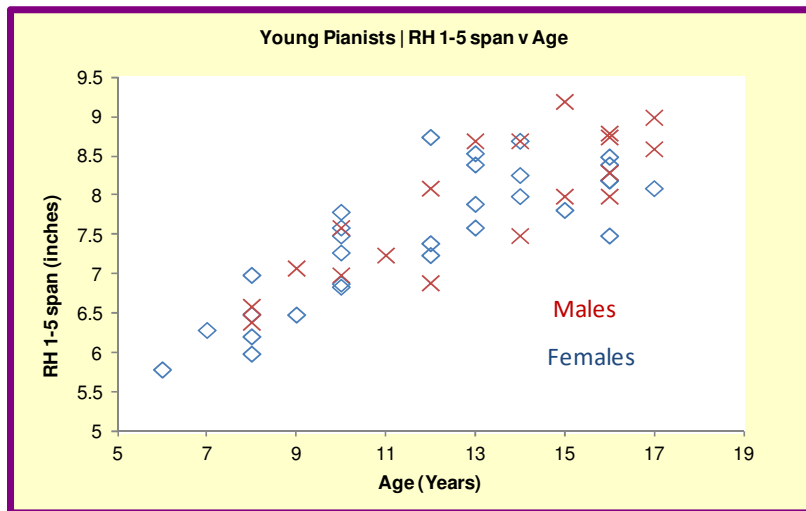
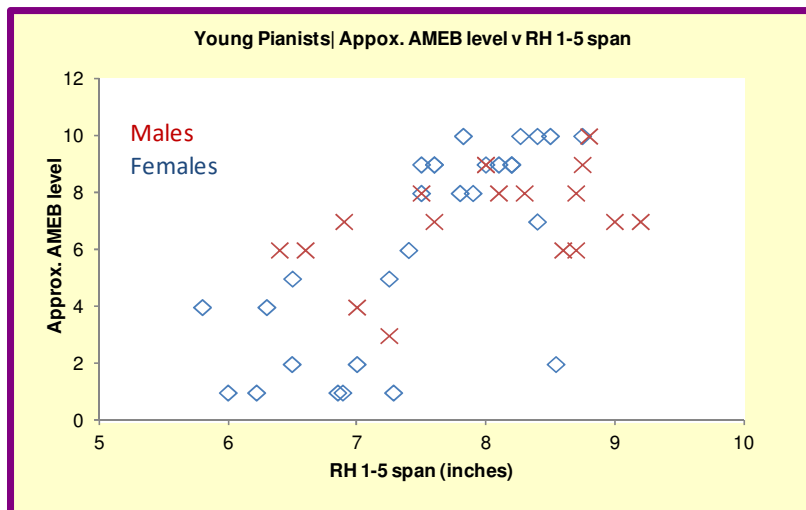


Figure 19 shows RH 1-5 spans versus AMEB⁷ level.

Figure 19: Young pianists – RH 1-5 span by AMEB level and gender



NB Level 9 corresponds to AMUS and level 10 corresponds to LMUS.

Further analysis of the Young Pianist database shows that some students reach a high level of study while still young and with their hands still growing. For example, some students in the database had achieved AMUS level (level 9 in Figure 19) while less than 15 years old (the youngest being 10) with 1-5 spans considerably less than 8 inches (20.3 cm). The potential for injury among piano students who reach a high level at a young age, but who must use a piano keyboard not designed for their hands, is an issue worthy of further attention. (Refer to section 7.1.2.)

⁷ AMUS=Associate diploma; LMUS-Licentiate diploma
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It is worth noting that 10 children, aged from 6 to 13 years, had 1-5 spans between 6 and 7 inches (15.2 and 17.8 cm). There were 10 adult women pianists in the Adult Pianist database and 13 business students in the Business Student database with spans in that range. Hence, the smallest adult female hands appear to be similar to those of many children.

6.0 COMPARISON WITH OTHER DATA SETS ON HAND SIZE

6.1 Pianists' hand spans and gender differences

As mentioned in section 1.1, Wagner's survey and analysis (1984, 1988) is the most comprehensive of any published relating to pianists. The majority of his sample of what he called 'professional' pianists were teachers or students specialising in piano at the Musikhochschule in Hannover, Germany. The school had an international reputation, with Wagner's subjects drawn from 28 countries.

As described in section 1.1, Wagner measured many hand size dimensions and characteristics, including 1-5 and 2-5 spans for both hands and summarised the results with key statistical measures. (He does not provide summary statistics for 2-5:1-5 ratios.)

A difference between the measuring processes used by Wagner and that used in the authors' study needs to be noted. Wagner measured active 1-5 spans from the middle of the finger tips, while the authors' study measured from outside edges of the finger or thumb, consistent with Steinbuhler (2004) and other recent epidemiological and clinical studies. Everything else being equal, Wagner's measurement process should produce results very close to the authors' for the 1-5 spans, however, his results for the 2-5 spans would be slightly smaller than in the authors' and other studies. This difference for the 2-5 span is considered to be of the order of 0.2 inches (0.5 cm).

David Steinbuhler collected his data at the US Music Teachers National Association (MTNA) 2004 National Conference, where attendees were invited to have their active 1-5 hand spans measured (for either their left or right hand). Of the 160 who participated, 90 were adult females, 66 were adult males and four were students not fully grown. The distribution of their active 1-5 hand spans is shown in the chart on the Steinbuhler website.⁸ The difference in hand spans between genders is obvious from the chart. Summary statistics from Steinbuhler's data (excluding the four young students) were derived previously by the authors (Boyle & Boyle, 2009).

Table 28 compares summary statistics for 1-5 spans for the Steinbuhler (2004), Wagner (1988), and the authors' Adult Pianist data.

⁸ www.steinbuhler.com/html/our_research.html
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Table 28: Comparison of pianist 1-5 span data – inches (centimetres)

	Males			Females		
	Steinbuhler (Mix of R and L hands)	Wagner (RH)	Boyle et al. (RH)	Steinbuhler (Mix of R and L hands)	Wagner (RH)	Boyle et al. (RH)
Sample size	66	111	159	90	105	314
Minimum	7.7 (19.6)	7.91 (20.1)	7.8 (19.7)	7.0 (17.8)	7.01 (17.8)	6.4 (16.3)
Maximum	10.2 (25.9)	10.24 (26.0)	10.8 (27.4)	8.9 (22.6)	9.33 (23.7)	9.5 (24.1)
Arithmetic mean	8.9 (22.6)	8.93 (22.7)	8.9 (22.6)	7.9 (20.1)	8.17 (20.7)	7.9 (20.1)
Median	8.9 (22.6)	8.86 (22.5)	8.9 (22.6)	7.9 (20.1)	8.11 (20.6)	7.9 (20.1)
First Quartile	8.5 (21.6)	8.62 (21.9)	8.5 (21.6)	7.5 (19.1)	7.83 (19.9)	7.6 (19.2)
Third Quartile	9.3 (23.6)	9.21 (23.4)	9.2 (23.4)	8.2 (20.8)	8.50 (21.6)	8.3 (21.0)
Range	2.5 (6.4)	2.32 (5.9)	3.0 (7.7)	1.9 (4.8)	2.32 (5.9)	3.1 (7.9)
Inter Quartile	0.8 (2.0)	0.59 (1.5)	0.7 (1.8)	0.7 (1.8)	0.67 (1.7)	0.7 (1.8)
Standard deviation	0.56 (1.42)	0.45 (1.14)	0.56 (1.43)	0.47 (1.19)	0.45 (1.14)	0.53 (1.35)

The major points from this comparison are:

- For males, the three sets of results are very similar for key summary measures, in particular, the mean, median and quartile values.
- For females, the Steinbuhler and Boyle results are very similar for key summary measures, with the Wagner results slightly higher. (The authors believe that the Steinbuhler and Boyle data are more representative of adult female pianists – see discussion below.)
- No females measured by Steinbuhler had hand spans of 9 inches or above.
- The range of values, for both males and females, were greatest for the authors' survey, possibly a reflection of the larger sample size.

The authors believe that the higher female measures for Wagner's data are explainable by the fact that they were a select group of elite female students and therefore likely to have bigger hands, combined with only 15% of his female students being Asian. Further support for this contention is that females with a National or International level of

acclaim in the authors' study have a mean 1-5 span of 8.2 inches, very close to Wagner's mean of 8.17 inches.

Table 29 compares Wagner's 2-5 data with the authors' results. Note that Steinbuhler did not collect 2-5 data while Wagner did not measure 2-5 spans of all his pianists.

Table 29: Comparison of pianist RH 2-5 span data – inches (centimetres)

	Males		Females	
	Wagner	Boyle et al.	Wagner	Boyle et al.
Sample size	44	159	60	314
Minimum	5.51 (14.0)	5.0 (12.7)	5.20 (13.2)	4.7 (11.9)
Maximum	7.52 (19.1)	8.6 (21.9)	7.12 (18.1)	7.7 (19.5)
Arithmetic mean	6.46 (16.4)	6.7 (17.0)	6.18 (15.7)	6.2 (15.7)
Median	6.42 (16.3)	6.8 (17.1)	6.18 (15.7)	6.2 (15.7)
First Quartile	6.10 (15.5)	6.3 (16.0)	5.80 (14.7)	5.9 (15.0)
Third Quartile	6.88 (17.5)	7.0 (17.8)	6.68 (17.0)	6.5 (16.5)
Range	2.01 (5.1)	3.6 (9.2)	1.93 (4.9)	3.0 (7.6)
Inter Quartile Range	0.78 (2.0)	0.7 (1.8)	0.88 (2.2)	0.6 (1.5)
Standard deviation	0.50 (1.27)	0.55 (1.40)	0.50 (1.27)	0.51 (1.30)

Key points to note are:

- Mean and median values in the authors' study are slightly higher than Wagner's for males, for reasons given earlier relating to measurement procedures.
- For females, mean and median values are very similar in both studies, suggesting that the different measurement procedure has compensated for the larger hands of Wagner's females.
- The range of values in the authors' study is much greater than the ranges found by Wagner both for males and for females (possibly due to the authors' larger sample).

6.2 Pianists' hand spans and level of acclaim

In an earlier study, Wagner (1984) selected two 'extreme' groups of male pianists from his database in order to compare their hand size characteristics:

- 'Successful Performers' – 26 well-known soloists and winners of international competitions.
- 'Problem Cases' – 10 pianists who had struggled with technical problems over a long period of time, such as lack of speed, manual dexterity or timing, and/or those with injury problems.

While he found that there were no significant differences in hand shape measures (e.g. length and breadth of hands) between the two groups, all active hand span measures

(involving all possible combinations of fingers) for the Successful Performers were statistically significantly larger. They had a median 1-5 span of 9.2 inches (23.4 cm) compared with 8.7 inches (22 cm) for the Problem Cases group (results for the arithmetic mean were not provided).

For the 2-5 span comparisons (based on fewer measurements), the difference was 6.9 inches (17.5 cm) compared with 6.1 inches (15.5 cm), again significant statistically.

While not directly comparable with the three 'levels of acclaim' defined by the authors, Wagner's results support the authors' findings that the most successful and acclaimed pianists tend to have significantly bigger hand spans (sections 3.5 – 3.6).

6.3 *Left-right hand differences*

Wagner (1988) found very slight, but statistically significant, differences in some of his active hand span measures in favour of the left hand. The data in the authors' study (discussed above in 3.8) also show slight differences in favour of the left hand but they were not significant statistically. From a practical point of view, the differences in both cases are negligible.

Kloeppel (2000) addressed the question of increased spans due to playing particular instruments by measuring spans between fingers (excluding thumbs) and also finger lengths for cellists, guitarists and a control group. Consistent with a common belief that these particular musicians develop greater spans as a result of playing these instruments over many years, she found slightly greater spreadability of the left hand than the right hand, including the 2-5 span, among cellists compared with the control group. The same was true for guitarists, although the 2-5 span was not measured for them given it was not relevant to their playing. The greater spreadability was statistically significant for cellists but not for guitarists. The slightly longer index finger in cellists (less than 1 mm) was attributed to the development of calluses. She found no relationships with age of starting to learn the cello. She concluded that although the changes over time in finger spans were statistically significant in the case of cellists, they were negligible in any practical sense (2-3 mm at most for the 2-5 span).

A recent Australian study (Driscoll & Ackermann, 2012) included left and right 1-5 hand span measurements in an anthropometric study of 408 professional orchestral musicians in Australia. They found the left hand span to be on average 0.2 inches (0.5 cm) larger than the right, both for males and females. They also found significant differences between the left (but not right) hand spans among different instrument groups, with lower string players (cello and double bass) having the largest left hand spans (taking gender differences into account). Left-right 1-5 span differences for lower string players were 0.3 inches (0.8 cm) for males and 0.2 inches (0.6 cm) for females.

6.4 *Ethnic differences within the general population*

It is often stated that people of Asian ethnicity have smaller hands than those of Caucasian origin (e.g. Sakai, 1992, 2008, Furuya et al., 2006). Some comparative hand anthropometry data has been published, e.g. Saengchaiya & Bunternghit (2004), Nag, Nag & Desai (2003) and Mandahawi et al. (2008), the results of which clearly show that people of Asian descent have smaller hands than Caucasians.

Results of the study by Nag et al. indicate that the hands of Indian women are significantly smaller than those of British, American and West Indian women – particularly in terms of hand width. That study does include hand span data; the active 1-5 span of the sample of Indian women was only 6.8 inches (173 mm) and the active 2-5 span was 5.4 inches (137 mm).

There may be significant differences among different Asian groups. There is anecdotal evidence that people from Korea and Northern China tend to be bigger (and have larger hands) than those from southern China, Southeast Asia and Japan.

As discussed in 3.3, the authors' study found the 1-5 spans of Caucasian pianists were statistically significantly larger than for Asian pianists. But 2-5 spans were found to be comparable for both ethnic groups, hence the 2-5:1-5 ratio is greater among Asians. The Business Student survey (section 4.3) also showed a similar ethnic difference among a general population of students.

The authors' findings that Asian pianists have smaller 1-5 hand spans than Caucasian pianists is consistent with findings from a wide range of surveys which indicate that Asians have smaller hands overall.

6.5 *Comparison of pianists with non-pianists*

How do pianists' hands compare to the population at large?

Much of the published anthropometrical data relating to human hands has not been based on random samples of the adult population. Examples of surveys of particular groups include measurements from armed forces personnel in the USA: e.g. Garrett (1968, 1971), Greiner (1991), Donelson and Gordon (1996) and from industrial workers in various countries: e.g. Nag, Nag & Desai (2003) and Saengchaiya & Bunternghit (2004). For Caucasian males generally, non-pianists tended to have broader hands than pianists. Matzdorff (1968) and Garrett (1968) measured active hand spans thus allowing direct comparison with findings from the authors' survey and those by Steinbuhler and Wagner.

Wagner (1988, p.117) notes that, based on studies prior to that time, musicians tend to have greater finger spans than non-musicians. Of particular interest is Matzdorff's

(1968) study which surveyed non-musicians in Germany. She measured 1-2, 1-3 and 1-5 active spans of 373 men and 396 women of different ages. They were described as middle class, and were all in the workforce employed in a variety of jobs. Wagner compared her results with his own data and found that his pianists (both men and women) had significantly higher mean values for the 1-5 span, and that the female pianists had a significantly greater 1-3 span. There was no significant difference in 1-2 spans. He also found the variability of spans to be lower among Matzdorff's non-musicians.

In his specific study of male air force pilots (1968), Garrett measured active hand spans – including both 1-5 and 2-5 spans. His mean 1-5 span was 8.5 inches (21.6 cm) and his mean 2-5 span was 6.4 inches (16.3 cm). Table 30 summarises these findings. As it is assumed most respondents in the Matzdorff and Garrett studies would have been Caucasian (as in Wagner's sample), for comparative purposes Table 30 includes the means with those obtained for Caucasians in the authors' Adult Pianist and Business Student surveys.

Table 30: Comparison of hands spans of pianists with other groups					
	Total sample size (n)	Mean male 1-5 span	Mean female 1-5 span	Mean male 2-5 span	Mean female 2-5 span
Boyle et al. – All Adult Pianists	473	8.9 (22.6)	7.9 (20.1)	6.7 (17.0)	6.2 (15.7)
Boyle et al. – Adult Pianists (Caucasian sub-group)	332	9.0 (22.8)	8.0 (20.2)	6.7 (17.0)	6.2 (15.6)
Wagner 1988 (pianists)	214 (1-5) 104 (2-5)	8.93 (22.7)	8.17 (20.7)	6.5 (16.4)	-
Steinbuhler 2004 (pianists)	156	8.9 (22.6)	7.9 (20.1)	-	-
Driscoll & Ackermann 2012 (orchestral musicians)	408	LH:8.9 (22.7) RH:8.7 (22.2)	LH: 8.1 (20.5) RH: 7.9 (20.0)		
Boyle et al. – All Business Students	216 (1-5) 210 (2-5)	8.3 (21.2)	7.6 (19.2)	6.6 (16.6)	6.1 (15.5)
Boyle et al. – Business Students (Caucasian sub-group)	72	8.8 (22.3)	7.7 (19.6)	6.6 (16.8)	6.1 (15.5)
Garrett 1968 (US air force pilots)	27	8.5 (21.6)	-	6.4 (16.3)	-
Matzdorff 1968 (German adults)	769	8.5 (21.7)	7.7 (19.5)	-	-

These results support Wagner's earlier finding that pianists tend to have larger hand spans than non-pianists. Thus, note that the first four rows relating to surveys of pianists show higher arithmetic means for 1-5 spans for both males and females than the last four rows which are surveys of non-pianists. For the orchestral musicians (nearly all Caucasian) in the fifth row of Table 30, male left hand 1-5 spans are similar to the pianist groups and their right hand spans are 0.2 inches less while for females, their right hand 1-5 spans are similar to the pianist groups but left hand spans are 0.2 inches greater.

The question is, would one expect pianists as a group to have different hand spans to the 'general' adult population or to specific sub-groups of non-pianists, with everything else (such as ethnicity and socio-economic background) being equal?

One factor that might explain some of the difference between the Boyle, Steinbuhler and Driscoll & Ackermann results compared with earlier studies is the documented increase in the size of humans over time due to improved childhood nutrition.⁹ This growth in stature in wealthy countries is now believed to have levelled off. However, an increase in *mean* hand span does not negate the significant *variability* in hand spans (in terms of *range* and *standard deviation*). It will be argued in section 8 that a significant proportion of *today's* pianists have hands which are 'too small' for the current standard keyboard.

A further factor that could partially explain the significantly lower spans of Matzdorff's workers compared with Wagner's pianists is the age mix of the sample groups; it is likely that Matzdorff included a larger proportion of middle-aged adults compared with Wagner. Anecdotal evidence suggests that hand spans contract somewhat with age.

Several authors, including Wagner (1984), Ortmann (1929) and Kloeppel (2000) have found no evidence, nor scientific basis to support the contention that hand spans increase significantly over time due to playing a musical instrument and/or stretching exercises. Although Driscoll & Ackermann (2012) suggested that the significantly greater left hand 1-5 spans among lower string players would most likely result from the stretching of ligaments, muscles and tendons from many years of playing those instruments, the magnitude of the average difference (0.2 inches) is still relatively small. The lack of evidence of any significant left-right span differences among cello players in the authors' study could be attributed to the cello players not being professional or even regular players, and/or their piano playing having resulted in a small increase in the spans of both hands to the maximum extent possible.

It is certainly plausible that those with 'small hands' are more likely to give up playing the piano at a relatively early age, while those with favourable hand spans find piano

⁹ www.scientificamerican.com/article/why-are-we-getting-taller/
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playing comfortable and enjoyable, are more likely to achieve some success and are therefore more encouraged to continue. This pattern of self-selection is evident in many sports. The results in Table 30 suggest that self-selection does play a role in at least partly explaining the smaller spans of non-musicians.

A further issue relevant to Caucasian males is the anecdotal evidence that some with particularly thick fingers cannot play comfortably between the black keys on the conventional keyboard. While this problem may well discourage those men from continuing to play, it is not believed to be an issue that affects a significant proportion of males¹⁰ but further research on this issue is needed.

Finally, everything else being equal, it would be expected that females, with their generally smaller hands, would be more likely than males to discontinue piano studies to an advanced level. However, the fact that females predominate among adult pianists may be explainable by other factors: perhaps they simply enjoy the piano more and/or are more interested in pursuing a teaching career or perhaps are even more ardent than men about a performance career. For males, the significant difference in 1-5 spans among the business students (largely reflecting the much smaller spans among the Asian students) compared with the adult male pianists suggests that the drop-out rate for males with relatively small hands (even though they may have hands bigger than most females) could be even higher than for females. Lack of career opportunities other than teaching may be an important factor influencing their decisions.

Clearly, much of this assessment is speculative and further research comparing pianists with non-pianists is necessary. However, in summing up these comparisons, the authors believe that their data and the earlier findings of others indicate that adult pianists tend to have bigger hand spans than the population at large. *Certainly, the authors believe there is no evidence suggesting that pianists have smaller hand spans than the population at large.*

Before applying all findings as presented so far in this paper, the question of 'what is a small hand?' needs to be addressed.

7.0 WHAT IS A 'SMALL HAND' FOR A PIANIST?

The discussion to date has clearly shown that there is significant variation in adult pianists' hand spans. While the 473 pianists in the Adult Pianist data base had a mean 1-5 span of 8.2 inches (21.0 cm), the smallest hand span in the group was just 6.4 inches (16.3 cm) while the largest was 10.8 inches (27.4 cm). This difference between the

¹⁰ The authors conducted a brief 'desk-top' investigation by comparing anthropometrical summary data on male finger widths with the widths of the gaps between the black keys on the conventional keyboard.

smallest and largest of 4.4 inches (11.2 cm) is close to the width of five white keys on the standard piano keyboard.

Clearly those with small hands will have different piano playing experiences to those with large hands and to those who are in the middle range. Many pianists who have hand spans in the middle range consider their hands too small for some advanced repertoire.

In order to reach a conclusion about what hand span is 'too small' *in relation to the current piano keyboard from an ergonomic perspective*, the next section (7.1) presents evidence from different fields to help shed light on the relationship between a pianist's hand span and their choice and performance of classical piano repertoire. In the section following (7.2), an attempt is made to quantify the concepts 'small hand' and 'large hand'. Using these definitions and the data presented earlier in this paper, the proportions of pianists affected are estimated in section 8.

7.1 The impact of 'small hands' on a pianist's health, success and enjoyment – the evidence

While not all classical pianists aspire to be performing artists, it is assumed that pianists wish to gain maximum possible enjoyment from playing and maximum possible return from their hours of study and practice. This would mean having access to a wide choice of repertoire, avoiding pain and injury, and not having constant technical challenges preventing full musical expression despite long hours of practice and good technique.

However every pianist today – whether they have small, large or middle-sized hands – is effectively limited to the choice of just one sized instrument. Clearly some will cope better than others: some find their hands are the right size to sit comfortably over the notes they need to play while others are severely handicapped due to a mismatch between the piano keyboard and their hand size for much of the repertoire they attempt. The most obvious example to an observer is when a pianist finds it physically impossible to reach the notes printed on the score, and alternative approaches such as 'rolling' chords are impracticable or musically inappropriate. But the inability to play notes as written represents the 'tip of the iceberg'; many of the technical challenges relating to hand span issues are not at all obvious to observers, and are often not appreciated by those with larger hands – who often have quite large hands by the time they are attempting challenging repertoire.

The fact that the modern piano keyboard was standardised over a century ago to a size that is 'large' in a historical context, based on the needs of certain European male virtuosos (Parakilas et.al., 1999; summarised by Booker & Boyle, 2011) suggests that,

purely because males tend to have significantly larger hands, the current keyboard is likely to be more suited to males than females. However, in Section 8, we also show that there is a significant proportion of males for whom the keyboard is too large, not to mention young pianists.

'The one-size-fits-all approach has prevailed in the piano-keyboard world for nearly 100 years. And, like other one-size-fits-all systems, the largest was fitted, not the average...Manufacturers were not about to make an instrument that would cause some European Caucasian male who sat before it to say. "These keys are too small." What developed was a standard keyboard too small for nobody, but too large for many.' (Christopher Donison, 2000, p.112).

What do the significant gender, ethnic and age differences in hand spans outlined in this paper mean in terms of playing classical piano repertoire? The following discussion supports the conclusion that the current keyboard is heavily skewed towards those with larger hands (mostly males) and that the rest, the great majority, are disadvantaged as a result. Further evidence presented also helps us to define a 'small hand' and a 'large hand' based on the hand span needed to perform a wide range of repertoire with comfort on the current keyboard. The common assumption that small-handed pianists somehow 'compensate' by adopting special techniques or tricks is not based on any scientific evidence; instead the evidence is that those with small hands are more likely to play at a lower standard and/or suffer more from pain and injury.

7.1.1 Underlying biomechanics and ergonomics

Since the pioneering work of Otto Ortmann early last century (1929), there have been relatively few investigations of piano playing from the perspective of ergonomics. Wristen (2000) has noted that small-handed pianists are at a higher risk of injury due to greater degrees of lateral wrist motion, flexion, extension and deviation than for larger-handed players. Large chords, octaves and arpeggios repeatedly force small hands and fingers out of an ergonomically neutral, relaxed position.

More recently, Farias et al. (2002) investigated hand shapes among pianists. They categorised hands in two classes: type A (wide hand) and type B (narrow hand). They concluded that a pianist with a type B hand is at a disadvantage due to the higher degree of wrist flexion needed to play large intervals than those with type A hands. Women were found to be more likely to have Type B hands.

Muscles and joints operating near the middle of their range rather than close to their limits will have a greater range of dynamic response. This means that those with large hands are more likely to be operating within the optimum range, while those with small

hands are more likely to be operating at the extremes and therefore less efficiently due to increased muscular tension. *'Fine dynamic gradation with the fingers in extreme stretches is physiologically impossible'* (Ortmann, 1929, p. 320).

Further, small hands are at a biomechanical disadvantage due to the need for increased hand movement (compared with larger hands) in getting to the keys. Ortmann notes the difficulty of controlling tonal intensity when there are rapid arm shifts, and that abrupt and angular movements are associated with accents. This increased hand movement also means loss of power and speed, as well as longer practice times just for the sake of accuracy (Boyle, 2013).

According to Ortmann, technical mastery can be linked to the accuracy with which a musical excerpt can be repeated, and this depends on a *minimum of movement and angular displacement*. He concluded that hand size affects entire technique, going far beyond whether or not certain notes can be physically played.

'The three factors of hand width, finger length and finger abduction, will explain a surprisingly large number of technical difficulties that are often wrongly attributed to defects of coordination or studentship'. (Ortmann, 1929, p. 313).

The impact of muscular fatigue on the central nervous system has been discussed by Wagner (1984, p.169). He states: *'Perhaps the most important effect of biomechanical disadvantage lies in the increased load on the central nervous system.'* He says that many musicians, despite the best training and preparation, never develop reliable technique; they suspect it is biomechanically based, and subconsciously realise that they have reached their limits in compensating for peripheral weaknesses. A pianist attempting extended passages where extreme stretches are required is likely to experience a progressive loss of power and control, with the additional mental effort required just to keep playing limiting their ability to focus on musicality.

These issues have been discussed in more detail by Boyle (2013).

'The ability to control the sounds at the piano, and this means producing lovely tone as well as finely shaped phrases with a wide range of dynamics, depends to a large extent on the ease with which we can play.' (Cooke, 1985, p. 16).

7.1.2 Pain and Injury

Performance-related piano and injury is a significant issue affecting many pianists. Several studies have found that female pianists run a significantly greater risk (approximately 50% higher) of pain and injury than males. One example, Farias et al (2002) found that, from a group of 222 pianists, 78% of females and 47% of males had suffered from RSI.

Given the gender difference of approximately one inch in the 1-5 span, this finding is not surprising given that peer-reviewed epidemiological and clinical research on pianists using the conventional keyboard has demonstrated that small hand spans are a significant risk factor for pain and injury. Children and teenagers have also been found to suffer from pain and injury related to piano playing (Ranelli et al., 2011).

More recently, with the availability of ESPKs (keyboards of different sizes), researchers in the US have been able to experiment with the same pianists trying different sized keyboards (for example, Wristen et al., 2006; Yoshimura & Chesky, 2009). These experiments have found a reduction in pain and tension when the pianists move to keyboards with narrower keys (in effect, reflecting the effect of getting 'larger hands') and hence, indirectly supporting the demonstrated statistical association between pain or injury and hand size. Keyboards used in these studies have included those with keys approximately 7/8 the conventional width (i.e. with a 5.5 inch (14.1 cm) octave) and those with keys approximately 15/16 the conventional width (i.e. with a 6.0 inch (15.2 cm) octave), in addition to the conventional keyboard which has a 6.5 inch (16.5 cm) octave).¹¹

Yoshimura & Chesky (2009) documented levels of pain and tension reported by 35 piano performance students associated with performing selected exercises (octave and chordal scales) and an excerpt from Debussy's *L'Isle Joyeuse*. The students performed the same tasks on the conventional (6.5 inch octave) keyboard as well as on a 6.0 inch octave keyboard. Students with hand spans above 22 cm (8.6 inches) experienced very little or no pain on either keyboard. Those with the smallest hand spans reported significantly higher levels of pain than those with larger spans. When the students (with spans less than 8.6 inches) moved from the conventional to the smaller keyboard, the level of pain was significantly reduced.

These results are consistent with the conclusions from clinical evidence reported by Sakai (2002) that pain and tension is often related to the playing of octaves and large chords, with small-handed pianists being more at risk.

This literature has been reviewed in more detail elsewhere (Boyle & Boyle, 2009; Boyle, 2013, and on www.smallpianokeyboards.org/pain-and-injury.html).

7.1.3 Performance quality

Very few studies have directly investigated aspects of the quality of a piano performance and considered how this might relate to hand span. Ortmann (1929) referred to this

¹¹ Refer: www.steinbuhler.com/html/our_research.html for definition of keyboard sizes.

issue while Wagner (1984, p.169) discussed the impact of muscular fatigue on the central nervous system.

One study (Lee, 1990) did not find hand ergonomic variables to be correlated with performance quality measures (dynamic and temporal evenness), however, the excerpts chosen (a simple five finger exercise and an arpeggio) did not involve wide stretches or leaps, thus this lack of association in relation to finger spans is perhaps not surprising. As mentioned below (section 7.1.5), female pianists appear to be far less affected, if at all, when performing Baroque or early Classical repertoire such as Bach and Mozart, as the musical figures tend to fall naturally 'under the hand' even for those with small hands.

While not specifically about hand size, a more recent study of pianists by Goebel & Palmer (2013) that used a three-dimensional motion capture system provides firm evidence for the link between the efficiency of wrist/hand/finger movements and performance quality (measured in terms of accuracy, precision of timing and control of tonal intensities).

The far greater movement of hands and wrists, and greater abduction of wrists and fingers of small-handed pianists can readily be observed and has been noted by various writers and mentioned in 7.1.1. For them, leaping and slanting strokes are more frequently required to reach notes than for large-handed pianists. This reduction in hand movement is obvious to a pianist transferring to a keyboard more compatible with their hand size. The study by Goebel & Palmer provides an example of how 21st century technology can be used to validate Ortmann's conclusions (see 7.1.1).

As there are many factors that contribute to a quality performance, isolating the hand span factor has been complicated by having just the one sized keyboard. This means that in order to draw conclusions about the impact of hand span on performance quality a statistical approach involving many pianists has been necessary. The availability of ESPKs in recent years greatly increases the scope for research as the same pianist can be tested on different sized keyboards to identify any change in performance quality.

7.1.4 The experiences of pianists using ESPKs

Although only a relatively small number of pianists around the world have experienced ESPKs, their reactions are remarkably consistent. It is important to remember that a pianist moving to a keyboard with narrower keys is, in effect, experiencing piano playing as if they had 'larger hands' on the conventional keyboard. This means that a female with an 'average' size span for their gender who moves from the 6.5 inch 'standard'

keyboard to a 5.5 inch keyboard¹² suddenly discovers what it means to have an 'average male' hand span on the conventional keyboard.

Pianists with small hands overwhelmingly report how much easier it is to play on a keyboard with narrower keys and, almost without exception, they adapt to the smaller size within hours. A key factor determining perceived ease and comfort is the extent to which a particular figure falls comfortably 'under the hand'.

A survey of pianists with spans of 8 inches (20.3 cm) or less who play or have played ESPKs was reported by Boyle (2012). All pianists reported significant advantages after transferring to a smaller keyboard (most played the DS5.5™) – not only did problems of pain and injury greatly diminish or disappear, but they found many advantages in musical and technical outcomes, including increased power and speed when needed, improved tonal and rhythmic control, greatly increased comfort with passages of octaves and large chords, improved legato lines, greater speed of learning, as well as increased accuracy and security. Unsurprisingly, they suddenly had access to an expanded repertoire and were no longer forced to make repertoire choices based mainly on their hand spans. Importantly, these pianists reported that they had a much greater ability to focus on the music itself, rather than being mentally pre-occupied in overcoming technical obstacles. These benefits are consistent with the benefits that would be expected, based on the discussion in sections above (sections 7.1.1, 7.1.2 and 7.1.3).

Many of these experiences are described by Dr Carol Leone (2003, 2015), Chair of Keyboard Studies at SMU Meadows School of the Arts, in Dallas, Texas. Leone has been teaching and performing on DS5.5™ and DS6.0™ keyboards for many years. In her most recent article (2015), she says:

'I often witness pianists place their hands for the first time on a keyboard that better suits their hand span. How often the pianist spontaneously bursts into tears. A lifetime of struggling with a seemingly insurmountable problem vanishes in the moment they realise, "It's not me that is the problem; it is the instrument!" Following on that, the joy of possibility overwhelms them.'

A (male) pianist who recently acquired a DS5.5™ keyboard sums up the feelings of many:-

'I have been playing on the piano and I am starting to grow quite accustomed to the keyboard. Inevitably, of course, my first few hours of practicing has been wrought with awkward mistakes, but also with astonishing revelations. It goes without saying that

¹² All ESPKs used by pianists surveyed were made by Steinbuhler & Co. The 5.5 inch octave keyboard (approximately 7/8 normal width) is labelled DS5.5™.

chords which were merely played in wishful daydreaming are quite comfortably reached. That is not even the tip of the iceberg, however, as I saw, as I progressed in my practicing, that the whole gamut of piano playing is infinitely easier with the right keyboard size. Chord leaps, trills, scales, arpeggios, ascending and descending octaves could be played with virtually no effort in comparison to what I had to labor through hitherto. Consider, how I had neglected an Etude of Chopin's, after seeing that no matter how much I practiced this one passage, it can only sound at best clumsy and amateurish. Indeed, when I played it on the smaller keyboard, I thought to myself, "Wow, I sound like Yefim Bronfman!"

One of the authors, who has a 1-5 span of only 7 inches (17.8 cm), has been playing a DS5.5™ keyboard for several years. On the conventional keyboard, she can only just play octaves at the extreme front edge of the white keys which requires an uncomfortable stretch and makes any rapid octave playing impossible. The DS5.5™ keyboard effectively enlarges her active 1-5 hand span to 8.2 inches (20.3 cm), slightly above that of an 'average' female using the conventional keyboard. Although this keyboard opens up a significant amount of repertoire that she is unable to play on the conventional keyboard, she notices that fast octave playing is still associated with some unavoidable tension which builds up in extended passages. She recently had the experience of playing an even smaller keyboard (5.1 inch octave, DS5.1™), which effectively enlarges her hand span to about 8.9 inches (22.6 cm) – an 'average male' span. She found that any tension and discomfort associated with such passages on this keyboard to be totally absent, in addition to the many other benefits reported by other pianists who move to a smaller (6.0 or 5.5 inch octave) keyboard.

There is anecdotal evidence that even pianists with 1-5 spans significantly above 8 inches also find significant benefits from playing ESPKs, including reduced tension and the ability to play 10ths which requires a 1-5 span of at least 8.5 inches on the conventional keyboard. In particular, from trials by many pianists playing keyboards of different sizes since the 1990s, David Steinbuhler (ESPK manufacturer) has defined keyboard 'zones' for different hand spans as summarised on the Steinbuhler website¹³. This indicates that those with 1-5 spans below about 8.2 inches are likely to prefer a DS5.5™ keyboard, while those with spans between about 8.2 and 8.8 inches are likely to prefer a DS6.0™ keyboard.

¹³ Refer to dot chart: www.steinbuhler.com/html/handsizepage.html.
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7.1.5 Piano competition results and discography

While females usually outnumber males studying piano performance in tertiary institutions, it is males who dominate the lists of prize winners in major international piano competitions and also the ranks of solo professional performers. A notable exception relates to piano competitions specifically focused on Mozart or Bach, where females dominate among prize-winners. In the nine major international competition results reviewed (excluding Bach and Mozart competitions), 97 males compared with 19 females have won first prize. The question of ethnic background of female prize-winners is also interesting. Of these 19 females, only three were of Asian ethnicity.¹⁴

The same pattern of gender difference is not so apparent when one looks at violin competition results, or indeed, from observing the gender mix today among string players in world class symphony orchestras and chamber groups. The violin is an instrument for which different sizes and variations in design are available and children normally have the benefit of starting on smaller instruments.

For the piano, major performing and recording artists over the last 100 years have overwhelmingly been male. Many of the best known female artists have been known mainly for excellence in Baroque and early Classical repertoire. The rarity of award-winning recordings by female pianists of *complete sets* of Romantic or later works (such as the Chopin or Liszt Etudes, Prokofiev sonatas, or even the Beethoven sonatas) may well reflect their need to be selective in their choice of repertoire.

In many careers, people reach their peak in terms of status and income in their 40s or 50s after two to three decades of commitment and women may be relatively disadvantaged as a result of taking time out for child-rearing responsibilities. Clearly, this would not be a significant factor affecting women succeeding in piano competitions, where contestants are in their late teens, 20s or early 30s at most. Sustaining a long term solo performing career, however, may be interrupted or affected to some extent by child-rearing. But a further consideration is that pianists with hands that are not quite large enough to play advanced Romantic and later repertoire without some tension being present may find that they are unable to sustain a performing career over decades. The known risk factors for pain and injury among pianists include not only hand size but also intensity of practice.

7.2 Defining 'small hands'

The previous section describes how 'small hands' have an impact on a pianist's health, success, performance quality and enjoyment, while the earlier sections reveal that there

¹⁴ www.smallpianokeyboards.org/piano-competitions.html
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is significant variability in human (and pianist) hand size. We now return to the question of the definition of a 'small hand' in relation to piano playing.

Many previous writers who have referred to 'small hands' have only given vague indications of what is 'large', 'average' or 'small', and have rarely considered gender or ethnic differences. Thus, the term is generally used loosely. Male pianists complaining about their 'small hands' may well have hands larger than those of the vast majority of females, but not as big as their acclaimed male counterparts; 'small hands for a male' would be a more appropriate description. Alicia de Larrocha is often assumed to have had 'small hands' because she was very short (less than 5 feet tall), but she said herself that she could reach a 10th in her heyday.¹⁵ The authors' regression and correlation analysis (section 4.5) of height versus 1-5 span indicates that a person's height may not always be a good guide to hand span. Also, hands that may appear small from casual observation (perhaps being thin and bony) may have a surprisingly large span.

In general, the term 'small hands' conveys the notion of relative disadvantage for classical piano playing, especially at advanced and elite levels. The findings of the authors' study indicate that females are most affected, as only a very small percentage of male pianists have hand spans less than the average female pianist. However, some males do have 'small hands' based on the authors' definition given below. And the authors found that those of Asian ethnicity tend to have hands somewhat smaller than those from Caucasian backgrounds.

What is perceived to be a 'small hand' for one person might seem to be a 'large hand' for someone else. While the term 'small hand' might be best applied in the context of what a pianist aspires to do, as discussed earlier it is assumed that any pianist would like to have access to a wide range of repertoire without hand span limitations dictating selection, to be able to overcome technical challenges and play to the best of their ability, to minimise the risk of pain and injury and to gain maximum possible enjoyment from playing.

7.2.1 Definitions by others

Kamolsiri (2002) defines small hands as those unable to reach a ninth and/or unable to play an octave comfortably. Wristen et al. (2006) defines small-handed pianists as those having an active 1-5 span of 8 inches (20 cm) or less. Farias et al. (2002) defines small hands as those that cannot reach a tenth. The survey of pianists using ESPKs (Boyle, 2012) only included pianists with active 1-5 spans of 8 inches and below, all of whom preferred the smaller keyboard over the conventional. And as discussed above, there is anecdotal evidence that pianists with spans of more than 8 inches also prefer playing

¹⁵ www.nytimes.com/1995/11/23/garden/at-home-with-alicia-de-larrocha-a-pianissimo-star.html

ESPKs. In the future, assuming ESPKs were to become widespread, a more accurate definition could be based on the hand size characteristics (including finger widths) of those who prefer to play on the narrower keys of an ESPK rather than on the conventional keyboard.

7.2.2 *Comfortable octave playing and the ability to play larger intervals*

What is meant by 'comfortable playing' in the case of octaves?

Octave playing is a fundamental requirement of the classical piano repertoire. Although a pianist with a 1-5 span even below 7 inches can just play an octave on the front edge of the keyboard, there is strong evidence (based on the discussion in 7.1.2 and 7.1.4) that tension is likely to be present for 1-5 spans below about 8.5 or 8.6 inches.

The authors reported previously on a calibration of 1-5 hand spans and maximum intervals playable, based on white key intervals (Boyle & Boyle, 2009). On this basis, they defined the following approximate threshold 1-5 spans whereby a pianist can *just* play (with considerable discomfort and not at speed) on the extreme outer edge of the white keys:

- Octave – 6.7 inches
- Ninth – 7.6 inches
- Tenth – 8.5 inches

Considering octave playing in particular, a span of about 7.6 inches is required to be able to move in from the outer edge of the white keys, but this generally does not allow the elimination of tension in rapid playing of octaves and octave-based chords. Tension is often associated with wrists being raised to avoid clipping adjoining white notes and to gain additional power. Based on the work of Yoshimura & Chesky (2009) discussed above, plus the personal experience of the authors (refer Boyle and Booker, 2011; Boyle, 2013) and anecdotal evidence from other pianists, it is believed that a span of around 8.5 inches is needed to totally eliminate tension in fast octave playing while bridging the hand comfortably over the black keys.

Other aspects of octave playing also need to be considered: the ability to play legato octaves (using 3rd and 4th fingers), ease with 'cross-over' octaves (right hand crossing over to the bass, left hand to treble), and ability to minimise forward and backward hand movement in fast chromatic octaves (such as in dotted rhythms found in polonaises). Pianists with spans of less than about 8.5 inches are likely to experience greater difficulty with these tasks.

With a hand span of 8.5 inches, a pianist can normally just play a tenth. A ninth becomes more comfortable, with the ability to move in from the outer edge of the keyboard. As piano repertoire does not normally contain extended fast passages involving ninths or tenths, the ability to eliminate tension when playing these larger intervals is not nearly as critical as it is for octaves.

Based on the above, one of the authors (Boyle, 2013) has previously supported the definition of a 'small hand' to be consistent with that of Farias et al. (2002), i.e. 1-5 spans of less than about 8.5 inches (21.6 cm). This is based on the presumption that most classical pianists aspire to play a wide range of repertoire from Beethoven and Schubert onward. The analysis of the hand span statistics described in this paper lends further weight to this definition, in particular, on the basis of the internationally acclaimed solo performers in the sample (who perform across a wide range of repertoire) all having spans considerably larger than 8.5 inches.

7.2.3 Second to fifth finger spans

Prior to this study, spans between the second and fifth fingers in relation to piano playing have not previously been considered by the authors. Clearly, this span (in addition to stretches between all other digits) is important for the playing of chords, arpeggios, broken chords and arpeggiated figures in general, and also for the ability to maintain an unbroken legato line.

For the purposes of this paper, a quick calibration was done involving several pianists with varying 2-5 spans. This suggests that a 2-5 span of around 6 inches (15.2 cm) is required to play relatively comfortable major (white key) sixths and just play a seventh. A span of at least 7 inches (17.8 cm) is required to be able to play a seventh comfortably. (As noted previously for 1-5 spans, a 7 inch span can just manage an octave on the edge of the keyboard.) Further more detailed work is needed in relation to 2-5 and other finger spans in the context of piano playing.

Advanced repertoire frequently includes chords (or broken chords) where a stretch of a seventh is required. The authors therefore consider that a 2-5 span of less than 6 inches should also be defined as a 'small hand' in relation to the current keyboard.

All pianists rated in the authors' study as international performers had 2-5 spans above 6.5¹⁶ inches, with most being close to 7 inches or higher.

¹⁶ Apart from the right hand 1-5 span of one pianist which was 6.2 inches.
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7.2.4 *Threshold spans defining 'small' versus 'large' hands*

The hand span zone boundaries defined later reflect the ability to *just* play certain intervals on the current standard keyboard. But of course piano playing is not only about performing fast passages of octaves and large chords and being able to play ninths and tenths. Many of the other difficulties faced by pianists with small hand spans, including the higher risk of pain and injury, have been touched on in section 7 and in other papers (Boyle, 2012; Boyle 2013). Taking all of the above into account, the authors believe that threshold values of 8.5 inches (21.6 cm) for the thumb to fifth finger span and 6.0 inches (15.2 cm) for the second to fifth finger span are reasonable.

8.0 HOW MANY PIANISTS HAVE 'SMALL HANDS'?

In section 7.2, we have defined 'small hands' in relation to playing the standard piano keyboard as being:

- those with an active thumb to fifth finger (1-5) span of less than 8.5 inches, or
- those with a second to fifth finger span (2-5) of less than 6.0 inches.

In order to estimate proportions of pianists with spans in these ranges, further analysis of the Adult Pianist database was undertaken. Given the closeness of these results to those of Wagner and Steinbuhler, the authors have used their Adult Pianist database for estimating proportions in the pianist population at large. For each of six sub-groups – all females, all males, male Caucasians, female Caucasians, male Asians, female Asians – the frequency distribution was analysed to see how closely the data resemble a normal distribution derived from the means and standard deviations from the authors' database. Methods used were visual inspection, quartile checks and 'goodness-of-fit' tests. On the basis of this analysis, the authors were satisfied that they could assume that each of the various population distributions followed normal distributions with corresponding arithmetic means and standard deviations derived from the databases. The proportions of pianists in each zone were then calculated from these theoretical normal distributions.

8.1 *Thumb to fifth finger (1-5) spans*

For 1-5 spans, four separate hand span 'zones' were defined using the minimum threshold values defined in section 7.2.2 for playing octaves, ninths and tenths, plus one higher threshold reflecting reasonably comfortable tenths. Zones A and B represent 'small hands' with zone A being 'very small'. Zones C and D represent 'large hands' with zone D being 'very large'. Tables 31, 32 and 33 give the proportions in each zone as well as cumulative values. Arithmetic means and standard deviations from the Adult Pianist database are also provided.

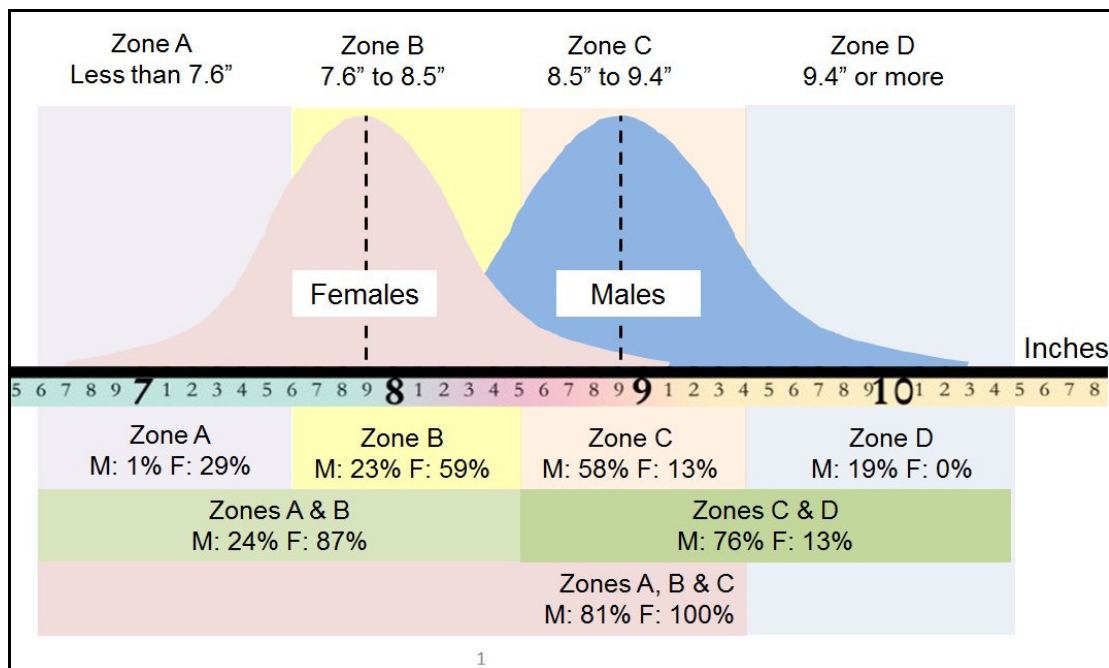
Table 31: All adult pianists – Proportions in each 1-5 span zone				
1-5 span zones	All Males		All Females	
	Cumulative	In the zone	Cumulative	In the zone
A: Less than 7.6"	1.0%	1.0%	28.6%	28.6%
B: 7.6" to < 8.5"	23.8%	22.7%	87.1%	58.6%
C: 8.5" to < 9.4"	81.4%	57.7%	99.8%	12.6%
D: 9.4" or more	100.0%	18.6%	100.0%	0.2%
Arithmetic Mean	8.9		7.9	
Standard Deviation	0.56		0.53	

Table 32: All adult Caucasian pianists – Proportions in each 1-5 span zone				
1-5 span zones	All Caucasian Males		All Caucasian Females	
	Cumulative	In the zone	Cumulative	In the zone
A: Less than 7.6"	1.0%	1.0%	22.9%	22.9%
B: 7.6" to < 8.5"	20.2%	19.3%	82.3%	59.3%
C: 8.5" to < 9.4"	74.8%	54.5%	99.5%	17.2%
D: 9.4" or more	100.0%	25.2%	100.0%	0.5%
Arithmetic Mean	9.0		8.0	
Standard Deviation	0.60		0.54	

Table 33: All adult Asian pianists – Proportions in each 1-5 span zone				
1-5 span zones	All Asian Males		All Asian Females	
	Cumulative	In the zone	Cumulative	In the zone
A: Less than 7.6"	0.2%	0.2%	32.8%	32.8%
B: 7.6" to < 8.5"	29.9%	29.7%	94.0%	61.2%
C: 8.5" to < 9.4"	96.7%	66.8%	100.0%	6.0%
D: 9.4" or more	100.0%	3.3%	100.0%	0.0%
Arithmetic Mean:	8.7		7.8	
Standard	0.38		0.45	

Figure 20 provides a visual representation of the data in Table 31 with the four zones (labelled A, B, C and D) overlaid on the estimated normal 1-5 span distributions for all adult pianists. The proportions in each zone (and cumulative values) are shown beneath.

Figure 20: Pianist 1-5 hand span 'zones'



The key results to note from these tables and graphs are:

- Approximately 24% of adult male pianists have hands that can be classed as small, based on 1-5 spans (i.e. within zones A or B).
- An estimated 87% of adult female pianists have hands that can be classed as small, based on 1-5 spans (i.e. within zones A or B).
- For Caucasian pianists alone, the respective proportions in these 'small hands' zones are slightly smaller but still contain over 20% of males and over 80% of females.
- For Asian pianists alone, approximately 30% of males and 94% of females have hands that can be classified as 'small' on the basis of 1-5 spans.
- Zone A, representing the most disadvantaged group with 'very small' spans, contains almost one quarter of Caucasian female pianists and nearly one third of Asian female pianists. Only a tiny proportion of males are in zone A.
- Virtually no females fall within the 'very large' group, zone D.
- Note that of the 12 internationally acclaimed pianists in the authors' database, six had 1-5 spans in zone D and the other six in zone C. Only one nationally acclaimed pianist had a 1-5 span within zone A. (Refer to the discussion about this pianist in section 3.6.)

8.2 Second to fifth finger (2-5) spans

Four zones have also been defined for 2-5 spans, based on the estimated minimum threshold values for playing sixths, sevenths and octaves. Zones E and F represent 'small hands' while zones G and H represent 'large hands'. Tables 34, 35 and 36 give the proportions in each zone as well as cumulative values. Arithmetic means and standard deviations from the Adult Pianist database are also provided.

2-5 span zones	All Males		All Females	
	Cumulative	In the zone	Cumulative	In the zone
E: Less than 5.0"	0.1%	0.1%	0.9%	0.9%
F: 5.0" to < 6.0"	10.2%	0.1%	34.7%	33.8%
G: 6.0" to <7.0"	70.7%	60.6%	94.2%	59.4%
H: 7.0" or more	100.0%	29.3%	100.0%	5.8%
Arithmetic Mean	6.7		6.2	
Standard Deviation	0.55		0.51	

2-5 span zones	All Caucasian Males		All Caucasian Females	
	Cumulative	In the zone	Cumulative	In the zone
E: Less than 5.0"	0.2%	0.2%	0.9%	0.9%
F: 5.0" to < 6.0"	11.4%	11.2%	34.7%	33.8%
G: 6.0" to <7.0"	69.8%	58.4%	94.2%	59.4%
H: 7.0" or more	100.0%	30.2%	100.0%	5.8%
Arithmetic Mean	6.7		6.2	
Standard Deviation	0.58		0.51	

2-5 span zones	All Asian Males		All Asian Females	
	Cumulative	In the zone	Cumulative	In the zone
E: Less than 5.0"	0.0%	0.0%	0.6%	0.6%
F: 5.0" to < 6.0"	6.0%	6.0%	33.8%	33.2%
G: 6.0" to <7.0"	74.8%	68.8%	95.2%	61.4%
H: 7.0" or more	100.0%	25.2%	100.0%	4.8%
Arithmetic Mean	6.7		6.2	
Standard Deviation	0.45		0.48	

The key results to note from these tables are:

- Just over one third of female pianists can be defined as having 'small hands' (zones E and F) on the basis of their 2-5 spans.
- About 10% of male pianists can be defined as having 'small hands' (zones E and F) on the basis of their 2-5 spans.

- It is estimated 60.6% of males have 2-5 spans between 6 and 7 inches (zone G) and that 59.4% of females are also in this range. However, there are approximately 0% of males and about 35% of females below 6 inches (zones E and F) with 29% of males and only 6% of females above 7 inches (zone H). As noted in the original analysis for 2-5 spans, ethnic differences for females are small, with similar proportions in each zone.
- However, the greater range of values for male Caucasians is clear with about 11% of Caucasian males falling in the 'small hands' zones E or F for 2-5 spans compared with only 6% of Asian males. But 30% of Caucasian males fall in zone H ('very large hands') compared with 25% of Asian males.
- Of the 12 internationally acclaimed pianists in the authors' database, seven had 1-5 spans in zone H and the other five in zone G – all above 6.5 inches.

8.3 Overall estimate of proportions of pianists with 'small hands'

An analysis of the authors' Adult Pianist database shows that, of those pianists with 2-5 spans of less than 6 inches, all except two (with spans only slightly below 6 inches anyway) are contained within the set of pianists with 1-5 spans less than 8.5 inches. Hence we have assumed that this inter-relationship would hold for the general population of pianists, i.e. the proportion of pianists with small 2-5 spans (<6 inches) but adequate 1-5 spans is insignificant and can be ignored for the purposes of an overall estimate. This means that an estimate of the proportion of pianists with 'small' hands for the conventional piano keyboard using the stated threshold 1-5 and 2-5 values can be based solely on 1-5 span limitations alone (i.e. proportions within zones A and B).

Table 37 summarises the results from Tables 31-33 using 1-5 spans to estimate the proportions of adult male and female pianists classified as having 'small' or 'large' hands.

Table 37: Proportions of adult pianists with 'small' or 'large' hands		
	'Small' hands: 1-5 spans less than 8.5"	'Large' hands: 1-5 spans 8.5" or more
All males*	23.8%	76.2%
All females*	87.1%	12.9%
Caucasian males	20.2%	79.8%
Caucasian females	82.3%	17.7%
Asian males	29.9%	70.1%
Asian females	94.0%	6.0%

*Based on the ethnic mix in this particular sample of Adult Pianists

We conclude that while approximately 20% of Caucasian male adult pianists have 'small' hands, the proportions for the other groups are significantly larger with 30% of Asian males, 82% of Caucasian females and 94% of Asian females having 'small' hands. These proportions are broadly consistent with the results of a survey (Son & Chesky, 2014) of university piano students (female to male ratio was 3:1) which found that 75% wished they had 'larger hands'.

These proportions may well underestimate the magnitude of the problem globally. Further speculation can only be done with extreme caution due to the lack of data about the gender, ethnic and age make-up of the piano playing population around the world. In the next section the authors suggest hypotheses for further research.

8.4 *What might be the magnitude of the 'small hands' problem?*

The authors believe that the results given in the previous section and earlier provide a conservative basis for hypotheses about the true proportions of *pianists* (by gender, ethnicity and age) who have 'small hands'. To better understand the total magnitude of the 'small hands problem', further research is needed to establish:-

- hand and finger spans of the population at large, including age, gender and ethnic splits
- the numbers of pianists globally according to age, gender and ethnic background
- more precise estimates of hand and finger spans of different ethnic groups as well as children and teenagers
- more precise hand and finger span thresholds (and including other characteristics, particularly finger width) applicable to piano keyboards of different sizes.

8.4.1 *The population at large*

The proportions given in Tables 31 to 37 apply to adult *pianists*; they do not necessarily reflect those who do not play the piano. However, the authors have made the observation in this paper that there is no reason to believe pianists have smaller hand spans than the population at large, and the evidence points to pianists having somewhat larger spans. A major reason for this difference is considered likely to be the result of self-selection.

Hypothesis: The proportions with 'small hands' in the adult population at large are greater than those shown in Tables 31 to 37.

Even if only 2% or 3% more, this represents a very large number of people.

8.4.2 Adult pianists allowing for different gender and ethnic mixes

The earlier tables showed that the proportion of adult males and female pianists (mostly living in Australia) with 'small hands' are estimated as 23.8% and 87.1% respectively. If the same numbers of males and females played the piano worldwide, then assuming the same ethnic make-up as in the Adult Pianist database, the average of these two values could be used. However, the authors believe that the number of adult female pianists significantly outweighs the number of male pianists, in which case a *weighted mean* should be used.

Note that the male/female split in the authors' Adult Pianist survey is about 2:1, i.e. twice as many females as males were surveyed. It should be noted that at piano pedagogy conferences and similar events organised mainly for teachers, the ratio of females to males present was far greater. (At the time of writing (2014), the Victorian Music Teachers Association's piano teacher database¹⁷ recorded 513 accredited teachers in Victoria, 85% of whom were female.) At these events, the authors made an effort to survey any men present to boost the male to female ratio. Therefore, it is possible that for adult pianists who still play regularly, the ratio of females to males could be somewhat greater than 2:1. Based on recent anecdotal evidence from university piano keyboard staff, females tend to comprise around 60-70% of undergraduate piano students. It may therefore be the case that a greater percentage of males who do study piano at tertiary level choose careers other than teaching, though of course some may continue to play regularly.

Hypothesis: The proportion of adult pianists with 'small hands' is at least (and possibly greater than) 66%.

The figure of 66% is derived by assuming a minimum ratio of two female adult pianists to every one male adult pianist and applying a weighting of 2:1 to the proportions given in Table 31, that is, 87.1% and 23.8%.

If the number of Asian adult pianists significantly outnumbers the number of Caucasians around the world, the estimate of 66% would be a significant understatement and the true figure globally could be as high as 80%.

8.4.3 Young pianists

For younger pianists, anecdotal evidence from several piano teachers suggests that:-

¹⁷ www.victorianmusicteachersassociation.org.au/

- For young children (under 12 years) learning the piano in Australia today, boys and girls are in roughly equal proportions.
- For teenagers in secondary school (12-17 years), there are more girls than boys still taking lessons.

Detailed analysis of the authors' Young Pianist database showed that all children surveyed under the age of 12 had 1-5 spans less than 8.5 inches and that of those aged 12 to under 18 years, the number with 1-5 spans less than 8.5 inches outweighed those with bigger hand spans by two to one.

Hypothesis: Given that most children start the piano at an early age, close to 100% of children will at some stage play on keyboards that are larger than ideal.

8.4.4 Definition of hand and finger span thresholds for piano keyboards of different sizes.

The threshold values for 1-5 and 2-5 spans separating 'small' from 'large' hands defined by the authors are judgements based on the available evidence to date and require further research. The authors believe that the true thresholds may well be somewhat higher, based on anecdotal evidence from pianists even with spans above 8.5 inches finding that they prefer keys that are somewhat narrower than those of the current standard keyboard, at least for some repertoire.

Hypothesis: The 1-5 span thresholds of 8.5 inches and 2-5 span threshold of 6 inches underestimate the proportion of pianists with 'small hands' in relation to the current standard keyboard.

9.0 CONCLUSION

Research from different fields indicates that, everything else being equal, pianists with smaller hands are disadvantaged on the current keyboard in several ways. Firstly, they are more likely to suffer from pain and injury. Secondly, technical challenges and learning times are increased and a significant amount of the piano repertoire is either physically impossible to play without significant modification of the score or is totally ruled out for them. Thirdly, the quality of their performances, especially for advanced level repertoire from the time of Beethoven and Schubert onwards, is likely to be compromised due to hand span limitations. Finally, enjoyment in performing, particularly in having the confidence to tackle repertoire previously reserved for 'big hands' and being free to focus on musicality rather than just 'getting the notes', is affected. These factors often preclude pianists from reaching elite performance standards across a wide range of repertoire.

The authors' survey of Adult Pianists has confirmed the results of previous surveys of pianists' hand spans. The one inch gender difference in thumb to fifth finger spans, representing slightly more than the width of one white key, is highly significant in relation to piano playing as it means being able to play (or not play) fast passages of octaves or large chords with comfort, speed and power, plus minimal pain or tension and reduced risk of injury. Those of Asian descent are disadvantaged compared with Caucasians in relation to their thumb to fifth finger spans, though not for their second and fifth finger spans.

Based on a comparison of the authors' Adult Pianist and Business Student survey results together with a review of earlier studies, it is considered most likely that pianists have larger hand spans than the population in general. However further research is desirable.

From earlier evidence and recent investigations by the authors, 'small hands' are defined in relation to both 1-5 and 2-5 spans, with the 1-5 span being the dominant factor given the threshold values chosen. Using statistical distributions based on the authors' hand span data, the proportions of pianists with 'small hands' in relation to the standard piano keyboard have been calculated. This equates to around 87% of adult female pianists and 24% of adult male pianists. Given the evidence that more women than men play the piano regularly, it is most likely that a majority of adult pianists overall are disadvantaged by the current keyboard.

The dominance of male over female prize-winners (generally by a ratio of three or four to one) in major international piano competitions – despite the greater numbers of women studying at advanced levels – has been discussed in 7.1.5. It is quite plausible that hand span limitations are the major reason for this gender disparity. Table 31 shows that 77% of male pianists versus only 13% of female pianists are within the 'desirable' zones of C and D, a ratio of nearly six to one.

Based on a range of evidence, supported by the authors' analysis of pianists who have reached a certain level of acclaim, it is believed that pianists with hand spans of around 8.5 inches or less would benefit significantly from keyboards with narrower keys (ESPKs). In particular, a keyboard with a 5.5 inch octave essentially removes the one inch advantage men have over women. This hand span threshold could even underestimate the number of pianists with hands that are too small for the current keyboard, given the anecdotal evidence that some pianists with spans above 8.5 inches prefer playing a 6.0 keyboard.

It appears to be an accident of history that we have just one piano keyboard today, and this keyboard is larger than most that were available prior to 1880 and is highly skewed towards large hands. Women generally outnumber men at advanced levels of piano

studies and are more likely to continue playing as adults, there is a growing interest in piano playing in China and other Asian countries, and children must also learn on a keyboard designed to suit large-handed males.

These conclusions point to a need to move away from the concept of the one 'standard' piano keyboard being seen as suitable for all pianists. The authors believe that in the future, there should be three 'standard' keyboard sizes: the current 'large' size (6.5 inch octave), a 'medium' size (6.0 inch octave) and the 'small' size with 5.5 inch octave which would suit the majority of women and children.

Clearly if keys are narrower, pianists can span a greater number of keys and there would be far fewer people with 'small hands' given the demands of the classical piano repertoire. Using the same means and standard deviations as in Table 31, Table 38 illustrates how access to three different keyboard sizes would even out the playing field. The second last row shows that on a 6.0 inch keyboard the proportion of females with 'small hands' drops from 87% to 46% while on a 5.5 inch keyboard only 11% of females are estimated to have 'small hands' with less than 1% being 'very small'.

Zone	6.5 inch octave		6.0 inch octave		5.5 inch octave	
	Males	Females	Males	Females	Males	Females
A: Very Small	1%	29%	0%	5%	0%	<1%
B: Small	23%	59%	3%	41%	0%	10%
C: Large	58%	13%	32%	47%	5%	47%
D: Very Large	19%	0%	65%	7%	94%	42%
'Small hands' (A+B)	24%	87%	3%	46%	0%	11%
'Large hands' (C+D)	76%	13%	97%	54%	100%	89%

*Based on the ethnic mix in this particular sample of adult pianists

When imagining a future world with the three keyboard sizes widely available, it is important to bear in mind the demonstrated ease of adapting to different sizes. Pianists of all ages who have switched to ESPKs¹⁸ have found that in virtually all cases, they adapt to the 5.5 inch octave size (reduced octave width approximately the width of one white key) within hours, and need even less time to adapt to the 6.0 inch octave size (Boyle, 2012)¹⁹. After the initial adaptation process, pianists are able to swap back and forth between different sizes without effort; those who now perform on ESPKs (predominantly in the US) may often need to perform on the current 'standard' keyboard

¹⁸ Because acoustic ESPKs only require a different action/keyboard, the piano itself including soundboard and strings are unchanged hence sound level is unaffected.

¹⁹ Also based on considerable anecdotal evidence.

as well. Perhaps this ease of adaptation and switching between sizes is not surprising when one considers that string and woodwind players may regularly switch between different instruments (e.g. violin to viola, flute to piccolo, different clarinets).

Practical issues in a three-size piano keyboard world would not be insurmountable; scenarios in different situations – the private home, teaching studios, piano competitions, schools and universities, concert venues – are described on the Pianists for Alternate Size Keyboards website: www.paskpiano.org/vision-for-the-future.html. Technology is already available to make keyboards as small as the 5.1 inch octave size²⁰. The barriers to achieving this vision are largely cultural; a significant problem is the 'Catch 22' problem whereby pianists are discouraged from playing (and sometimes even from trying) a keyboard of a different size due to their lack of availability elsewhere.

The findings of this research should be of interest to all piano teachers and students. Currently, many students are failing to reach their potential due to the ergonomic mismatch of the current keyboard to the majority of pianists. The potential for a greatly expanded piano market worldwide, if keyboard choice were available, should certainly be seriously considered by all piano manufacturers.

²⁰ www.steinbuhler.com/html/our_research.html
12th Australasian Piano Pedagogy Conference Proceedings

APPENDIX 1: STUDENT SURVEY FORM

DEAKIN UNIVERSITY	STUDENT HAND SPAN SURVEY	SEMESTER 1, 2013	CLASS _____
Please circle, indicate or write in your responses to the following questions:			
Q.1	Your Gender: M or F _____	Q.2	Your Age (years): _____
Q.3	Your Height (centimetres): _____	Q.4	Your Weight (kilograms): _____
Q.5	Your Ethnic Background (as described below):		
	(a) Caucasian	(b) East Asian	(c) Other (please describe) _____
	Notes: (a) Caucasian - European, Middle Eastern, North African, Indian/Pakistani/Bangladeshi/Sri Lankan, American (b) East Asian - Chinese, Japanese, Korean, Thai, Vietnamese, Malaysian, Indonesian (c) Other - Including African, Indigenous, Mixed, etc		
Q.6	Musical instruments: (a) Have you ever learned to play the piano? Y or N (b) If yes, do you still play the piano? Y or N (c) What other instrument(s) do you currently play? _____		
Q.7	Your hand span measurements (as described below) in centimetres to <u>one decimal place</u> :		
	(a) Left hand 1-5 _____	(b) Left hand 2-5 _____	(c) Right hand 1-5 _____ (d) Right hand 2-5 _____
	(a) Lay your left hand flat over the ruler below with fingers out-stretched like a starfish. Align the outside tip of the little finger at 0 cm and stretch out the thumb to the maximum extent possible so it starts to hurt. Mark where the outside edge of your thumb occurs, and write in the result above.		
	(b) Repeat this, again with the little finger at 0 cm but this time using the index finger (the one next to the thumb) stretched to the maximum. Write in the result.		
	(c) Repeat (a) but using the right hand, with your thumb at 0 cm and your little finger stretched to the maximum along the ruler. Write in the result.		
	(d) Repeat (b) but using the right hand, with your index finger at 0 cm and your little finger stretched to the maximum along the ruler. Write in the result.		
	<p>Left Hand - Centimetres</p> <p>Right Hand - Centimetres</p>		

APPENDIX 2: SURVEY OF ADULT PIANISTS – RESULTS

	Right hand 1-5 span		Right hand 2-5 span	
Sample size	473		473	
	Inches	Centimetres	Inches	Centimetres
Minimum	6.4	16.3	4.7	11.9
Maximum	10.8	27.4	8.6	21.9
Arithmetic mean	8.2	21.0	6.4	16.2
Median	8.2	20.8	6.3	16.0
First Quartile	7.8	19.8	6.0	15.2
Third Quartile	8.8	22.4	6.8	17.3
Range	4.4	11.2	3.9	10.0
Inter Quartile Range	1.0	2.5	0.8	2.0
Standard Deviation	0.71	1.81	0.58	1.47

	Males		Females	
Sample size	159		314	
	Inches	Centimetres	Inches	Centimetres
Minimum	7.8	19.7	6.4	16.3
Maximum	10.8	27.4	9.5	24.1
Arithmetic mean	8.9	22.6	7.9	20.1
Median	8.9	22.6	7.9	20.1
First Quartile	8.5	21.6	7.6	19.2
Third Quartile	9.2	23.4	8.3	21.0
Range	3.0	7.7	3.1	7.9
Inter Quartile Range	0.7	1.8	0.7	1.8
Standard Deviation	0.56	1.43	0.53	1.35
Difference in sample means: Mean Males – Mean Females = 0.985 inches				
Two-tail test for difference in means: Males v Females, p-value = 0.0000				
95% confidence interval for difference in means: 0.88 inches to 1.09 inches				

Right 1-5 span (inches)	Gender		
Frequency count:	Female	Male	Total
6.0 to < 7.0	10	0	10
7.0 to < 8.0	160	4	164
8.0 to < 9.0	135	91	226
9.0 to < 10.0	9	57	66
10.0 to 11.0	0	7	7
Total	314	159	473
Percent of Total:			
6.0 to < 7.0	2.1%	0.0%	2.1%
7.0 to < 8.0	33.8%	0.8%	34.7%
8.0 to < 9.0	28.5%	19.2%	47.8%
9.0 to < 10.0	1.9%	12.1%	14.0%
10.0 to 11.0	0.0%	1.5%	1.5%
Total	66.4%	33.6%	100.0%
Percent of Rows:			
6.0 to < 7.0	100.0%	0.0%	100.0%
7.0 to < 8.0	97.6%	2.4%	100.0%
8.0 to < 9.0	59.7%	40.3%	100.0%
9.0 to < 10.0	13.6%	86.4%	100.0%
10.0 to 11.0	0.0%	100.0%	100.0%
Total	66.4%	33.6%	100.0%

Percent of Columns:			
6.0 to < 7.0	3.2%	0.0%	2.1%
7.0 to < 8.0	51.0%	2.5%	34.7%
8.0 to < 9.0	43.0%	57.2%	47.8%
9.0 to < 10.0	2.9%	35.8%	14.0%
10.0 to 11.0	0.0%	4.4%	1.5%
Total	100.0%	100.0%	100.0%

Table 4: Adult pianists – Right hand 2-5 span by gender – Key statistical measures

	Males		Females	
Sample size	159		314	
	Inches	Centimetres	Inches	Centimetres
Minimum	5.0	12.7	4.7	11.9
Maximum	8.6	21.9	7.7	19.5
Arithmetic mean	6.7	17.0	6.2	15.7
Median	6.8	17.1	6.2	15.7
First Quartile	6.3	16.0	5.9	15.0
Third Quartile	7.0	17.8	6.5	16.5
Range	3.6	9.2	3.0	7.6
Inter Quartile Range	0.7	1.8	0.6	1.5
Standard Deviation	0.55	1.40	0.51	1.30
Difference in sample means: Mean Males – Mean Females = 0.521 inches				
Two-tail test for difference in means: Males v Females, p-value = 0.0000				
95% confidence interval for difference in means: 0.42 inches to 0.62 inches				

Table 5: Adult pianists – Right hand 1-5:2-5 ratio by gender – Key statistical measures

	Males	Females
Sample size	159	314
Minimum	0.60	0.65
Maximum	0.88	0.90
Arithmetic mean	0.75	0.78
Median	0.76	0.78
First Quartile	0.72	0.75
Third Quartile	0.79	0.81
Range	0.28	0.24
Inter Quartile Range	0.07	0.06
Standard Deviation	0.05	0.04
Difference in sample means: Mean Males minus Mean Females = - 0.028		
Two-tail test for difference in means: Males v Females, p-value = 0.0000		

Table 6: Adult pianists – Male right hand 1-5 span by ethnicity – Key statistical measures

	Caucasian Males		Asian Males	
Sample size	116		37	
	Inches	Centimetres	Inches	Centimetres
Minimum	7.8	19.8	7.8	19.7
Maximum	10.8	27.4	9.4	24.0
Arithmetic mean	9.0	22.8	8.7	22.0
Median	8.9	22.6	8.7	22.1
First Quartile	8.6	21.8	8.5	21.6
Third Quartile	9.4	23.8	8.9	22.6
Range	3.0	7.6	1.7	4.3
Inter Quartile Range	0.8	2.0	0.4	1.0
Standard Deviation	0.60	1.52	0.38	0.97
Difference in sample means: Mean Caucasian Males – Mean Asian Males = 0.313				
Two-tail test for difference in means: Caucasian Males v Asian Males, p-value = 0.0033				
95% confidence interval for difference in means: 0.11 inches to 0.52 inches				

Table 7: Adult pianists – Male right hand 2-5 span by ethnicity – Key statistical measures				
	Caucasian Males		Asian Males	
Sample size	116		37	
	Inches	Centimetres	Inches	Centimetres
Minimum	5.0	12.7	5.5	14.0
Maximum	8.6	21.9	7.9	20.0
Arithmetic mean	6.7	17.0	6.7	17.1
Median	6.7	16.9	6.8	17.3
First Quartile	6.3	15.9	6.5	16.5
Third Quartile	7.0	17.8	7.0	17.8
Range	3.6	9.2	2.4	6.0
Inter Quartile Range	0.7	1.8	0.5	1.3
Standard Deviation	0.58	1.47	0.45	1.15
Difference in sample means: Mean Caucasian Males – Mean Asian Males = - 0.057				
Two-tail test for difference in means: Caucasian Males v Asian Males, p-value = 0.584				

Table 8: Adult pianists – Female right hand 1-5 span by ethnicity – Key statistical measures				
	Caucasian Females		Asian Females	
Sample size	216		87	
	Inches	Centimetres	Inches	Centimetres
Minimum	6.4	16.3	6.8	17.2
Maximum	9.5	24.1	9.0	22.9
Arithmetic mean	8.0	20.2	7.8	19.8
Median	8.0	20.3	7.8	19.8
First Quartile	7.6	19.3	7.5	19.1
Third Quartile	8.3	21.0	8.1	20.6
Range	3.1	7.9	2.2	5.7
Inter Quartile Range	0.7	1.7	0.6	1.5
Standard Deviation	0.54	1.38	0.45	1.15
Difference in sample means: Mean Caucasian Females – Mean Asian Females = 0.165				
Two-tail test for difference in means: Caucasian Females v Asian Females, p-value = 0.0127				
95% confidence interval for difference in means: 0.04 inches to 0.30 inches				

Table 9: Adult pianists – Female right hand 2-5 span by ethnicity – Key statistical measures				
	Caucasian Females		Asian Females	
Sample size	216		87	
	Inches	Centimetres	Inches	Centimetres
Minimum	4.7	11.9	5.2	13.2
Maximum	7.6	19.3	7.5	19.1
Arithmetic mean	6.2	15.6	6.2	15.8
Median	6.2	15.7	6.2	15.7
First Quartile	5.9	15.0	5.9	15.0
Third Quartile	6.5	16.5	6.6	16.8
Range	2.9	7.4	2.3	5.8
Inter Quartile Range	0.6	1.5	0.7	1.8
Standard Deviation	0.51	1.30	0.48	1.22
Difference in sample means: Mean Caucasian Females – Mean Asian Females = - 0.064				
Two-tail test for difference in means: Caucasian Females v Asian Females, p-value = 0.3189				

Table 10: Adult pianists – Caucasian right hand 1-5 spans by gender – Key statistical measures				
	Caucasian Males		Caucasian Females	
Sample size	116		216	
	Inches	Centimetres	Inches	Centimetres
Minimum	7.8	19.8	6.4	16.3
Maximum	10.8	27.4	9.5	24.1
Arithmetic mean	9.0	22.8	8.0	20.2
Median	8.9	22.6	8.0	20.3
First Quartile	8.6	21.8	7.6	19.3
Third Quartile	9.4	23.8	8.3	21.0
Range	3.0	7.6	3.1	7.9
Inter Quartile Range	0.8	2.0	0.7	1.7
Standard Deviation	0.60	1.52	0.54	1.38
Difference in sample means: Mean Males – Mean Females = 1.025 inches				
Two-tail test for difference in means: Males v Females, p-value = 0.0000				
95% confidence interval for difference in means: 0.90 inches to 1.15 inches				

Table 11: Adult pianists – Caucasian right hand 2-5 span by gender – Key statistical measures				
	Caucasian Males		Caucasian Females	
Sample size	116		216	
	Inches	Centimetres	Inches	Centimetres
Minimum	5.0	12.7	4.7	11.9
Maximum	8.6	21.9	7.6	19.3
Arithmetic mean	6.7	17.0	6.2	15.6
Median	6.7	16.9	6.2	15.7
First Quartile	6.3	15.9	5.9	15.0
Third Quartile	7.0	17.8	6.5	16.5
Range	3.6	9.2	2.9	7.4
Inter Quartile Range	0.7	1.8	0.6	1.5
Standard Deviation	0.58	1.47	0.51	1.30
Difference in sample means: Mean Males – Mean Females = 0.53 inches				
Two-tail test for difference in means: Males v Females, p-value = 0.0000				
95% confidence interval for difference in means: 0.41 inches to 0.65 inches				

Table 12: Adult pianists – Asian right hand 1-5 spans by gender – Key statistical measures				
	Asian Males		Asian Females	
Sample size	37		87	
	Inches	Centimetres	Inches	Centimetres
Minimum	7.8	19.7	6.8	17.2
Maximum	9.4	24.0	9.0	22.9
Arithmetic mean	8.7	22.0	7.8	19.8
Median	8.7	22.1	7.8	19.8
First Quartile	8.5	21.6	7.5	19.1
Third Quartile	8.9	22.6	8.1	20.6
Range	1.7	4.3	2.2	5.7
Inter Quartile Range	0.4	1.0	0.6	1.5
Standard Deviation	0.38	0.97	0.45	1.15
Difference in sample means: Mean Males – Mean Females = 0.877 inches				
Two-tail test for difference in means: Males v Females, p-value = 0.0000				
95% confidence interval for difference in means: 0.71 inches to 1.05 inches				

	Asian Males		Asian Females	
Sample size	37		87	
	Inches	Centimetres	Inches	Centimetres
Minimum	5.5	14.0	5.2	13.2
Maximum	7.9	20.0	7.5	19.1
Arithmetic mean	6.7	17.1	6.2	15.8
Median	6.8	17.3	6.2	15.7
First Quartile	6.5	16.5	5.9	15.0
Third Quartile	7.0	17.8	6.6	16.8
Range	2.4	6.0	2.3	5.8
Inter Quartile Range	0.5	1.3	0.7	1.8
Standard Deviation	0.45	1.15	0.48	1.22
Difference in sample means: Mean Males – Mean Females = 0.523 inches				
Two-tail test for difference in means: Males v Females, p-value = 0.0000				
95% confidence interval for difference in means: 0.34 inches to 0.71 inches				

	All adults		International		National		Regional/Amateur	
Sample size	473		12		51		410	
	Inches	Cm	Inches	Cm	Inches	Cm	Inches	Cm
Minimum	6.4	16.3	8.8	22.4	7.2	18.3	6.4	16.3
Maximum	10.8	27.4	10.8	27.4	10.2	26.0	10.5	26.7
Arithmetic mean	8.2	21.0	9.5	24.0	8.5	21.6	8.2	20.8
Median	8.2	20.8	9.4	23.9	8.4	21.3	8.1	20.6
First Quartile	7.8	19.8	9.1	23.2	8.1	20.6	7.7	19.6
Third Quartile	8.8	22.4	9.6	24.4	8.9	22.6	8.7	22.0
Range	4.4	11.2	2.0	5.1	3.0	7.7	4.1	10.4
Inter Quartile Range	1.0	2.5	0.5	1.1	0.8	2.0	1.0	2.4
Standard Deviation	0.71	1.81	0.52	1.32	0.57	1.45	0.70	1.77

Right 1-5 span (inches)	Level of Acclaim			
Frequency count:	International	National	Regional/Amateur	Total
Less than 7.5	0	1	53	54
7.5 to less than 8.5	0	26	223	249
8.5 or greater	12	24	134	170
Total	12	51	410	473
Percent of Total:				
Less than 7.5	0.0%	0.2%	11.2%	11.4%
7.5 to less than 8.5	0.0%	5.5%	47.1%	52.6%
8.5 or greater	2.5%	5.1%	28.3%	35.9%
Total	2.5%	10.8%	86.7%	100.0%
Percent of Rows:				
Less than 7.5	0.0%	1.9%	98.1%	100.0%
7.5 to less than 8.5	0.0%	10.4%	89.6%	100.0%
8.5 or greater	7.1%	14.1%	78.8%	100.0%
Total	2.5%	10.8%	86.7%	100.0%
Percent of Columns:				
Less than 7.5	0.0%	2.0%	12.9%	11.4%
7.5 to less than 8.5	0.0%	51.0%	54.4%	52.6%
8.5 or greater	100.0%	47.1%	32.7%	35.9%
Total	100.0%	100.0%	100.0%	100.0%

	All adults		International		National		Regional/Amateur	
Sample size	473		12		51		410	
	Inches	Cm	Inches	Cm	Inches	Cm	Inches	Cm
Minimum	4.7	11.9	6.2	15.7	5.0	12.7	4.7	11.9
Maximum	8.6	21.9	7.9	20.1	8.6	21.9	8.1	20.7
Arithmetic mean	6.4	16.2	7.0	17.7	6.5	16.5	6.3	16.1
Median	6.3	16.0	7.0	17.8	6.5	16.5	6.3	16.0
First Quartile	6.0	15.2	6.6	16.8	6.1	15.5	6.0	15.2
Third Quartile	6.8	17.3	7.3	18.4	6.8	17.3	6.7	17.0
Range	3.9	10.0	1.7	4.3	3.6	9.2	3.4	8.8
Inter Quartile Range	0.8	2.0	0.7	1.7	0.7	1.8	0.7	1.8
Standard Deviation	0.58	1.47	0.47	1.20	0.59	1.50	0.57	1.45

Acclaim & Recognition	Gender		
Frequency count:	Female	Male	Total
International	2	10	12
National	20	31	51
Regional/Amateur	292	118	410
Total	314	159	473
Percent of Total:			
International	0.4%	2.1%	2.5%
National	4.2%	6.6%	10.8%
Regional/Amateur	61.7%	24.9%	86.7%
Total	66.4%	33.6%	100.0%
Percent of Rows:			
International	16.7%	83.3%	100.0%
National	39.2%	60.8%	100.0%
Regional/Amateur	71.2%	28.8%	100.0%
Total	66.4%	33.6%	100.0%
Percent of Columns:			
International	0.6%	6.3%	2.5%
National	6.4%	19.5%	10.8%
Regional/Amateur	93.0%	74.2%	86.7%
Total	100.0%	100.0%	100.0%

APPENDIX 3: BUSINESS STUDENT SURVEY – RESULTS

	All Students		Deakin Semester A		Deakin Semester B		Monash Semester A		Monash Semester B	
Sample size	216		21		65		73		57	
	Inches	Cm	Inches	Cm	Inches	Cm	Inches	Cm	Inches	Cm
Minimum	6.3	16.0	6.3	16.0	6.4	16.3	6.7	17.0	6.4	16.3
Maximum	10.4	26.4	9.1	23.0	10.4	26.4	9.5	24.2	9.1	23.0
Arithmetic	8.0	20.3	7.9	20.2	8.2	20.9	7.9	20.2	7.9	20.0
Median	7.9	20.1	7.9	20.0	8.3	21.0	7.9	20.0	7.8	19.8
First Quartile	7.5	19.0	7.5	19.0	7.8	19.8	7.5	19.0	7.5	19.0
Third Quartile	8.6	21.9	8.7	22.0	8.7	22.0	8.3	21.0	8.2	20.8
Range	4.1	10.4	2.8	7.0	4.0	10.1	2.8	7.2	2.6	6.7
Inter Quartile Range	1.2	3.0	1.2	3.0	0.9	2.2	0.8	2.0	0.7	1.8
Standard Deviation	0.72	1.82	0.77	1.95	0.83	2.11	0.63	1.61	0.61	1.55

	All Students		Deakin Semester A		Deakin Semester B		Monash Semester A		Monash Semester B	
Sample size	210		21		65		70		54	
	Inches	Cm	Inches	Cm	Inches	Cm	Inches	Cm	Inches	Cm
Minimum	4.7	12.0	5.1	13.0	4.7	12.0	5.1	13.0	5.0	12.6
Maximum	8.3	21.2	7.5	19.0	8.0	20.2	8.3	21.2	8.2	20.8
Arithmetic	6.4	16.1	6.3	16.1	6.3	16.1	6.3	16.1	6.4	16.2
Median	6.3	16.0	6.3	16.0	6.3	16.0	6.3	16.0	6.4	16.3
First Quartile	5.9	15.0	5.9	15.0	5.9	15.0	5.9	15.0	6.0	15.3
Third Quartile	6.8	17.2	6.7	17.0	6.7	17.0	6.7	17.0	6.8	17.2
Range	3.6	9.2	2.4	6.0	3.2	8.2	3.2	8.2	3.2	8.2
Inter Quartile Range	0.9	2.2	0.8	2.0	0.8	2.0	0.8	2.0	0.7	1.9
Standard Deviation	0.68	1.72	0.66	1.69	0.69	1.74	0.68	1.74	0.68	1.73

	All students		Males		Females	
Sample size	216		123		93	
	Inches	Centimetres	Inches	Centimetres	Inches	Centimetres
Minimum	6.3	16.0	7.1	18.0	6.3	16.0
Maximum	10.4	26.4	10.4	26.4	9.1	23.0
Arithmetic mean	8.0	20.3	8.3	21.2	7.6	19.2
Median	7.9	20.1	8.3	21.0	7.5	19.0
First Quartile	7.5	19.0	7.9	20.0	7.1	18.0
Third Quartile	8.6	21.9	8.7	22.0	7.9	20.0
Range	4.1	10.4	3.3	8.4	2.8	7.0
Inter Quartile Range	1.2	3.0	0.8	2.0	0.8	2.0
Standard Deviation	0.72	1.82	0.62	1.57	0.60	1.52
Difference in sample means: Mean Males – Mean Females = 0.76 inches						
Two-tail test for difference in means: Males v Females, p-value = 0.0000						
95% confidence interval for difference in means: 0.59 inches to 0.93 inches						

Table 21: Business students – Right hand 2-5 span – all students and by gender						
	All students		Males		Females	
Sample size	210		119		91	
	Inches	Centimetres	Inches	Centimetres	Inches	Centimetres
Minimum	4.7	12.0	5.3	13.4	4.7	12.0
Maximum	8.3	21.2	8.3	21.2	7.5	19.0
Arithmetic mean	6.4	16.1	6.6	16.6	6.1	15.5
Median	6.3	16.0	6.5	16.6	6.1	15.6
First Quartile	5.9	15.0	6.1	15.4	5.6	14.2
Third Quartile	6.8	17.2	7.0	17.8	6.5	16.4
Range	3.6	9.2	3.1	7.8	2.8	7.0
Inter Quartile Range	0.9	2.2	0.9	2.4	0.9	2.2
Standard Deviation	0.68	1.72	0.65	1.65	0.63	1.59
Difference in sample means: Mean Males – Mean Females = 0.46 inches						
Two-tail test for difference in means: Males v Females, p-value = 0.0000						
95% confidence interval for difference in means: 0.28 inches to 0.63 inches						

Table 22: Business students – Male right hand 1-5 span by ethnicity				
	Caucasian Males		Asian Males	
Sample size	42		79	
	Inches	Centimetres	Inches	Centimetres
Minimum	7.4	18.8	7.1	18.0
Maximum	10.4	26.4	9.1	23.0
Arithmetic mean	8.8	22.3	8.1	20.5
Median	8.7	22.0	8.2	20.8
First Quartile	8.7	22.0	7.8	19.7
Third Quartile	9.1	23.0	8.5	21.5
Range	3.0	7.6	2.0	5.0
Inter Quartile Range	0.4	1.0	0.7	1.8
Standard Deviation	0.55	1.39	0.49	1.26
Difference in sample means: Mean Caucasian Males – Mean Asian Males = 0.70				
Two-tail test for difference in means: Caucasian Males v Asian Males, p-value = 0.0000				
95% confidence interval for difference in means: 0.51 inches to 0.90 inches				

Table 23: Business students – Female right hand 1-5 span by ethnicity				
	Caucasian Females		Asian Females	
Sample size	30		56	
	Inches	Centimetres	Inches	Centimetres
Minimum	6.5	16.5	6.3	16.0
Maximum	8.7	22.0	9.1	23.0
Arithmetic mean	7.7	19.6	7.4	18.9
Median	7.9	20.0	7.5	19.0
First Quartile	7.4	18.8	7.1	18.0
Third Quartile	7.9	20.1	7.8	19.8
Range	2.2	5.5	2.8	7.0
Inter Quartile Range	0.5	1.3	0.7	1.8
Standard Deviation	0.58	1.47	0.55	1.39
Difference in sample means: Mean Caucasian Females – Mean Asian Females = 0.28				
Two-tail test for difference in means: Caucasian Females v Asian Females, p-value = 0.027				
95% confidence interval for difference in means: 0.03 inches to 0.53 inches				

APPENDIX 4: SURVEY OF YOUNG PIANISTS – RESULTS

Frequency Count:	Total right hand span (inches)					
Age (years)	5" < 6"	6" to < 7"	7" to < 8"	8" to < 9"	9" to <10"	Total
5 to < 8 years	1	1	0	0	0	2
8 to < 11 years	0	8	8	0	0	16
11 to < 14 years	0	1	5	5	0	11
14 to 17 years	0	0	3	15	2	20
Total	1	10	16	20	2	49
Percent of Rows:						
5 to < 8 years	50.0%	50.0%	0.0%	0.0%	0.0%	100.0%
8 to < 11 years	0.0%	50.0%	50.0%	0.0%	0.0%	100.0%
11 to < 14 years	0.0%	9.1%	45.5%	45.5%	0.0%	100.0%
14 to 17 years	0.0%	0.0%	15.0%	75.0%	10.0%	100.0%
Total	2.0%	20.4%	32.7%	40.8%	4.1%	100.0%

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DISCLAIMER

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