THE BENEFITS OF REDUCED-SIZE PIANO KEYBOARDS FOR SMALLER HANDED PIANISTS: AN EXPLORATION OF BIOMECHANICAL AND PHYSIOLOGICAL FACTORS

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Previous research by the author has documented the perceived benefits of reduced-size piano keyboards for smaller-handed pianists. This paper reviews the biomechanical and physiological factors that might explain these perceptions.

Referring in particular to the work of Otto Ortmann early last century, the factors described include direct mechanical disadvantages from a mismatch between hand span and keyboard size, the resulting muscular tension and fatigue, and the compounding impacts on the central nervous system.

The availability of smaller piano keyboards combined with new technology provides many exciting research opportunities. This could help to create the momentum for a break from the 'one size fits all' paradigm that has prevailed for over a century.

1. INTRODUCTION

Piano keyboards with narrower-than-normal key widths are becoming more prevalent in universities, schools and homes in North America. This has mainly come about through the foresight and commitment of the inventors of the Steinbuhler DS™ 7/8 keyboard. Steinbuhler & Company now retrofits 7/8 and 15/16 keyboards to grand pianos and produces the same keyboards for installation in Walter upright pianos.

Seven universities[1] in the United States now (June 2013) have reduced-size piano keyboards available for student use, recitals and research. This has made it possible to look at the implications of a pianist having 'larger hands' by comparing performance and health outcomes associated with different sized keyboards. So far, this new body of research has focused on relief from pain and injury associated with pianists transferring to smaller keyboards, building on and confirming the results of epidemiological and clinical research that links small hand spans with pain and injury on the conventional keyboard.

Between 2009 and 2011 I undertook a survey of 22 adult pianists using reduced-size keyboards in the US and Australia, focusing mainly on their perceived performance benefits – both technical and musical. Results from the initial survey group of 14 were published by APPCA 2009 (Boyle & Boyle, 2009) and results from the enlarged group of

[1] See http://www.smallpianokeyboards.org/resources-and-call-to-action.html#unis for the latest listing.

22 by the US MTNA (Boyle, 2012). The results of that survey support and add to anecdotal reports by individuals who were early users of reduced-size keyboards, for example, Donison (2000) and Leone (2003).

These reported benefits cover a very wide range of pianistic skills and outcomes, such as improved ability to play passages of octaves and large chords, increased feeling of power and control of dynamics, as well as access to a much greater repertoire; reduced learning times; relief from pain, stretching and tension; greater security; and far greater overall comfort and enjoyment. Many of those (mostly women) who used or purchased smaller piano keyboards from Steinbuhler & Company were driven primarily by chronic pain or injury problems. In virtually all cases, these problems disappeared after moving to a reduced-size keyboard. All survey respondents had active 1-5 hand spans[2] of 8 inches (20 cm) or less, representing the smaller half of adult females. The mean and median hand span for adult females is approximately 8 inches (20 cm) (Boyle & Boyle, 2009). Of the two keyboard sizes available (7/8 and 15/16), most were playing a 7/8 keyboard, which effectively gives a pianist an increased hand span of one extra white key.

The aim of this paper is to explore the possible underlying physiological and biomechanical factors that might explain these perceptions of greater technical ease, comfort and overall performance quality experienced by pianists who have played reduced-size keyboards.

2. PERCEIVED BENEFITS OF REDUCED SIZE KEYBOARDS

Detailed results of the survey of all 22 pianists are reported elsewhere (Boyle, 2012). Respondents were asked to rate, for various skills listed, their perceived degree of improvement when comparing their experience of the reduced-size with the conventional keyboard. The options given were: 'negative', 'nil' 'slight', 'considerable' and 'dramatic'.

The two skills for which there was 100% agreement that the degree of improvement was either 'considerable' or 'dramatic' were:

- Ability to hold down notes as intended rather than releasing early and masking with sustaining pedal
- Feeling of power where needed.

Other skills for which more than 50% of those who responded rated the perceived degree of improvement as either 'considerable' or dramatic' were:

- Fast passages of octaves or large chords (95% of respondents)
- Time taken to master technically difficult passages (90%)

[2] Distance from outside tip of thumb to fifth finger when stretched to a maximum on a flat surface.

- Broken octaves (86%)
- Broken chords/arpeggios (86%)
- Overall feeling of security (86%)
- Awkward or non-ideal fingering (85%)
- Changes of hand position (79%)
- Leaps (75%)
- Legato playing (67%)
- Accuracy (67%)
- Time taken to learn new repertoire (63%)
- Balance (53%)

Additional skills for which more than 50% of those who responded recorded some degree of improvement (whether 'slight', 'considerable' or 'dramatic') were:

- General tone quality (81%)
- Evenness of rhythm and tone (80%)
- Double sixths (75%)
- Sight-reading (68%)
- Double thirds (67%)
- Scale passages (59%)
- Trills and similar ornaments (57%).

The only skill listed where a slight majority (58%) of respondents did not record any improvement was 'ease of memorisation'. As discussed in the detailed report on the survey results, variability of repertoire would be a significant factor in the different ratings given by different respondents. Two respondents mentioned an additional skill: 'voicing of chords', as showing dramatic improvement – this could be considered as one aspect of tone quality. Others have commented on the immediate increase in speed that becomes possible; an example given by one respondent was the ability to play a Chopin Etude at 'concert standard'.

An important perception reported by many is the increased ability to focus on musicianship on a smaller keyboard, rather than the previous undue focus on just 'getting the right notes'. In the words of Christopher Donison, co-inventor of the DS™ keyboard:

"I realise now, looking back, that most of the time I spend practicing was used trying to overcome difficulties because of my hand size." (Donison, 1998).

Given the widespread agreement about the greater ease and facility associated with many of these skills, it is assumed there are underlying biomechanical and physiological factors which relate to pianists' hand spans. Changing to a smaller keyboard effectively provides the same pianists with the experience of having 'larger hands'.

3. BIOMECHANICAL AND PHYSIOLOGICAL EXPLANATORY FACTORS

In researching the biomechanical and physiological factors that might underlie the perceived greater success and comfort for small-handed pianists using a smaller keyboard, the work of Otto Ortmann (1929) is a key reference. Ortmann's major work: *The physiological mechanics of piano technique* was revolutionary in its time, representing the first comprehensive, scientifically based piece of work on piano playing. He backed up his work with careful experiments – although the technology available at the time is now very dated, his findings have not been proven incorrect by any scientific research since. Ortmann never completed his work on the psychological aspects, but other writers (for example, Kochevitsky, 1967) have since acknowledged the importance of the central nervous system in piano playing.

In order to analyse the range of piano skills and outcomes, it is useful to separate the factors rated in my survey, or described elsewhere, into three levels: (1) actual physical tasks at the piano (for example, scales, broken octaves), (2) performance outcomes apparent to the pianist and audience (for example, accuracy, dynamic variation) and, (3) the resulting benefits experienced by the pianist, but not necessarily obvious to others. The perceived advantages of a smaller keyboard described above are drawn from each of these three levels. See Table 1.

Table 1: Pianistic tasks, performance outcomes and benefits experienced

Level 1: Specific tasks ↓	octaves large chords broken chords & arpeggios leaps broken octaves scales double thirds double sixths holding down notes as intended tremolos ornaments number of hand position changes fingering choice
Level 2: Performance outcomes ↓	tone quality (including voicing and balance) appropriate speed dynamic variation legato and phrasing accuracy evenness of rhythm and tone
Level 3: Benefits experienced by the pianist	security comfort choice of repertoire minimal pain and tension sight reading ability overall enjoyment shorter learning times ability to focus on musical rather than technical aspects

Biomechanical and physiological factors relevant to the tasks in the first level of Table 1 also have secondary and tertiary impacts as follows:-

1. Direct mechanical disadvantages from hand span not being well matched to keyboard size relate to:
    i. Extent of finger abduction[3] and curvature of fingers
    ii. Wrist position
    iii. Extent of lateral hand movement
    iv. Extent of forward and backward hand movement
    v. Percussive versus non-percussive strokes.
2. Muscular tension and fatigue resulting from (1) above.
3. Additional load on the central nervous system resulting from (1) and (2) above.

Appendix 1 lists some basic, widely accepted biomechanical and physiological principles.

3.1 DIRECT MECHANICAL DISADVANTAGES

3.1.1 Finger abduction and curvature

Ortmann and other authors have deduced that to maximise energy transfer (which is directly responsible for the intensity of sound) and tonal control, a straight line skeletal position is the optimum – this means that the arm should extend in a straight line directly behind the playing finger. This position is easily achievable for scales and close passage work however, when playing octaves or large chords, some finger abduction will always be necessary. Comparing a large-handed with a small-handed pianist playing the same repertoire, or a pianist moving from a smaller to a larger keyboard, it is apparent that the extent of finger abduction (spread) will necessarily be increased. Ortmann (p.24) and other writers have identified, based on principles of Newtonian mechanics and vector analysis, that the more that a finger deviates from the line of the forearm, the greater the reduction in the resultant force, meaning an increase in the wastage of kinetic energy and hence, reduced intensity of the sound produced.

A second mechanical principle identified by Ortmann (p.227) relates to curved versus flat finger strokes. Based on the fact that the relative forces are inversely proportional to the relative lengths of the lever arms, the flat finger stroke delivers only about 3/5 the force of a curved finger stroke which provides a direct vertical descent to the key. While a flat finger stroke is often useful to produce soft to moderate tones, it is a significant disadvantage if loud tones are desired. Once again, a smaller hand needing greater finger spread – and hence flatter fingers – to reach large chords or octaves, will necessarily be operating at a greater mechanical disadvantage. Ortmann (p.19) pointed out the impossibility of flexing the hand knuckles while the fingers are widely spread.

[3] Sideways movement away from neutral position.

Based on these principles, Ortmann established that the position of maximum force and control of tone requires curved fingers held close to the keys. So, straight and widely abducted fingers will not only deliver less force, but will have less ability to control tone. This includes the voicing of chords, balancing a melody line against accompaniment within the same hand, holding down one note and performing ornaments with other fingers, and varying dynamics in octave or chordal passages, broken octaves, tremolos and double sixths. Ortmann (p.361) states that accentuation of a melody line (voicing) demands various degrees of hand knuckle fixation, however when the fingers are widely abducted the level of this fixation must increase, reducing the difference between accented and unaccented tones. In addition, for widely spread broken chords and arpeggiated figures played at high speed, a small hand is more likely to hit some of the notes with slanting strokes – an unfavourable angle for tone control – in order to maintain the desired speed and rhythm.

Consistent with Ortmann's analysis and experiments, more recent experimental research (Harding et al, 1989) measured the force generated at the tip of the index fingers of several pianists when playing a single key and concluded that a curved finger position reduces finger joint forces by more than 50% compared with a straight finger position, *for the same acoustic volume (level of sound)* produced. This means that the joints are able to operate at twice the efficiency when a curved stroke is used.

Other authors have echoed many of Ortmann's findings, for example, Trevor Barnard (2008) has stressed that for octave playing, 'the closer to the keys, the more control' and the negative effect on fluency if the fourth finger cannot be used. From measurements of the hand spans of pianists and calibration of active 1-5 spans against the ability to play certain intervals (Boyle & Boyle, 2009; Booker & Boyle, 2011) it is apparent that the ability to play legato octaves (using third and fourth fingers) is not always feasible for pianists with hand spans of less than about 8.5 inches (21.5 cm). (This is about the same span required to just be able to play a tenth on the edge of the white keys.) Neuhaus (1973, p.77) has identified the dynamic dominance of the thumb over the fifth finger when small-handed pianists play large chords and octaves, an effect which requires extra practice to minimise.

Ortmann (p.312) states that finger span is determined by three factors: finger length, maximum angle of abduction and hand width. From hand anthropometry data (refer Booker & Boyle, 2011), Caucasian male hands are approximately 13-15% wider than those of females. Hands of Asian females are narrower than Caucasians, so an Asian female pianist is likely to have a hand that is 20-25% narrower than that of a Caucasian male. There is anecdotal evidence that people of Asian ethnicity have more mobile joints (i.e. greater flexibility) than Caucasians, with the result that Asian pianists are more likely to have a relatively good hand span (including the stretches between non-thumb fingers)[4] given their relatively narrow hands. However, the extremely wide finger abduction necessary for the playing of octaves and large chords is a significant mechanical disadvantage for many Asian female pianists.

3.1.2 Wrist and arm position

The optimum position for the wrist is to be in a neutral position, directly aligned with the forearm and hand, as much as possible. Wristen (2000) and Meinke (1995) have noted the smaller the hand, the greater the degree of radial and ulnar deviation of the wrist from the neutral position. As well as the loss of energy through the dissipating of forces to non-productive directions, there is a reduction in dynamic control.

The tendency for small-handed pianists to raise their wrists when playing octaves and large chords has been noted by Ortmann (p.313), Neuhaus (1973, p.124) and others. The wrist is raised higher than the palm to gain strength and to minimise the risk of other fingers hitting adjacent keys; the result being that the thumb and fifth finger lose their independence and become 'pokers'. For pianists with very restricted spans (1-5 spans of 7.5 inches or less) Ortmann (p.313) has commented on their playing of octaves on the outer edges of the white keys, making any rapid octave playing impractical and uncomfortable. His view is that both of these techniques are 'makeshifts of the small hand' and 'brilliance in extended work is normally absent'.

The inability of small-handed pianists to play legato octaves was noted above (3.1.1). Another difficulty with octave playing arises for small-handed players when the right hand needs to cross over into the bass or the left hand cross over into the treble. For active 1-5 spans less than about 8.5 inches (21.5 cm), this requires excessive wrist abduction, bringing the thumb forward to the front edge of the key and sometimes leaning the body back and stiffening the elbow. It is a position of particular discomfort which has an impact on speed, tonal control and muscular tension.

Pianists with smaller hand spans (mostly women) are also likely to have shorter arms and narrower shoulders. When playing at the extremities of the keyboard, this necessitates greater deviation of the arm from neutral, a position of mechanical weakness. In situations where both arms move to one end of the keyboard together, there may be the opportunity to minimise this disadvantage by shifting the body sideways.

[4] Hand span database of active 1-5 and 2-5 spans being assembled by the author suggests a relatively high 2-5/1-5 ratio for Asian pianists.

3.1.3 Lateral hand movement

A smaller hand will necessarily have further to move to get to the keys in a particular passage; this becomes more of an issue in fast passages with wide skips and leaps, widely spread arpeggios and broken chords, rolled chords, and also in broken octaves and octave tremolos. Even with double sixths, for hands that do not easily play a sixth using the second and fifth fingers, there will be additional lateral movement (and stiffer fingers) than for a larger hand which is very comfortably over the keys. For example, a hand that just play an octave but cannot play a 9th even on the edge of the keys, will have to travel around two inches (five centimetres) when rolling a chord covering a tenth.

In all of these situations, the additional lateral movement means either a reduction in speed, or if the pianist employs greater speed in order to get to the keys, there is the associated loss of tonal control, perhaps notes of shorter duration than desired, loss of legato, additional percussiveness (see 3.1.5) and potentially reduced accuracy.

From personal experience, the greater the increase in lateral movement (i.e. the less that the passage is 'under the hand'), the more difficult the technical challenge, particularly when both hands are involved (see 3.3 below). This does not apply so much to leaps from one chord position to another, assuming the chords can be played with reasonable comfort (in fact, all pianists are required to make such leaps), but where fast passages are intended to be connected (extended arpeggios and broken chords) or comfortably 'under the hand' (broken octaves, octave tremolos, double sixths). With a small hand, these intentions cannot be achieved as the connections are often broken by 'mini-leaps'.

Ortmann (p.367) has also noted that wide skips are associated with accents – the greater the lateral movement (and associated increased velocity), the stronger the accent. Also, rapid arm shifts and changes of hand position are normally associated with a lack of dynamic control (Ortmann, p.278). A small-handed pianist often has to make more frequent shifts in hand position than a larger-handed pianist, again potentially affecting speed as well as dynamic control, rhythm and accuracy. The degree of technical mastery depends on being able to reproduce a movement accurately; according to Ortmann (p.370) greater accuracy is associated with smaller movements of the arms and hands.

Ortmann (p.191) says that finger action is necessary to achieve synchronisation of notes in the outer chords of chord tremolos. This becomes more difficult for small hands where much forearm rotation has to be used, resulting in the extreme notes being accented.

For those with a short thumb, the passing of the thumb under the hand in scales and arpeggios can affect the smoothness of playing and evenness of rhythm (Ortmann p.321).

To achieve very loud (*fortissimo*) tones, a small-handed pianist can often achieve this by using their upper arm and shoulder to increase the effective mass of the playing parts of the body. However this results in a loss of speed, with greater momentum and inertia to be overcome, and less tonal control. For fast passages, the smaller muscles of the fingers and hand need to be used to achieve speed and dexterity. Therefore, the lateral shifts necessitated by a small hand for widely spread arpeggiated figures or broken octaves, for example, are more likely to lack the required tonal intensity and control, and rhythmic precision.

3.1.4 Forward and backward hand movement

Ortmann (p.287) has noted the excessive forward and backward motion for small-handed pianists playing chromatic octaves. This involves added muscular energy and creates dynamic irregularity (p.368). Ideally, the white keys should be played as close to the black keys as possible (Kochevitsky, 1967). Pianists with active 1-5 spans of less than 8.5 inches may have difficulty achieving this; their white note octaves tend to be played towards the front edge of the keyboard away from the black keys, as they cannot comfortably arch their hand over the black keys and risk hitting adjacent white keys. In repertoire where fast chromatic octaves are required or in dotted rhythms involving octaves or large chords, the required speed and precise rhythm is not always obtainable for these pianists.

The additional hand, wrist and body movement required for small-handed pianists playing 'cross-over' octaves was noted in 3.1.2.

3.1.5 Percussive versus non-percussive strokes

According to Ortmann (pp.135, 152), judgment of dynamics is seriously hampered when percussiveness is present. A percussive stroke is one where the finger strikes a blow from some distance above the key, with the result that the key descent is beyond the control of the finger after the initial impact. A non-percussive touch is one where the finger is resting on the surface of the key before it is depressed. Ortmann (p.154) showed that the retardation of key depression resulting from a percussive attack results in a reduction in control of the tone. Percussive strokes also produce unwanted 'noise' from the finger hitting the key and other movements of hardware inside the piano. The smaller the hand, the greater the likelihood of percussive touches being needed to reach the keys and achieve the desired speed.

3.2 MUSCULAR TENSION

Ortmann (p.31) states that ease of motion requires maximum accuracy of kinaesthetic judgment and minimum fatigue. Finger, hand and arm positions should therefore be those that permit joints and muscles to operate near the middle of their range, rather than close to their limits. A powerful muscle has a greater range of gradation than a weak muscle, hence giving a player a greater range of dynamic responses. A muscle with greater strength and operating in a favourable position will operate with less fatigue than a smaller muscle operating close to its limit. Ortmann (p.57) also noted that muscular activity will be most efficient at the start of playing, after a brief warming up.

Increased muscular tension reduces accurate judgment of key resistance, resulting in loss of control of tone and rhythm. The earliest onset of muscular fatigue affects the relaxation rate before it starts to affect the contraction rate of the muscle. According to Wagner (1982), performers will try to compensate for joint resistance (when operating at extreme limits) with increased muscular effort, which in turn causes an increase in tension. As muscular tension increases, blood flow is interrupted, muscular contraction becomes progressively weaker and the joint becomes harder to move, leading to higher nervous system engagement in order to overcome unfavourable conditions (see 3.3). Hence continued playing under these conditions leads to a downward spiral of increasing tension, pain, loss of control until the pianist may be forced to stop playing after a relatively short time.

Long passages involving repetition often produce fatigue by over-shortening the period of adjustment between movements. To offset this, a pianist may accompany a long octave passage, for example, with a slower raising and lowering of the wrist.

Recent research involving small-handed pianists using the conventional and reduced size keyboards has clearly demonstrated the expected reduction in muscular tension and pain associated with playing the smaller keyboard (Wristen et al, 2006; Yoshimura & Chesky, 2009). Figures 1 and 2 from the study by Yoshimura & Chesky (2009, Figures 6a and 6b) show 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 keyboard as well as a 15/16 keyboard. Figure 1 shows the significantly higher levels of pain experienced by those students with (left) hand spans of less than about 220 mm (8.6 inches). Figure 2 shows the same scatter plot when the students used the 15/16 keyboard, and although pain was still present for those with smaller hands, the level of pain was significantly reduced. In both cases, students with hand spans above 22 cm (8.6 inches) experienced virtually no pain.

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 more at risk. It is also consistent with my own experience of playing octaves on a 7/8 keyboard which effectively enlarges my active 1-5 hand span from 7 inches (17.8 cm) to 8 inches (20.3 cm). This hand span is definitely associated with unavoidable tension (and often, a raised wrist) when I play fast octaves which is not present if I play sevenths (which is equivalent to a pianist with a 9-inch hand span playing octaves on the conventional keyboard).

FIGURE 1

Figure 6a: *Scatterplot and Regression Line of Left Hand Span (X) and Pain on the* ***188-mm*** *Keyboard (Y)*

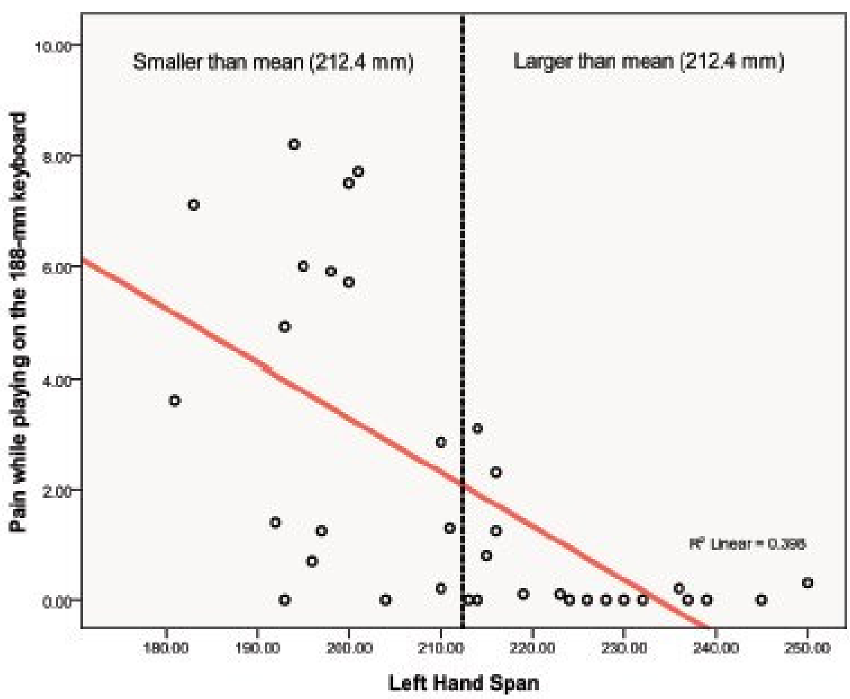
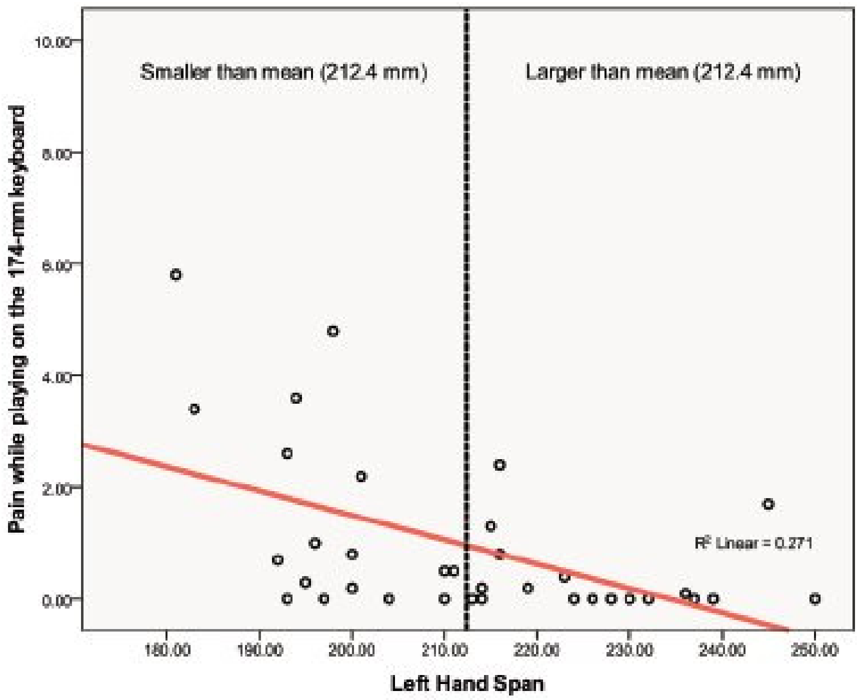


FIGURE 2

Figure 6b: *Scatterplot and Regression Line of Left Hand Span (X) and Pain on the* ***174-mm*** *Keyboard (Y)*



3.3 LOAD ON THE CENTRAL NERVOUS SYSTEM

'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).

Although Otto Ortmann did not complete his work on the psychological factors relevant to piano playing, he did recognise the importance of minimising muscle fatigue due to its impact on the quality of playing, and the need to avoid wastage of both physical and psychological energy. Other writers since, in particular Kochevitsky (1967), have emphasised the importance of the central nervous system in piano playing, sometimes going to the extreme of discounting the importance of a pianist's physical characteristics and technique. The impact of muscle fatigue on the central nervous system has been mentioned above (3.2); in fact Wagner (1984, p.169) 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.

Kochevitsky believed that the ability to develop speed also requires an ability to estimate distance, which depends on the in-born and trained capacities of the central nervous system. Muscle overstrain clearly produces a disturbance of mental activity. An extreme example of how physical stress can close down other brain activity is described by Kochevitsky (p.39); an experiment involved a student being required to lift and hold up a corner of a grand piano. While holding it he was asked to name several large cities and say a times table. He was unable to do this until he put down the piano! In many sports where there is a desire to look 'elegant' in some way (for example, skiing), a lack of technical mastery of the necessary skills in a certain situation interferes with the ability to focus on elegance.

As discussed in 3.2, the compounding effects of mechanical disadvantage (muscles and joints not operating in optimum positions), muscular tension and fatigue further affect control of dynamics, rhythm and accuracy. Clearly, one would expect small-handed pianists to be more affected with greater engagement of their central nervous system in overcoming these physical disadvantages and the resulting muscular fatigue. In turn, one would expect that their ability to focus on artistic intentions would be reduced compared with their larger-handed counterparts (everything else being equal).

Apart from the impact of muscular tension on the central nervous system, Kochevitsky (1967, p.48) hints at the mental impacts of certain technical tasks at the piano where muscular strain is not necessarily involved. He talks about 'regrouping of notes' as a practice method to make it easier for the brain, saying: 'mental convenience is worth more than motor inconvenience'.

The impact of mental effort can be felt by any pianist when they undertake hand position changes compared with the alternative of not changing positions – for example, using the thumb and fifth finger on the outer notes of a succession of simple, closely spaced chords covering a fifth or sixth, rather than making use of other fingers (in place of thumb and fifth) so that the hand position is essentially unchanged. The impact of hand position changes is immediately obvious to small-handed pianists when they first play a piece on the smaller keyboard that they used to play on the larger one. This freedom from mental effort is one of the more unexpected benefits of moving to a smaller keyboard and in my case I now often prefer to avoid hand position changes that I previously could not avoid on the conventional keyboard, even when some chords are physically awkward as a result.

Based on my own experience and comments from others, tasks that seem to impact significantly on the central nervous system, irrespective of the presence of any muscular tension, include:-

- Octave playing, especially when playing on the edge of the white keys.
- Large chords not comfortably under the hand, where some fingers are stiff or uncomfortably stretched, and especially leaping quickly onto such chords.
- Rolled chords – the longer the roll, the greater the impact, and the mental effort is markedly increased where the second finger to play (normally the index finger in a right-hand chord) has to leap slightly to get to the second key – i.e. no part of the chord is 'under the hand'.
- Arpeggios, broken chords, and any widely spaced figures not comfortably 'under the hand'. Again, the wider the stretches or leaps, the greater the impact.
- Broken octaves, tremolos.
- Hand position changes.
- Awkward fingering where fingers are forced into contorted positions or sharp, angular movements are required.

The impacts are compounded when both hands are dealing with these sorts of tasks. Figure 3 shows an example of a passage where the impact on the central nervous system was very obvious to me when comparing my experience of playing it on the conventional and 7/8 keyboards. This is consistent with comments from other pianists; some examples:

"A significant reduction of tension (psychological and physical) associated with octaves and great spans has resulted in a far more pleasant and more secure playing experience…Subsequently, I found myself focusing more on tone and technique and mostly, the music itself. Joy." (Respondent to survey, Boyle, 2012).

"Also, I had to spend less time working on the technical issues, which allowed me to focus more on the musical issues. My senior recital that I played on the reduced-size keyboard …..was by far the strongest piano performance I ever gave." (Respondent to survey, Boyle, 2012).

"Wide sweeping left-hand arpeggiated figures so prevalent in Chopin become not only possible, but one gets to actually get on with the business of cultivating the right sound rather than practising with endless futility the same passage over and over. Also, the larger the sweep becomes, the greater the difference. On a 7/8 keyboard, a 2½ octave sweep is 2 and ½ normal key widths smaller. That is about 2½ inches! When the smaller-handed pianist is attempting a sweep like this, the hand has to be very loose and is

practically flung from top to bottom to cover the distance is time. Landing in the right place is the great achievement. With a larger hand, landing in the right place is so easy that the force with which you land there now is an option!" (Christopher Donison, 2000, p.113).

Figure 3: Extract from Chopin's Scherzo No. 1 in B flat minor.

4. DISCUSSION

The analysis described above identifies the separate but inter-related impacts of mechanical disadvantage, muscular fatigue and the resulting mental (central nervous system) impacts for small-handed pianists playing the conventional keyboard. While many of these issues may not significantly disadvantage these pianists for some repertoire – most notably, Baroque and early Classical – they arise very frequently in the advanced repertoire from Beethoven and Schubert on through composers of the 20th century.

Kochevitsky (1967) has described the various 'schools' of piano playing which evolved during the 19th and 20th centuries:

- The 'finger school' which evolved from harpsichord and clavichord technique, involving lifting the fingers high, an arched hand and minimal movement of the upper arms and shoulders.

- The ‘anatomic-physiological school’ which included concepts such as ‘weight playing’ with a relaxed and loose arm, and little need for hand or finger exertion.
- The ‘psycho-technical’ school which focused on the mental conception of musical purpose.

Each of these ‘schools’ focused on one part of the human body (hand and fingers, arms, brain) to the exclusion of others, whereas most pedagogues today appreciate that all are important, as reflected in the analysis relating to hand size in section 3 of this paper.

Ortmann’s work has often been ignored or misinterpreted, even though he frequently highlights the impact of biomechanical and physiological factors explaining technical difficulties, and he acknowledges the importance of psychological factors in the learning process. Remnants of the ‘psycho-technical’ school seem to prevail in some quarters up to this day, whereby a pianist’s physical attributes and technical training are thought to be of little importance. Kochevitsky (1967, p.14) quotes one teacher (Beata Ziegler) who suggested that great pianists overcome all physical difficulties through inward hearing and artistic inspiration. He also quotes Walter Gieseking (p.38): *“It is useless to look for the reason of the beautiful tone in some particular finger or hand position; I am convinced that the only way to learn to produce beautiful tone is systematic ear training.”*

Kochevitsky himself appears to discount the important of Ortmann’s work, for example:

“Any normal bone-muscle apparatus is sufficient for the development of a high degree of technique because of the brain behind the hands” (p.17) and he concludes:

“The roots of technique are in our central nervous system. The problems connected with muscular conditions and outward appearance of our playing apparatus are important, but they are secondary” (p. 18).

Associated with these sorts of discussions about the over-riding importance of the brain, one often sees anecdotal or ill-informed commentary about certain famous pianists who have or had ‘small hands’, inferring that ‘size does not matter’. Foremost among these is Alicia de Larrocha, who was assumed to have small hands because she was very short. In fact, she herself stated that she could reach a tenth in her heyday, putting her among the top 20% of women. (New York Times, 1995). Kochevitsky (1967, p.17) discusses famous pianists with ‘small hands’, including Josef Hoffmann (who incidentally had a reduced-size keyboard specially made for his Steinway), and Leopold Godowsky. Alan Kogosowski (2010, p.17) discusses the performance of Chopin’s Etudes and in relation to Opus 10 no. 1, he says: *“But surprising as it may seem, and to the continual amazement of most students, amateurs and even professionals – the size of the hand (given an average natural size, of course) is immaterial, and even freakishly outsized* *hands like Lhévinne's and Rachmaninoff's will do us no good here. Size – theoretically, at any rate – doesn't enter into the equation of the first Etude…"*

Meinke (1995, p.52), in his discussion of piano virtuosity, also makes comments which are entirely anecdotal and based on subjective views about what constitutes a small or a large hand: "*Certainly, there is a range of both physical and functional differences among performers. Attention has almost invariably been centred on these differences as expressed in the hands and fingers. Yet experience, both recent and in the past, fails to support even the simplest and most intuitive of suppositions about these variations, that the larger hand with long, tapering fingers should have fewer technical difficulties (and fewer injuries) than the smaller, short-fingered counterpart. Even casual perusal of the historical record provides a small-handed Mozart for every large-handed Liszt, a de Larrocha for every Horowitz. For every injured "small hand" (Gary Graffman) there seems to be an injured "large hand" (Leon Fleisher) as well. No clear pattern emerges. These observations suggest (though they do not prove) that even the smallest, shortest fingers and hands have the physical capability for piano virtuosity."*

Many of these writers probably based their experience of hand size on their own vague perceptions about 'average hands', influenced by the few pianists that they may have taught or had some knowledge of, and their focus of attention was probably largely Caucasian male pianists for whom 'small hands' really meant 'small for an adult male'. Surprisingly, statistical summary data on hand spans of adult male and female pianists in Germany published back in the 1980s (Wagner 1984; 1988) was never analysed at the time in relation to the demands of the piano repertoire. Wagner (1984) did however, analyse various features of the hand including its shape and the length of fingers, and found a significant direct relationship between performance success at the piano and both passive mobility (joint resistance) and active mobility (maximum stretch) between the thumb and other fingers.

Even back in 1929, Ortmann recognised the significance of hand span in being able to play at the highest level. He said that the three physiological factors that determine the amount of stretch – length of finger, width of hand and angles of abduction "*explain a surprisingly large number of technical difficulties that are often wrongly attributed to defects of coordination and studentship"*. (p. 313). He goes on to say that a small hand encounters not only the obvious differences in stretch compared to a large hand, but 'entire technique' is affected (p.318). Certainly Meinke's assertion that small hands were no more likely than larger ones to suffer injuries has not stood up to peer-reviewed research over the last two decades.

As part of his ergonomic analysis of virtuosity, Meinke (1995) also says: *"The work space, the piano keyboard, has been highly resistant to change. (There is little ergonomic justification for change, anyway.)"* (p.50). Again, he does not provide any sound evidence to back up this assertion, nor does he refer to the general acceptance of a choice of size in many other instruments (such as violins) based on ergonomic principles. As the 'one size fits all' situation has prevailed around the world for over a century, the vast bulk of pianists have never experienced an alternative size, so often cannot conceive, nor have they really thought about, the likely benefits of a different size.

International piano competition results over the last 60-70 years (Booker & Boyle, 2011)[5] consistently show the predominance of male prize-winners over females, despite the fact that women normally outnumber men in most conservatories. The same pattern is much less evident in international violin competitions, an instrument where sizes vary and ergonomic suitability can influence a performer's choice of instrument. The fact that women outnumber men among prize-winners in just two single composer piano competitions – Bach and Mozart – is not surprising, given the repertoire of those two composers generally suits smaller hands. Many of the most famous women pianists of the 20th century[6] were best known as interpreters of Baroque and Classical repertoire.

For piano competitions focusing on Romantic composers and the world-renowned general competitions, such as Leeds and Van Cliburn which demand a wide variety of repertoire up to the 20th century, the ratio of male to female prize winners (approximately three or four to one) is unsurprising. This is similar to the ratio of men to women who can reach a tenth on the conventional keyboard (approximately 80% versus 20%). The Sydney International Piano Competition seems to acknowledge the expectation that women will not succeed to the same extent as men, in that they award a special prize for the top female competitor! Is it not conceivable that there would be some female pianists with small hands who have the talent to match the level of the top male pianists if contestants had the choice of a smaller keyboard?

The results of the International Beethoven Piano Competition are interesting in respect of the dominance of male versus female prize winners at a ratio (three to one) similar to many other competitions. Considering Beethoven's repertoire, one might expect women to do better, as fewer stretches are involved compared with the repertoire of many later composers, with tenths being relatively rare. Part of the answer may relate to the question of 'power', particularly in achieving a high level of technical and rhythmic precision combined with speed in *fortissimo* passages of arpeggios, broken chords, broken octaves and the like. As discussed in section 3, it is rarely possible to play such

[5] See http://www.smallpianokeyboards.org/health-and-success.html#piano for the latest updates.
[6] See www.smallpianokeyboards.org/health-and-success.html#artists;

passages at high speed and also use the upper arm and shoulder to help increase the tonal intensity. In some Beethoven works, a relatively good hand span as well as good stretches between other fingers is needed, in order to perform such tasks as holding down lower notes with the thumb and performing trills with other fingers.

Ortmann notes that in his experience, boys play louder than girls, and men play louder than women. He puts this down to muscular strength in the fingers, hand and arm. Although he provides many clues throughout his book that hand span may be a very significant factor, he does not draw these threads together, but attributes the difference entirely to 'muscular strength'. As outlined above, several factors he discusses could explain much of the inadequate intensity of sound from many female pianists when playing Beethoven on the conventional keyboard: - the direct mechanical disadvantages associated with a more widely abducted hand, high wrist position for octave playing, additional lateral and forward and backward movements of the hand which reduce speed, in addition to the effects of muscular fatigue and cumulative load on the central nervous system. As noted earlier (section 2), pianists who play smaller keyboards are in total agreement about the noticeable increase in 'power' they experience compared with playing the conventional keyboard.

The amount of energy delivered to the keys (which determines the level of sound) depends on both mass of the playing parts and velocity; this is equivalent to the work done which is defined as the resultant force exerted over the distance the key is depressed (see Appendix 1). Hence mass and velocity are the relevant input variables. The mass attributed to the pianist may be just that of the hand, but will often include the forearm, and sometimes also the upper arm and parts of the torso. This mass will partly be made up of muscles but also consists of bones and soft tissues. To summarise the biomechanical/physiological factors relevant to achieving a desired tonal intensity:-

- Mass of the parts used in playing (muscles, bones, soft tissues)
- Muscular strength (partly related to mass, as muscular strength depends on the size of the muscles)
- Minimising loss of force through undesirable mechanical factors (finger and wrist abduction, straight fingers)
- Minimising the accumulation of muscular fatigue and increased load on the central nervous system.

While pianists are limited in their ability to influence the first of these two factors (total mass and muscular strength), the second two factors which lead to loss of force can be reduced significantly on a smaller keyboard. While mass and muscular strength may still be factors that put female pianists at a disadvantage in certain repertoire, one notes that many very successful male concert pianists are very lightly built and do not appear to have great muscular strength or 'chunky' hands and arms. However they do have hand spans wide enough to prevent excessive loss of force due to mechanical factors and fatigue. Hence it is likely that more widespread availability of smaller keyboards will surely go a long way to narrowing the difference between and women in relation to achievement of a greater intensity of sound (and hence dynamic range) where needed.

A final question concerns the definition of a 'small hand'. As discussed above, many writers have only the vaguest idea of what is 'average, 'large or 'small', and have rarely thought about gender and ethnic differences. Kamolsiri (2002) defined 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) defined small hands as those that cannot reach a tenth. Putting these three different definitions into context (Boyle & Boyle, 2009), (Booker & Boyle, 2011):-

- A pianist with a span of about 7.5 inches (19 cm) can only just play a ninth 'on the edge' of the white keys; octaves are playable but not comfortable. Approximately 20-25% of adult females (and virtually no adult males) are at or below this level.
- A pianist with a span of about 8 inches (20 cm) can play a 9^{th} (but not comfortably) and an octave reasonably comfortably, but with more-than-ideal forward and backward movement in chromatic octaves, discomfort in 'cross-over' octaves, and often cannot play legato octaves. Fast octave passages are often associated with muscular tension in the hand. They cannot play a tenth. About 50% of adult females and less than 5% of adult males are at or below this level.
- A pianist with a span of about 8.4 inches (21.3 cm) can just play a tenth 'on the edge' and a ninth reasonably comfortably. Their octaves are very comfortable with no feeling of tension and they can move their fingers towards the back of the keyboard over the black notes enabling the performance of rapid chromatic octaves, and they can normally perform legato octaves. Only about 20-25% of adult females and approximately 80% of adult males are at or above this level.

The database being assembled by the author[7] includes measurements of pianists' active 2-5 spans. While data collection is still underway, it is apparent that a significant proportion of pianists (mostly female) do not have a stretch that allows them to play a very comfortable sixth using the second and fifth fingers, while larger-handed pianists can often accommodate a seventh or even an octave. Advanced repertoire frequently

[7] http://www.smallpianokeyboards.org/hand-size-and-the-piano-keyboard.html#hand

includes chords (or broken chords) where a stretch of a seventh (for example, C-D flat-C) is required.

My own survey of pianists using reduced-size keyboards includes pianists with active 1-5 spans of 8 inches and below – all of whom preferred the smaller keyboard over the conventional. One pianist included in the database has a span slightly larger than 8 inches and prefers a 15/16 keyboard.

Given the advantages of being able to play a tenth in much of the Romantic and 20th century repertoire, the desirability of having a relaxed hand when playing sustained octave passages, the ability to perform legato and rapid chromatic octaves, plus the advantages of control over dynamics, the need for a reasonably good stretch (ideally at least a seventh using second and fifth fingers) between the non-thumb fingers, freedom from muscular tension and the resulting technical ease, I would support the definition of Farias et al. (2002) and say that pianists with a hand span of less than around 8.5 inches (21.5 cm) are disadvantaged using the conventional keyboard if their aim is to play a wide range of repertoire.

5. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

This paper has summarised many of the benefits perceived by smaller-handed pianists when they play reduced-size keyboards. This exploration of underlying biomechanical and physiological factors attempts to provide a logical explanation for many of these benefits, with reference to soundly based mechanical principles, and more recent disciplines such as ergonomics and neuroscience. To the average lay person, it is 'common sense' that a pianist with larger hands will find the task easier (everything else being equal), given the wide variation in hand spans in the human population and the fact that the piano keyboard was designed to suit the larger half of the population.

Although some may say that certain small-handed (mostly female) pianists manage advanced repertoire very well, the key question is, how much better would they perform and how much more comfortable would they feel on a piano keyboard that is better matched to their hand span? As Ortmann (1929) said: *'In the fine adjustments used in piano playing even the slightest restriction is a hindrance.'*

Because technology has advanced so much since Ortmann's research was completed more than 80 years ago, and with the reduced-size keyboards now being available, the opportunities for research that confirm his experiments at a much higher level of precision, and explore the issue of hand span in relation to keyboard size, are almost unlimited.

Technology of the 21st century offers so many possibilities, including electromyography to measure muscle load, electrogoniometers (or joint-angle sensors) to measure joint motion (used by Wristen et al. (2006), as well as MIDI (Musical Instrument Digital Interface) systems. Yoshimura & Chesky (2009) used video recorders which clearly demonstrated the additional muscular tension and discomfort associated with use of the conventional keyboard compared with a reduced-size keyboard. Further research could involve comparing detailed aspects of performance excellence on keyboards of different sizes, comparing learning times, and in the field of neuroscience, one could explore impacts of hand span and related muscular tension on brain activity when pianists play the same excerpts or repertoire on different keyboards.

The widespread use and reliance on the Internet and increasing use of social media now provide the means of spreading awareness of the disadvantages of the 'one size fits all' approach to the piano keyboard that has prevailed for over a century, and generate sufficient momentum for change within the piano industry. The potentially massive market (most probably even greater than for the conventional size keyboard in the long term) should be evident when one considers the weight of evidence from many perspectives - performing arts health (epidemiology, clinical, direct studies comparing keyboards), performance excellence and success, this review of the underlying biomechanical and physiological factors, and from statistical analyses of hand spans related to piano playing tasks.

APPENDIX 1: SOME BASIC BIOMECHANICAL AND PHYSIOLOGICAL PRINCIPLES RELEVENT TO PIANO PLAYING

Laws of motion relevant to piano playing (Meinke, 1995)

- Momentum should assist the worker, and should be minimised where it does not.
- Use continuous curved motions rather than straight and/or sudden changes of direction.
- Use the least number of basic divisions (basic moving parts of the body) at the lowest possible classification (i.e. fingers, then hands, then arms).
- Wherever possible, work should be done with wrists in a neutral position, neither flexed not extended, nor deviated towards radial or ulnar directions.

Ortmann (1929)

- Differences in tone quality are made up of differences in tone intensity and duration, and in combinations of tone and noise.
- Tonal intensity depends entirely on key speed at the moment the key hits the escapement.
- Finger, arm and hand positions should allow joints to operate at the middle of their ranges.
- A muscle operates most effectively with relatively light loads rather than close to its limit.
- Economy of effort is fundamental to coordinated movement.
- Delivery of maximum force requires straight line skeletal positions.

Basic equations from Newtonian mechanics

F = ma = m($\frac{dv}{dt}$)

Momentum = mv

v = $\frac{ds}{dt}$

E = ½ mv^2

W = Fs

The Work (W) done by a resultant force (F) for an object to achieve a given speed (v) is equivalent to the kinetic energy (E) acquired.

P = $\frac{dW}{dt}$

F_g = mg

Where: -

E = kinetic energy

F = force

s =distance through which the force acts

m = mass

W = work

P = power

a = acceleration

v = velocity

t = time

F_g = weight

g = free fall acceleration due to gravity.

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As a child, Rhonda Boyle studied piano with Lilian Harvie in Geelong. She gained tertiary qualifications in science, environmental science and urban planning from Melbourne and Monash Universities and then pursued a career as a public servant in Victoria, working in metropolitan planning, environmental science and policy development.

Rhonda returned to the piano in 1999 as a student of Robert Chamberlain. In 2009 she purchased a 7/8 reduced-size keyboard for her piano and presented a paper: *Hand Size and the Piano Keyboard* at the 2009 APPCA Conference. She then teamed up with Sydney teacher Erica Booker to present a paper: *Piano Keyboards – One Size does not Fit All! Pianistic Health for the Next Generation* at the 2011 APPCA Conference.

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