The art of pianism meets science, sustainable performance: Use of arm weight

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Abstract

Playing the piano can result in intense muscular activity with the potential to cause injury to the hand and fingers. It was reasoned some time ago that technique had to be made sustainable. This resulted in the exploration of ways to make muscular use more economic in playing because even small energy savings are worthwhile in making technique physiologically efficient. The substantial changes in the musical environment including keyboards led musical theorists of more than a century ago to respond with technical concepts applying mechanical and physiological principles to technique based on efficient muscle use. One solution was to use arm weight with the assistance of gravity, an ever-present force affecting our body movements, particularly downward vertical movements.

Recent neuroscience research examined the effect on muscle activity by a process of lifting the hand and dropping it onto the keys and comparing with a downstroke generated at key level. Results showed that gravity could be used successfully, with enhanced efficiency of muscular use and a reduction in the finger-key force generated. Playing expressively with increased tempo or sound level intensified finger force, but increasing both simultaneously had a very more detrimental effect on force levels, particularly through increasing the sound level. It was also deleterious to movement organisation in these circumstances and could result in reduced performance time without fatigue. The outcomes of the studies are explained in terms of mechanical and functional principles.

The implications of the findings include the need to apply the findings to teaching strategies for application to performance itself. Piano practice also needs careful consideration and the need for education in injury prevention so individuals know how to protect themselves. Pedagogy aimed at teaching children is another urgent area of attention.

Key words: arm weight, physiological efficiency, non-muscular force, musicians, pianists, music teachers.

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Introduction

A primary goal of piano performance is for a pianist, when conveying musical images, to produce the appropriate tempo, dynamic, tone and timbre. It embraces a very complex skill, taking years of training for the achievement of proficiency. Performance is underpinned by the playing technique[1], the aspect of music we must control to allow concentration on interpretation to occur and as technique gains in command phrasing and expression takes shape. Technique itself encompasses the basic physical tools to create the necessary movement patterns, and the end-product relies on our capacity for physical movement through motor skills organizing movement by coordinating muscle and joint action. The necessary motor skills are controlled by the brain through the sensori-motor system and executed by the body, the musculo-skeletal system (MS) in particular. The resulting

1. The physical act of playing enabled by the complex system coordinating the intellectual and bodily demands implicit in a musical work.

complexities of the system which operates between the musical idea and the motor skills come within the ambit of movement science. The idea involves art but its execution has implications for the science of movement.

Playing a composition expressively means varying the delivery of key force to achieve the necessary dynamics and tempo. So under some circumstances, technique can result in intense and repetitive movement, the effects of which are exacerbated by the many hours of practice needed to meet a high playing standard leaving the body vulnerable to injury through overuse. At the same time, it is also necessary for playing to appear aesthetically elegant and effortless, so technique must be sustainable during a recital, and over the long-term working life as a professional pianist. However, the high-exposure to muscular activity to produce virtuosic movement patterns can cause micro-trauma to muscle and tendon tissues in the hand and forearm (Dennerlein, 2008). Human tissues are not designed for the repetitive, forceful actions needed and cumulative damage is a major cause of playing-related musculoskeletal disorders [PRMD] (Zaza & Farewell, 1997).

The prevalence of injuries in pianists is disturbing with reports of more than 60% of active piano players at some time experiencing muscular discomfort through to more serious symptoms such as tendonitis and focal dystonia (Bragge, Bialocerkowski & McMeeken, 2006; Bruno, Lorusso & Labbate, 2008). Today's typical professional training aggravates the problem by the perceived need to acquire a repertoire dominated by fast/loud playing thus setting the scene for injury to occur. The no-pain, no-gain attitude of young pianists increases the problem, because they do not wish to reduce practice time through admitting to a PRMD (Bruno et al., 2008).

A problem appears to be that teaching practice may not have changed sufficiently to meet the needs of the current music environment. We have moved on from earlier lighter keyboards played in small concert halls to present day conditions with heavier action and resistance in pianos, and the need for louder playing to fill the large spaces in concert halls. In addition, an avid musical public expects pianists to achieve physical motions of accuracy, speed and subtlety, in other words, almost the impossible (Kuerti, 2012). The number of piano competitions for young classical pianists has increased, and with it generated additional pressures. However, the problem with teaching practice responding is that a traditional approach to teaching still exists (Lister-Sink, 2004; MacKie, 2007). This makes it difficult for a change to occur now even though it is better understood how the structure and function of the body, and natural mechanical laws can enhance technique style.

Pedagogues in the early part of last century, realizing the new challenges to keyboard use began to re-think earlier ideas on playing technique by applying scientific thought. They hypothesised that arm weight could assist the fingers by using external force to drop the arm, and the term *use of arm weight* was coined (e.g., Matthay, 1903). This led to the concept of *muscular efficiency* to reduce muscle fatigue and tissue wear (Ortmann, 1929) by creating functional, economic movement patterns to meet the challenge of repeatedly performing the same movements. However, only recently have scientists such as performance neuroscientist had the tools to empirically analyse and quantify the benefits of using external force.

The objective of this paper is to review selected studies investigating the use of external forces relying on a downward forearm movement by using the weight of this segment to help generate key impact. It could assist the development of sustainable technique by focusing on cost-effective energy output while playing by keeping muscle activity to comfortable levels to allow focus on interpretation. First discussed are the relevant movement mechanics which are an outcome of the environment in which we live, followed by the empirical research investigating the implications to force generated by the fingers during keyboard use when varying the expressive components of the playing technique. The implications of the research findings are dealt with in the final sections.

Movement Mechanics

Gravity

Gravity is a pervasive phenomenon in which we live, and the body and each of its segments is acted on by this force, which causes all unsupported bodies to fall and despite their weight, at the same acceleration (rate of change of speed). Gravitational acceleration, being ever present in every-day life actions plays an important role in several body functions. For instance, organs of the vestibular system in the ear provide the central nervous system (CNS)2 with valuable information concerning spatial orientation, visual perception, and balance control (Pozzo et al., 1998). As a force affecting our bodily movements, gravity has been studied in the context of its compensation in vertical arm movements (Papaxanthis, 2003). Study of trained typists showed that successful use was made of it in the production of the finger fall onto the keys (Kuo et al., 2006). However, typing a computer key does not typically require graded exertion of finger force as needed with keystrokes to provide the tone and timbre needed.

Although the rate of acceleration does not change with the weight of objects, what does change is their momentum[3], so in music this means that greater impact force can be imparted to the keys. In addition, higher falls build up greater speed, so the larger the momentum with a similar effect on the impulse that can be delivered. In music this applies to the height of the hand above the keyboard. So whereas the traditional approach of playing with the hand at key level may not generate enough impact, lifting the hand first could prove to be beneficial. Therefore, research was needed to test this idea by increasing the understanding of how to work with gravity to lessen muscular activity and the resulting energy expended. Allied to gravity is the natural law stating that *for every action there is an equal but opposite reaction* (Newton's third law of motion), and this becomes relevant when the fingers deliver a force to the keys, because a rebound motion occurs initiating the lift for the next downswing.

Structure and Function of the Arm-Complex Muscles

Both the upper and lower limbs have evolved with larger muscles high on the limbs, and smaller ones at the periphery – the hands and feet, basically to lighten the load having to be moved in everyday actions. The other characteristic of the limbs is that they are made up of different segments which interact to make movement, resulting in the important function of load sharing which also contributes to economic muscle use. The muscles situated in the hand are very small and have little endurance, so the larger muscles on the arm help to move the fingers. Larger muscles have greater endurance (Herzog, 2000) so there is a decided advantage in deriving energy from larger muscles. Therefore, use of momentum transfer from the larger muscles of the arm ensures fast and accurate movement for longer periods contributing to technique sustainability. If this does not happen muscles situated on the forearm are active in assisting finger force, and these have long tendons passing through the carpal tunnel (see Figure 1). This is the anatomical structure responsible for carpal tunnel syndrome, to which females are particularly susceptible (Brandfonbrener & Kjelland, 2002).

2. CNS – includes the brain and spine

3. Momentum – a measure of the weight of an object and the speed at which it is travelling.

The Research and Arm Weight

(i) Gravity and the Downswing

To clarify whether pianists could successfully use the downward force of gravity to produce the downswing, muscular activity was investigated while playing right-hand octaves (Furuya, Osu & Kinoshita, 2009). Expert pianists all of whom had won international prizes were compared with novices, and the experimental set-up is illustrated in Figure 2. The trunk is inclined forward, with elbows clear of the trunk and the elbow is positioned at an angle between 100-110º, the position that allows the muscles to lift the forearm faster.

The expert pianists successfully relaxed the forearm muscles, showing clearly that the forearm was in free-fall, whereas the forearm was lowered by the novice pianists using muscular action, and so adding to the energy cost. The authors concluded that, for the experts, the energy for the key force was not generated solely by the muscles operating the fingers but by larger muscles of the upper-arm and shoulder which transferred energy to assist the smaller muscles.

This study showed that gravity can be used to make the downswing energy-efficient and so this study provided evidence supporting early opinions that proposing that the weight of the forearm could be used to provide the energy for a keystroke. The rest of the investigations used the struck and pressed touches for comparison.

Figure 1: The illustration shows there if limited space in the carpal tunnel so when the tendons get inflamed with muscle overuse, the median nerve which innervates the finger muscles is pressed against the transverse ligament.

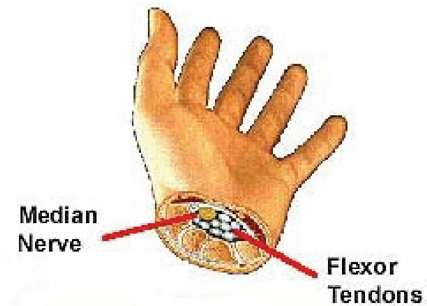

Image courtesy of www.carpal-tunnel.com

(ii) The Keystroke with Increasing Sound Level or Tempo

Varying loudness or tempo are both necessary adjuncts to playing, and finger force was determined using force transducers in the keys, with classical pianists. Each played with the the struck touch which is initiated after lifting the arm to above the key surface, and pressed touch which emanates from key level. Performance of an octave was used to study the impact of increasing the sound level at four dynamic increments from *piano* to *forte* (Kinoshita, Furuya, Aoki & Altenmüller, 2007). Tempo ranged from 70 to 260 bpm and was examined by alternately striking two keys an octave apart (Furuya, Goda, Katayose, Miwa & Nagata, 2011)

Figure 2: Experimental set-up for neuroscience research on piano playing technique. The keys are fitted with force transducers, and the pianist has joint markers and EMG electrodes on the arm complex for research data collection.

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In both conditions, the struck touch showed lower finger force levels at *forte* when compared with the pressed touch. Muscle activity was needed at key contact in the loudest and fastest conditions to provide greater control of the finger-tip. The struck touch produced higher hand acceleration and it was delivered faster. By contrast, the pressed touch needed longer application time to generate the required amount of force for key strike. Downward movement of the hand at the wrist was greater with the struck touch producing forward motion of the forearm. This movement raised the forearm for a vigorous key depression and louder and faster sound (Furuya et al., 2006) because more force is transmitted from the finger to the key when the end of the finger is perpendicular to the keys.

These findings suggest that for the struck touch, the large force at *forte* was due to the combined effect of greater energy transfer from the muscles of the upper arm and shoulder. The pattern of force delivery with the struck touch showed a rapid initial impact at *fortissimo* sound level; whereas the pressed touch needed a longer period of muscular action to deliver the force level needed. In addition, expert pianists had greater finger acceleration, and increased muscle activity to stabilise the finger joints was also need at the highest sound level, although not at the lower sound levels. Because high finger force results in greater precision of finger placement is needed (Fitts, 1954).

The struck touch in the alternate finger strikes resulted in higher movement paths of the thumb and little finger indicating that gravity was assisting the downstroke. In addition, this would have been complemented by rebound to lift the thumb or little finger quickly

(iii) Interaction of Loudness and Tempo on the Keystroke

To establish the effect of increasing both tempo and sound level simultaneously, eighteen skilled pianists played octaves with a combination of four each tempi and sound levels (Furuya, Aoki, Nakahara & Kinoshita, 2012). At fast tempo, muscle activity and finger force showed a progressively greater increase with loudness level, rather than an increase at the same rate.

However, not all pianists used the same movement pattern, and three variations were differentiated. The least successful patterns showed decreased speed in the elbow and, an increased movement speed in the fingers indicating a greater reliance on both the muscles in the hand and on the forearm. The most efficient group raised the wrist faster as sound level increased to place the fingers in an optimum position for force transfer and movement speed of the elbow joint increased indicating greater muscular activity from the larger muscles and assisting with efficient muscle use. Pianists in this cluster were international piano competitions winners, and only they were able to use gravity at higher tempo/sound level combination to prepare for the next keystroke.

(iv) Psychoacoustics – Perceived Timbre

Touch is known to create different audience perceptions of timbre (Goebl, Bresin & Galembo, 2004) which suggested touch type might be used to manipulate tone timbre. Therefore, differences between listener impressions of tone timbre when pianists used the struck or pressed touch were determined in a psychoacoustic experiment (Furuya, Altenmüller, Katayose & Kinoshita, 2010).

Listener reaction gauged in this study was that the struck touch appeared louder and the pressed touch softer. This indicated the difference is related to the key-force profiles, which is known to influence acoustic qualities (Kinoshita et al., 2007). As discussed above, the struck touch produces a rapid initial force with earlier movement of the key in comparison with the pressed touch. The pressed touch with a more gradual force development lengthened the acoustic qualities, leading to the conclusion that in spite of relative inefficiency over the struck touch, the pressed touch is indispensable in accomplishing soft tone timbre. So when loud timbre is needed, particularly during fast playing the struck touch is more physiologically efficient. In contrast, the pressed touch indispensable in producing sustained mellow timbre needed for cantabile playing (Furuya et al., 2012). So it belongs to fine movements and uses a relatively extended finger posture rather than curved.

Discussion

Playing technique is connected intimately with performance by providing movement patterns produced automatically to give the performer the opportunity to exhibit musicianship. This means that the playing technique must be physiologically efficient so playing looks unforced, and the pianist's concentrated can be dedicated to the aural effect and intelligent phrasing. The objective of this paper was to explore the use of external forces such as gravity in the downward motions of the forearms/hands to reduce muscular effort in playing. The research showed categorically that external force can be used successfully when applied by dropping onto the keys from above the keyboard, as long as muscles are relaxed during the downswing (Furuya et al., 2009). The findings indicated that pianists using the struck touch needed muscular assistance only at high tempo or sound levels for stiffening the finger joints for added precision. It also helped by producing lower force levels than with the pressed touch (Furuya et al., 2011). Finger force was also delivered faster with the struck touch through the increase in momentum which in turn increased the impact force resulting in greater physiological efficiency than the procedure needing a more sustained delivery of force.

Gravity has been shown to be useful to muscle activity in finger movement in typists (Kuo et al., 2006) and undoubtedly assists in the actual finger fall in playing the piano with curved fingers so as also to deliver greater impact force to the keys (Furuya et al., 2006). The contribution of gravity is noted also in hand and finger motion in alternating movements an octave apart with the bouncing movement, particularly when playing at a fast tempo, as long as the hand is held above the keys, so more force is delivered by one digit which then creates a reaction force to help with the alternating action for the other digit (Furuya et al., 2011). The evidence is strong that starting a keystroke from higher than key level is a valuable procedure in facilitating economic movement patterns in playing. It is essential also that reaction force not be inhibited at the end of force delivery because of unnecessary muscular contraction to do so. Correct training should build the motor skill to relax muscles after force has been absorbed in the keystroke.

The struck touch allowed playing octaves in the most efficient way, *staccato* touch and movement in alternating finger action which can be extrapolated to the action in trajectories of the hand and fingers in a leap across the keyboard. On the other hand, the traditional touch is far better for a warm, full-bodied legato sound needed in so many compositions. Extending the fingers while initiating the keystroke from keyboard level, rather than curving them is important because the fleshy pads of flatter fingers allow a bigger skin area to touch the surface of the key (Parncutt & Troup, 2002). Audience members in a live performance are also affected by their visual impression, so the latter type of playing induced emotions differing from those resulting from fast and loud playing which can leave the impression of loss of phase shape with regard to the theme (Schutz & Lipscomb, 2007).

Efficient muscular activity through the use of gravity and its associated mechanical laws can assist in preventing fatigue while playing compositions of long-duration especially sonatas which traditionally have fast first and third movements. This is important because fatigue causes a potential loss of accuracy making increased muscular action necessary to control the fingers necessary for touch precision (Fitts, 1954). This thinking also attaches to choice of repertoire for a competition, sometimes involving three scores being played concurrently, or during a concert performance.

Implications for Injury Prevention

Most medical problems of musicians are the shared consequence of performance technique and repertoire interaction with the physiological limitations of the MS tissues and restrictions of the skeletal architecture. The latter favours rotational and curvilinear motion, although the keyboard is linear which implies having to use greater muscular activity. Pianists are particularly prone to injury and the finger/hand has a high rate of PRMDs with overuse of muscular tissues a primary causal factor (Brandfonbrener & Kjelland, 1992). Some of commonly reported severe cases are carpal tunnel syndrome, and tendonitis developing in the forearms and hands (Fry, 1991; Pak & Chesky, 2001).There is some evidence that pianists using arm weight experience fewer injuries through working with, rather than against gravity (Allsop & Ackland, 2010). Of concern was that not all trained pianists had the motor skills to play at high tempo and with increasing sound level to keep muscular activity at a minimum (Furuya et al., 2012), so there existed the potential for stress to tissues (Fry, 1991). Very small intervals between keystrokes appear to hinder proper organisation of the downstroke increasing muscular control of the fingers. This also has needs to be considered when organising practice strategy, particularly in the early learning stage of score preparation in helping to establish efficient movement patterns.

A concerning finding was that of increased stress of playing loudly with fast tempo resulting in almost continuous keystrokes (Furuya et al., 2012) with implications for fatigue and maintaining an efficient technique. Plus, given its high toll on the body, it is important for preventing injury in active pianists performing long hours of practice daily (Jabusch, Alpers, Kopiez, Vauth & Altenmüller, 2009). Help also needs to be given to students to plan practice strategies to reduce muscular overuse.

Benefits from even small increases in movement efficiency make good sense, particularly with repetitive force application. This implies also that time spent in active practice may need to have duration decreased, with an increase in mental practice. The strategies used by the expert pianists making full use of external forces, and in transferring energy from larger muscles to smaller are undoubtedly helpful in preventing injury. These are key factors for the stress related problems induced by finger force, and have important implications in the prevention of over-use injuries (Furuya et al., 2006). Early treatment of injury is to be preferred, but students have a fear of being told to cease practice, whereas some degree of customary musical activity is preferred, because it helps retain facility. In addition, tissues retain elasticity and vascularity even when the duration of use is reduced (Brandfonbrener & Kjelland, 2002).

Practice

Practice is a major activity in score development, because it becomes more prolific and concentrated at the tertiary level, and as most PRMDs occur with overplaying of some sort, and can become chronic, what happens in this time must be considered. It is important, therefore, that individual students be given instruction on how to organise practice-time. This means planning the duration of active and rest periods, and the order in which the skills are practiced so there is a warm-up period. Active periods should be aimed at reducing the potential for muscular overuse, remembering also that with increased work periods, as people become fatigued, their mental focus and accuracy decline. Research shows that it is not necessary always to practice in an active way, and other methods can lead to the same increases in neuronal development. Mental rehearsal is a cognitive process that complements physical rehearsal and helps lead to the development of performance expertise. For the performer, musical ideas are primarily registered in written notation, and mental rehearsal can take place with or without the score. Studying a score silently has benefits for musicians, and can enhance the quality of the eventual performance (Bravo & Fine, 2009). Practice methods being such an important field, they need to be tailored to the individual student.

There is also the question of how the practice regime fits score development. Slow practice seems the best way to begin because practicing piano keystrokes at fast tempo or loudly too early may have the risk of preventing the acquisition of skilful movement coordination. Spatial accuracy demand becomes higher with an increase in tempo and loudness (Fitts, 1954) so that so it is safer that training begins at a slower tempo (Furuya et al., 2012), and only when movement patterns are well established should work proceed at increased tempo with augmentation of sound levels later, or when necessary.

Motor Skills

Pianists must acquire appropriate motor skills to precisely control the timing of the muscular relaxation phases in the downswing and keystroke, the force needed, and the coordination movements of multiple joints in the hand and arm for accuracy and expressiveness. This requires highly skilled motor action (Bernstein, 1967). The pianists more successful in dealing with increased tempo and loudness showed they had developed specialized motor skills for virtuoso performance. The researchers implied that the needed motor skills develop after years of training by pianists with an innate talent to refine neuromuscular system control, (Furuya et al., 2012). It remains a mystery why some pianists can maintain virtuosic performance throughout a two-hour concert (Furuya et al., 2009). This, however, raises the question of the likely impact of the way students are taught right from their early years, so they have years of practice to develop the special facility needed. This, in turn raises the question of when to begin training in efficient playing procedures.

Skill Acquisition in Children

Neuroscience research shows that training children before seven to eight years can assist in developing special motor skills when the brain is most plastic (Altenmüller & Gruhn, 2002), and technical concepts such as arm weight can be introduced quite early (Kase, 2001). Such training has the potential to educate children about the use of their body in playing when they are receptive. It is also more cost-effective to learn good skills from the start rather than having to retrain pianists at a later stage. The automation of motor skills involves building extensive neuronal networks, and unlearning them means destroying present networks and building others to compensate, and this is counterproductive with both time and energy use (Altenmüller & Gruhn, 2002). Therefore, pedagogy should aim at methods to train pianists early to establish motor skills in the optimum way.

The Importance of Applications of Research Findings to Training

The use of proven protective mechanisms rely on academics actioning relevant scientific research findings. In its absence, teachers may not be equipped to prevent potential injuries to students especially at a time training becomes most intense. The result is that some pianists are robbed of future careers as elite pianists (Bruno et al., 2008). Proper training is the responsibility of the teaching facility, and there are legal implications with not providing direction to both music teachers and students. A not fully understood complication is that professional music teaching facilities have a *duty of care* under occupational health and safety law to manage potential risks to their students by way of meeting their legal responsibilities in relation to training and information (Bennett, 2007).

Each Australian state has enacted relevant laws with obligatory codes of practice addressing risk management. It is also a matter of best business practice, because it is less costly to the individual and to the community in the long-run. As overuse injuries are one of the identified problem areas, a policy such as has been established by RMIT University may be needed to indicate that health and safety is being attended to adequately.

Conclusions

This paper considered how an efficient and sustainable piano playing technique can bring benefits to playing expertise while protecting the MS structures on which technique relies for the sort of repertoire we expect them to learn, practice and perform. Consideration of areas related to playing technique prompt the following conclusions:Pianists need to continue work without physical discomfort and injury, and to ensure all students must have knowledge of causal factors for injury, and how to protect themselves as most injuries are preventable if early symptoms are recognised. When considering the financial outlay also consider how costly it is for the time of the pianist and community medical resources. This appears also to have overriding legal connotations.

Debate is needed on changes to the music education curriculum, by identifying areas in which it is best to instruct student so they have a holistic understanding of the needs of performance as affected by their brain/body interface, and interaction with their instrument. Certainly information needs to be given on injury recognition, and how they can help themselves in resisting the known causes of overuse.

Teaching is a very important area, and its goal is to help players find and experience a piano technique enabling musical expression. It is therefore a responsibility of tertiary educators to promote the study of pedagogy to ensure future students know how to produce a sustainable technique through teachers having a good understanding of skill acquisition in both pre- and post-pubertal young people. These two groups are at different levels of brain and MS development, and these need to be considered as the study of sport has done.

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