Article

Wrist Internal Loading and Tempo-Dependent, Effort-Reducing Motor Behaviour Strategies for Two Elite Pianists

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One of the greatest challenges in reducing high rates of performance injuries among musicians is in providing them usable tools to address playing-related musculoskeletal problems (PRMP) before they become disorders. Studies in biomechanics have the potential to provide such tools. In order to better understand the mechanisms through which PRMP manifest in pianists, especially in the distal segments of the upper limbs, the current study quantifies wrist internal loading (WIL) and wrist impact loading frequency. It does so while discussing pianists' motor behaviours and observed effort-reduction strategies in the wrists as a function of anthropometry. This concept has great utility for performers. A VICON 3D motion capture system documented two expert pianists performing a B major scale, hands together, at 4, 6, 8, 9, and 10 notes/sec. Biomechanical modeling quantified WIL. Changes in motor behaviour were observed at 8 notes/sec. Individualized anthropometry influenced the range of motor strategies available to each pianist. The pianist with the larger hand span employed a flexion/extension wrist strategy as a compensatory means for effort reduction, while the pianist with the smaller hand span employed a radial/ ulnar deviation strategy. The current study provides a new perspective in addressing PRMP among pianists by rationalizing anthropometric potentials in terms of ergonomic parameters and documenting the availability and utility of effort-reduction strategies in the wrists during piano performance as performers consider PRMP risk and avoidance. *Med Probl Perform Art* 2021;36(3): 141–149.

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SINCE PERFORMING MUSIC involves highly complex and repetitive low-load motor behaviours which must be precisely executed, all musicians can benefit from research dedicated to improving mechanical efficiencies during performance.(1) Playing-related musculoskeletal problems (PRMP), disorders (PRMD), and pain prevalence among adult and/or professional musicians are common, with rates as high as 60% to 87%.(2–7) For pianists, rates are documented from 60.6% to 77%,(8–10) and they most frequently occur in the neck, back, shoulders, elbow/forearm, wrists, and hands.(3,8,11) Problems include neurological disturbances (such as carpal tunnel syndrome), enthesopathy, tendinitis, tenosynovitis, and more.(12) Wrist PRMP are common, with 24% to 36.6% of pianists affected.(9,11,13–15)

In piano performance any injuries or pain will affect force production and inhibit motor behaviors, lowering performance quality. In a perfection-driven vocation, consequences of this can be dire.

> The wear and tear of playing an instrument are unseen by the audience, yet the consequences are all too familiar to many professional musicians. . . . For a soloist or a freelancer, there is no equivalent of baseball's disabled list—no performance, no income. (16)

Identified injury risk factors for piano performance include: insufficient warm-up and cool-down time, sudden increases in playing time, playing for more than 60 minutes without a break, practicing for more than 20 hours/week, playing technique, adverse working conditions, lack of exercise, hand size, and genetics.(8,17,18) Additionally, female musicians have been shown to experience higher complaint rates than males,(8,9,14,19,20) although this finding could be an artefact of workplace culture and reporting.(8,21)

The current paper postulates that, since playing the piano requires both gross and fine motor behaviours using an instrument that has fixed dimensions and is immobile during performance, pianists' occupational injuries should be recognized, in part, as an ergonomic problem.(22) As loading and the cumulative effects of long-term activity involve internal biologic processes, the current paper extends application of motion capture and biomechanical modelling to the case of music performance. These technologies have proven to be an effective indirect method of

FIGURE 1. The B major scale performed by the participants.

measuring the effects of activity in sports[23] and have shown utility in doing so for music performance.[24–26] The current research contributes to existing knowledge by providing kinetic analysis of wrist movement for a standardized piano performance task; the wrists are the location of the highest injury rates in the upper limbs.[11] Analyzing load intensity, frequency and duration is a generally accepted means of identifying physical workload associated with occupational tasks.[26,27] The objectives of this study were to quantify internal loading in the wrists of two expert pianists and discuss observed differences in motor behaviours in terms of ergonomics, anthropometry, and effort-reducing performance strategies.

METHODS

Data Collection

Drawing on the upper-body biomechanical model established by Shan and Visentin,[28–31] the current study utilized a 10-camera VICON MX40 motion capture system (3×3 Designs Ltd., Coquitlam, BC, Canada) to record and synchronize kinematics for two expert pianists. Data were collected at 200-Hz frequency with sub-millimetre accuracy (<0.6 mm calibration error). Fourteen 3M™ Super-Reflective Tape markers (VICON Motion Systems, Oxford Metrics Ltd., Oxford, UK) essential for the upper body biomechanical model were placed on the following anatomical landmarks: the sternal end of the clavicle, xiphoid process of the sternum, C7, T10, and the right and left acromion, lateral epicondyle, radial styloid process and ulnar styloid process. Reference markers were placed as follows: 2 on the front of the head, 2 on the back of the head, 1 on the right scapula, and 1 on each of the left and right humerus and forearm. Additionally, 88 markers were placed on the white and black piano keys to identify keystroke accuracy.

From the kinematic data, computer reconstruction permitted modeling of the skeletal structure and its movement. Inertial characteristics of the body were estimated using anthropometric norms embedded in VICON's motion analysis software following the standard practices in the field of biomechanics.[32,33] The biomechanical model quantified a value for wrist loading by using inverse dynamic analysis.

Participants

Two expert pianists, one male and one female, were recruited for the study. Both participants were right-handed, had doctoral degrees in piano performance, and were employed full-time as piano teachers and concert performers. The research protocol was approved by the Human Subject Research Committee at the University of Lethbridge (approval #2018-098). Participants gave written informed consent prior to their participation in the study.

Experimental Protocol

The protocol consisted of a modified B major scale played at a moderate volume and at different speeds. B major is a fundamental scale in piano playing because the black and white key combinations are complementary with a typical hand shape (length of the fingers). The scale was performed hands together in overlapping two-octave gestures, both ascending and descending (Fig. 1).

Five tempi were used: 4, 6, 8, 9, and 10 notes/second (N/s), representing a wide range of playing speeds with greater coverage at the fastest tempi where playing demands begin to become extreme. Data were collected in a concert hall where participants used a 9-foot New York Steinway concert grand piano. Participants adjusted bench height and seating distance from the keyboard according to personal preference and were permitted to warm-up for as long as they needed to feel comfortable with the instrument and the experimental environment. Anthropometric measurements necessary for biomechanical modeling and active range of motion (ROM) of the wrists were documented. For hand size, width was measured from the tip of the thumb to the 5th distal metacarpal while hand length was defined from the wrist to the 3rd distal metacarpal. Wrist ROM was quantified by asking the participants to move both wrists as far as possible in all planes of motion. Using motion capture and modeling, the wrist ROM values were determined. Finally, using the Beighton hypermobility protocol, it was determined that neither participant exhibited hypermobility in the upper limbs, including the wrists and fingers.

Data Processing and Analysis

Data were processed and analyzed using VICON Nexus software and Microsoft Excel 2017. The biomechanical model was based on a rigid-body system with multiple segments: head, trunk, shoulders, upper arms, forearms, and hands. Using inverse dynamic analysis, joint moments for the wrist were calculated from both kinematic data and the anthropometric properties of participants' hands. It

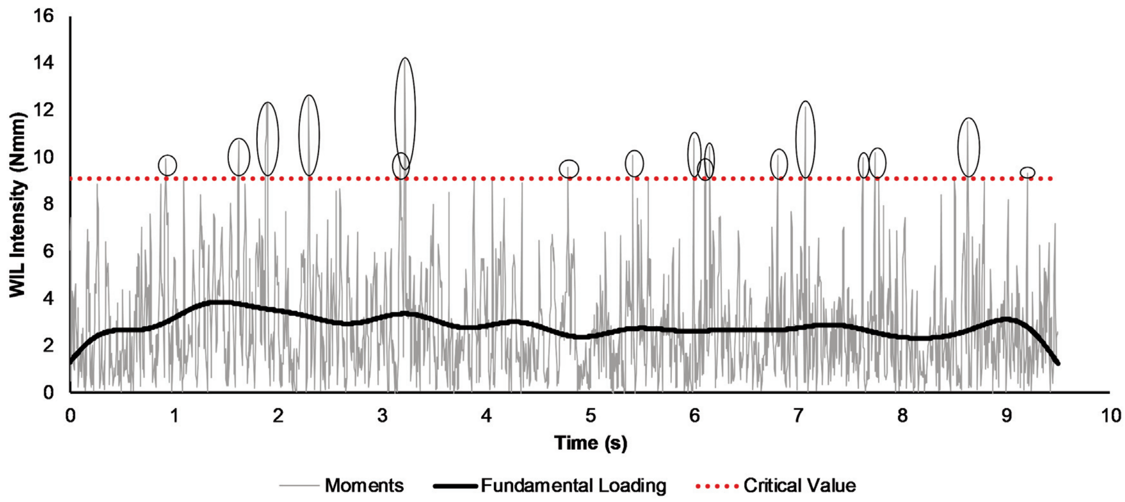

FIGURE 2. FL, IML, and CV for a single trial at 10N/s. The average FL and CV are equal to 2.66 Nmm and 9.09 Nmm, respectively. The short duration circled peaks represent the IML.

should be noted that, in using this model the calculated wrist moment is a net moment generated by muscles around the wrist, i.e., net muscle loading. Thus, in the current study, wrist internal loading (WIL) data are idealized, where no inefficiencies from extraneous co-contraction of agonist and antagonist muscle groups are considered. This should be considered a minimum loading calculation when analysing injury risk. Actual muscle loading could be significantly higher depending on a pianist's efficiency of coordination. Well-trained pianists should have more optimized coordination amongst agonist and antagonist muscle groups than novices.

For low-load activities such as playing a musical instrument, fundamental loading (FL), the basic muscle workload used by an individual at his/her current level of motor skill development, may be very small. Quantification of cumulative load requires consideration of load character as well as duration of activity; both contribute to risk profile. Since, for a biologic system, load intensity is a variable that changes during the course of an activity, points where load intensity is greatest can be identified and examined for the possibility that motor efficiencies may be found.[26] In the current study, an activity-specific maximum for WIL was determined for each trial by averaging the three highest WIL data points. 70% of this calculated maximum WIL was used as a critical value (CV) threshold so that load variability during each trial could be examined. As seen in Figure 2, the fundamental load, shown in black, was determined using a Fast Fourier Transform (FFT) function.

This process permitted a means for WIL to meaningfully quantify intensity of wrist movement and permit the examination of three tempo-dependent loading (work) characteristics of wrist movement: 1) the torque due to movement, 2) motor strategy distribution of torque in terms of flexion/extension (flex/ext) and radial/ulnar deviation (rad/uln), and 3) performance strategies that might be complementary between left and right wrists.

Impact loading (IML) frequency was defined as the number of times that WIL exceeded the CV for each trial. IML frequency was employed as a way to measure and evaluate workload distribution. The presence of tempo-dependent changes in IML frequency provided opportunity to examine how each performer employed alternative motor strategies to decrease work as the demands of the protocol challenged their functional limits. When and how this is accomplished reveals information about motor strategies preferred by each performer.

RESULTS

Anthropometric and Mobility Testing

The two subjects tested were anthropometrically different from each other. The male was significantly taller than the female (1.9 m and 1.645 m, respectively) and hand span, hand length, forearm length, and upper arm length were greater for the male (hand span 20.3 cm; hand length 21.9 cm; forearm length 27.0 cm; upper arm length 33.1 cm) than the female (hand span 17.8 cm; hand length 17.2 cm; forearm length 25.3 cm; upper arm length 28.9 cm). Wrist ROM was greater for the female than for the male: R(flex/ext) 93.3° vs 89.8°; R(rad/uln) 43.0° vs 21.1°; L(flex/ext) 126.7° vs 103.5°; L(rad/uln) 52.5° vs 30.5°. For both participants, the left wrist had a greater ROM than the right.

WIL Intensity

Inverse dynamic analysis revealed two types of WIL. WIL data points above the 70% CV were identified as impact loads (IMLs) (circled peaks in Fig. 2). These were due to abrupt changes in wrist movement.[28]

Load intensity was low for both subjects, a finding which was expected given the nature of the task (for exam-

TABLE 1. WIL Intensity and IML Frequency as a Function of Tempo in All Planes of Wrist Movement (Both Wrists)

Tempo (notes/sec)	Wrist Plane of Movement	Female: WIL Intensity (Nmm)	Female: IML Frequency: Individual Planes of Movement	Male: WIL Intensity (Nmm)	Male: IML Frequency: Individual Planes of Movement
4	R(flex/ext)	0.83	20	2.38	19
	R(rad/uln)	1.3	23	1.91	19
	L(flex/ext)	0.85	15	2.07	26
	L(rad/uln)	1.27	22	1.81	15
6	R(flex/ext)	1.01	18	3.48	38
	R(rad/uln)	1.49	25	2.62	9
	L(flex/ext)	1.2	17	2.94	8
	L(rad/uln)	1.5	10	2.57	9
8	R(flex/ext)	1.38	9	3.36	30
	R(rad/uln)	1.9	15	3.08	10
	L(flex/ext)	1.48	25	2.97	18
	L(rad/uln)	2	10	3.06	21
9	R(flex/ext)	1.52	12	3.35	24
	R(rad/uln)	2.03	33	3.36	13
	L(flex/ext)	1.64	15	2.99	9
	L(rad/uln)	2.2	9	3.34	16
10	R(flex/ext)	1.19	11	2.87	19
	R(rad/uln)	1.43	20	3.27	8
	L(flex/ext)	1.91	17	3.36	9
	L(rad/uln)	2.43	23	3.72	18

Note: A Newton millimetre (Nmm) is a unit of torque equal to the force of 1 Newton being applied to a moment arm which is 1 mm long.

ple, wrist torque during tennis is 50x greater than those found in the current piano performance study).[34] Table 1 identifies WIL intensity and IML frequency at all tempi for all planes of wrist movement (right and left wrists).

WIL intensity for left and right wrists of each performer as a function of tempo is shown in Figure 3. Loading was consistently greater for the male (1.81 to 3.72 Nmm) than for the female (0.85 to 2.43 Nmm). For both performers, left WIL increased steadily as tempo became faster. For the right WIL, intensity increased for both performers until 9 N/s, where it started to decrease.

An examination of WIL intensity broken into requisite components (rad/uln and flex/ext) as a function of tempo is shown in Figure 4. For the female, across all tempi, WIL intensity was consistently greater for rad/uln than flex/ext in both wrists. Intensity increased steadily as

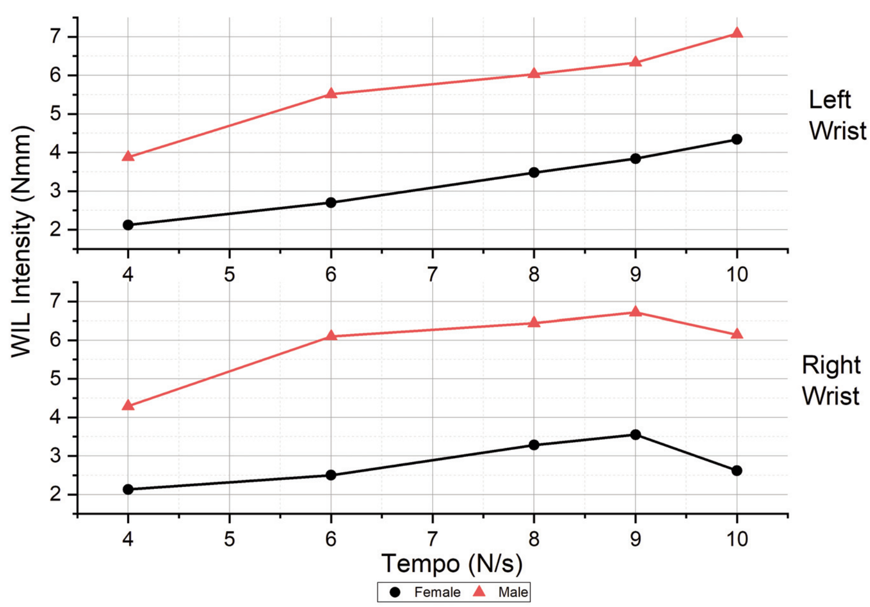

FIGURE 3. Left and right WIL intensity (totals of rad/uln and flex/ext) for the female and male pianists as a function of tempo.

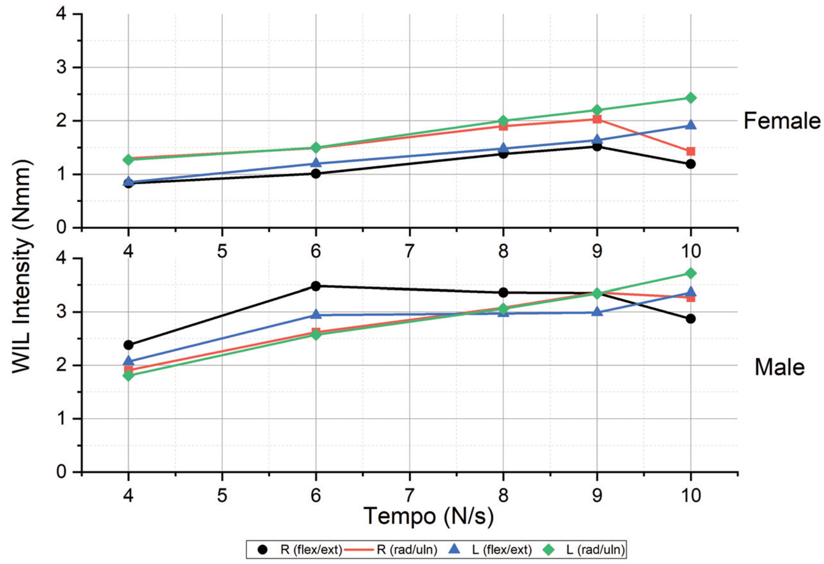

FIGURE 4. The female and male pianists' WIL intensity in the x and y planes of both wrists as a function of tempo.

tempi increased except at the very fastest tempo (10 N/s) where intensity sharply dropped for both R(rad/uln) and R(flex/ext). For the male, intensity in both wrists was greater for flex/ext than for rad/uln at slower tempi, and was lesser at the fastest tempo. Also, for the male, rad/uln increased for both wrists as tempo increased; flex/ext, however, increased only briefly, plateauing at 6 N/s. At the highest tempo WIL intensity of the right hand decreased (both planes of movement) while WIL for the left hand increased for both performers.

IML Frequency

Across the tempi tested, variation in IML frequency (all planes of movement) reveals distinct profiles for each of the subjects. IML frequency totals (sum of flex/ext and rad/uln for each wrist) and averages as a function of tempo are shown in Figure 5 (top row). For the female performer, the average IML decreased from the slowest tempo until 8 N/s, after which it began to increase. As well, left and right wrist IMLs are alternatingly high from 6 N/s to 10 N/s. For the male performer, except at the slowest tempo (4 N/s), the right wrist always exhibited higher IML frequencies than the left. His average IML remained virtually unchanged from 4–8 N/s, whereafter it began to decrease.

Figure 5 (bottom row) shows IML intensity broken into requisite components (rad/uln and flex/ext) as a function of tempo. For the female, IML frequency varied more for rad/uln deviation than for flex/ext in both wrists; right wrist rad/uln IML frequency varied from 15 to a peak 33 and the left wrist rad/uln IML frequency varied from 9 to 23. In both cases, greatest rate of change (steepest slope) occurred at higher tempi. For the male, the opposite holds true. IML frequency varied more for flex/ext than for rad/uln deviation in both wrists; right wrist flex/ext IML frequency varied from 19 to a peak 38 and the left wrist flex/ext IML frequency varied from 9 to 26. IML frequency for L(flex/ext) generally decreased as tempi became faster. For R(flex/ext) there was a sudden increase in IML frequency between 4 to 6 N/s that was followed by decreases at all other tempi.

DISCUSSION

In the current study, tempo was an independent variable, which permitted observation of alternative motor behaviors invoked by study participants to accommodate changes in playing speed. As a case comparison, the large difference in physical statures of the two subjects provides a means to consider results in terms of ergonomics and anthropometric capacity. This study begins a process of documenting the relevance of compensatory strategies, based in applied biomechanics, for music performance.

WIL Intensity

From a performer's perspective, reduction of movements that serve no purpose in forwarding musical outcomes has practical benefits: 1) extraneous movements undermine fine motor skill accuracy and repeatability, making the control of outcomes more taxing than necessary, and 2) since the development of PRMP has been shown to be related to loading type, loading intensity, and duration of activity[26] minimizations of physical effort should result in a reduction of injuries. The motor task of the protocol required participants to execute between 480 (slowest tempo) and 1,200 (fastest tempo) keystrokes per minute using both hands moving mediolaterally over a keyboard distance of 84.5 cm. The fine motor behaviour and intensity demands of this protocol clearly challenge the limits of human capacity; the difficulty is in finding parameters that meaningfully characterize performers' responses to these challenges.

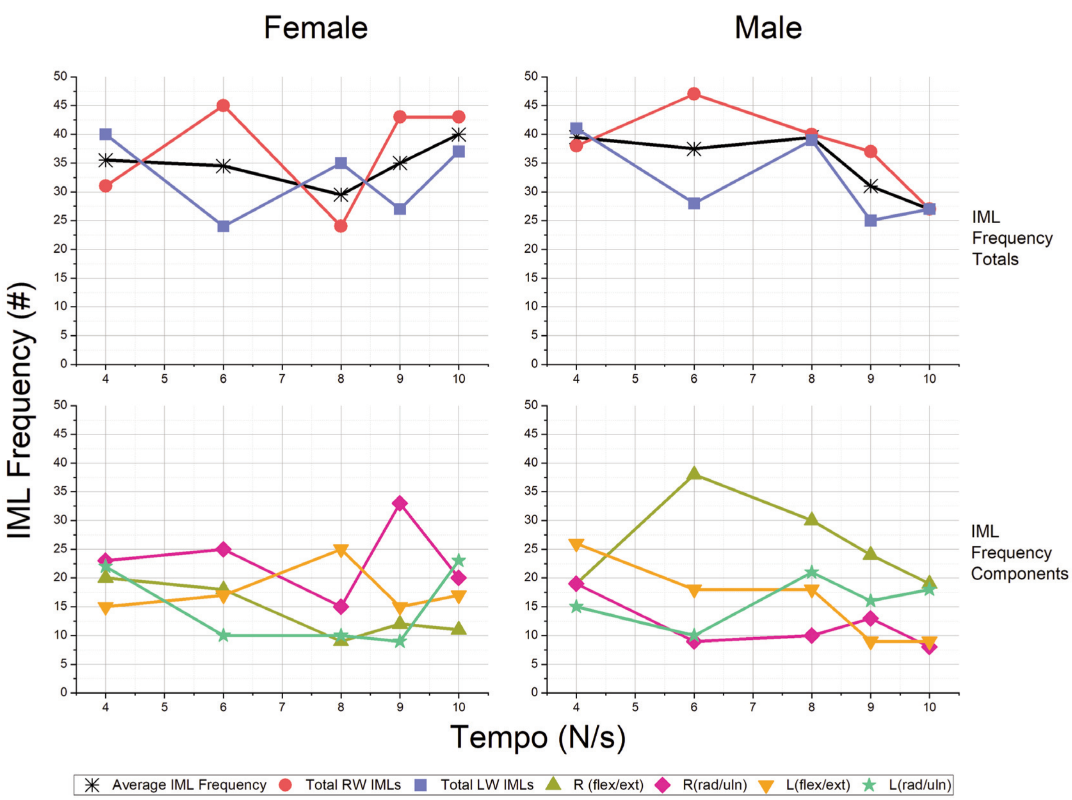

FIGURE 5. *Top row*, The female and male pianists' IML frequency totals (the sum of flex/ext and rad/uln for each wrist) and the average IML frequency for both wrists. *Bottom row*, The female and male pianists' IML frequency components (flex/ext and rad/uln) in the wrists as a function of tempo.

In the present study, WIL was used to quantify intensity of wrist movement. The male subject's generally higher WIL, in both wrists, may be explained as a reality of the physics of movement; for the same angular acceleration, his larger hand, with a greater moment of inertia than her smaller hand, results in higher WIL. Total WIL (left and right wrists) as a function of tempo (Fig. 3) revealed near-identical contours for each performer. As might be expected, left WIL increased linearly as the difficulty of the task increased due to faster tempi. However, for the right wrist, WIL decreased at the fastest tempo, which seems to indicate both performers were attempting to find efficiencies as a means of decreasing playing difficulty. Notwithstanding subjects' very different anthropometrics, this intensity reduction "strategy" occurred for both at the same tempo, and only in the right wrist. Since both pianists were right-hand dominant, it seems intuitively reasonable that dominant-hand motor behaviour strategies might be a "first recourse" to reduce effort.[35]

Although hand dominance might explain right-hand WIL decreases at the fastest tempo, it does not explain the individualized strategies used by each subject—anthropometry might. When looking at individual planes of wrist movement, WIL intensity (right and left wrists) was highest in rad/uln for the female and highest in flex/ext for the male, suggesting hand size might be a factor contributing to motor behaviour strategy selection. A greater use of rad/uln increases medial-lateral reach on the piano keys, something not needed by the male subject because of his larger hand size. For the female pianist (Fig. 4, top row), effort reduction in the wrists was accomplished through efficiency gains in both flex/ext and rad/uln WIL components. For the male pianist (Fig. 4, bottom row), most of the effect was accomplished by reducing WIL in flex/ext. Given the female pianist's reliance on rad/uln as a means to expand medial-lateral reach, manipulation of this component may have provided more "room" for effort reductions. For the male pianist, because he employed greater amounts of flex/ext than rad/uln deviation, there was more utility in manipulating flex/ext as an effort reduction strategy.

IML Frequency

For a task where motor training requires long hours of repetition (like playing the piano), it is rational to avoid working harder than is necessary; workload efficiencies enable longer periods of better practicing and learning. In the present study, IML frequency was employed as a way to measure and evaluate workload distribution and discuss the effects that anthropometry may have on some of the differences observed between subjects. At 8 N/s, the female's average IML frequency started to increase, while the male's decreased (Fig. 5, top row). For the two pianists, 8N/s might have been a threshold where the difficulty of the task necessitated a switch in motor behaviour strategy to optimize movement efficiency. The male utilized an efficiency optimization strategy where IML frequency in both wrists was refined in order to mitigate additional effort caused by increases in tempo. For the female, increases in average IML frequency above 8 N/s might indicate that due to a smaller hand size, the efficiency optimization strategy of reducing IML frequency at faster tempi was harder to come by.[36,37] Looking at the left and right wrists individually, IML distribution between the wrists seems to alternate for the female pianist (Fig. 5, top left). This might indicate an effort reduction strategy involving an alternating focus on different hands. For the male pianist, the right wrist was always more active than the left (Fig. 5, top right) and the left wrist IML was more highly variable, which suggests the dominant hand to have been the stabilizing influence.

When looking at individual planes of wrist movement, for the female, IML frequency varied more for rad/uln deviation than for flex/ext in each wrist (Fig. 5, bottom left). Simply, rad/uln was being used in greater capacity than flex/ext when responding to tempo-driven increases in work/effort. For both wrists, rad/uln showed greatest rates of change (steepest slopes) and greatest fluctuation at higher tempi. Between 9 and 10 N/s, IML increased, indicating the tempo at which the task became substantially more challenging. In the right wrist, the female pianist employed a rad/uln dominant wrist movement strategy to accomplish the task of lowering high IML frequencies at 10 N/s. In the left wrist, rad/uln increased markedly from 9-10 N/s after having been at very low levels between 6 and 9 N/s. Handedness could explain this behaviour; for our right-handed subjects a non-dominant hand might work harder because there tends to be a greater emphasis on right hand technique in piano performance.[35]

For the male, IML frequency varied more for flex/ext than for rad/uln in each wrist (Fig. 5, bottom right). Thus, flex/ext was the primary component of movement used to respond to tempo-driven increases in work/effort. For the right wrist, IML frequency (flex/ext) increased between the two slowest tempi, a result that might indicate the performer to have been paying less attention to the use of his motor resources since the task at these tempi was still simple. Above 6 N/s IML frequency (flex/ext) showed steady decreases for both wrists, indicating a steady refinement of flex/ext in response to increases in task difficulty; at these speeds the male pianist employed a flex/ext dominant wrist movement strategy to refine wrist movement as tempo increased.

When a tool is employed during any performative task, an individual's anthropometry is a central determinant of the range of motor possibilities available to execute that task.[38] Playing the piano requires motor manipulation of an instrument that has fixed dimensions and is immobile during performance.[39] Unlike instruments that are held by hand, such as the violin, the position of the piano cannot be adjusted during a performance to accommodate transitory motor needs of a performer; the performer must adjust to the instrument. This fact and a performer's anthropometry influence both the number and type of motor strategies available to effect desired musical outcomes; every performer, through years of motor training, develops a hierarchy of motor strategies to employ in the service of optimizing his/her performance. In all practicality, this means that there is no universally "correct" way to play the piano but, depending on musical context, there may be some strategies that are "better" for reducing effort.

Thus, understanding that motor strategies are linked to anthropometry has broad ranging implications. First, it may suggest more efficient approaches to pedagogy. Modeling is employed extensively in music pedagogy; however, applied anatomy and biomechanics are not standard subject matter in music training.[40] Hence, much of this modeling involves demonstrating musical outcomes and the mechanical means that the teacher has found to affect those outcomes. In the absence of a conscious and reasoned understanding of alternative motor strategies, a teacher can only model physical behaviours which come from their personal experience.[30] Awareness of alternative motor strategies may help an educator model more effectively for each student and, further, lend him/her a vocabulary to clearly explicate these alternatives. By directing students through a range of motor strategies best suited to their anthropometry, it seems reasonable to think that teachers could accelerate the learning process and improve musical outcomes. At the very least, by having several alternative motor strategies consciously rationalized, a teacher has an increased repertoire of starting points for imparting new skills to students. Second, in an industry where PRMP are prevalent, any effort invested in increasing learning efficiency has the potential to reduce injury rates. Rationalizing objectifiable parameters in terms of anthropometric potentials is a first step in addressing these issues.

Limitations and Future Research

The current study analyzes motor behaviours of two pianists, one taller and one shorter, in order to begin the process of examining anthropometrically driven alternative compensatory behaviours and behavioural strategy selection during piano performance. As such, it documents a limited number of compensatory behaviours available to pianists; other equally successful strategies may exist. Inferences about cause and effect should be understood as speculative until a larger body of research is available for pianists of varying anthropometry. The standardized protocol was chosen to limit interpretive variability that would normally be expected when performing in a concert setting. Hence, it measured a defined task and not the full range of the task's malleability. To do so the current study focused only on wrist kinetics and a more extensive examination of upper limbs might reveal additional compensatory mechanisms.

Conclusion

Performing the piano at expert levels requires long-term training. Throughout this training, many aspects of "playing technique" become subliminal for the performer, yet they are available for manipulation when circumstances and artistry so require. Since a piano keyboard is of fixed dimensions, anthropometric differences between individuals result in different performers having different performance-strategy options. The current study begins the process of documenting a range of motor behaviors that can be called upon during piano performance. It does so by employing a case comparison to explore the utility of analysing wrist kinetics for a standardized piano performance task. The objective was to 1) observe similarities and differences in motor behaviour/strategy between two expert performers, and 2) discuss observed results in terms of performers' notably different anthropometry. In the current study, wrist internal loading (WIL) and impact loading (IML) frequency were used to examine tempo-dependent loading and to measure both workload distribution and effort reduction strategies in the wrists during performance.

WIL and IML changes throughout the protocol both suggest that anthropometry and handedness might play a role in wrist effort reduction strategies. Both WIL intensity and IML frequency showed that, as task difficulty increased, changes in motor behaviour/performance strategy occurred at faster speeds for both expert performers. Further, the non-dominant wrist became more variable as the task became more difficult. For both performers, manipulation of IML frequency appears to be a prime strategy for reducing wrist effort as tempo of the protocol increased and the task became more difficult.

This study is the first to investigate pianists' wrist kinetics in terms of ergonomics and anthropometry. It sets the stage for future research by providing a framework for further examinations of effort-reducing piano performance strategies throughout the kinetic chain. The underlying hypothesis of the current research is that, since anthropometry varies from individual to individual, the identification of anthropometrically empathetic motor behaviour strategies can improve pedagogical practice. This has the potential to help performers optimize physical effort to prevent PRMP while simultaneously increasing the expressive vocabulary available to performers through the conscious manipulation of alternative motor strategies. Without improvements in current teaching and performance modelling practices, one can only expect existing rates of PRMP to continue. A systematic translation of biomechanical, anthropometrical, and ergonomic understanding into music teaching is needed so that learners may strive for musical excellence without compromising their musculoskeletal health.

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