Musculoskeletal Aspects in Measurement-Based Studies on Pianists' Posture and Movement: A Systematic Review

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ABSTRACT

Various studies are assessing risk factors and musculoskeletal disorders related to piano playing. Inspired by research made on string players,[1] this study is a review of piano/keyboard-related musculoskeletal assessments completed up to August 2019. The Cochrane Library, PubMed, CINAHL and Medical Problems of Performing Artists (MPPA) databases were interrogated using both various terms that include types of assessment as well as the use of associated types of evaluation. A total of 45 studies were reviewed, 21 of which measured movement and posture assessed by 2-dimensional (2-D) or 3-dimensioal (3-D) analysis. Six of the studies focused on instrument-based measurement of factors such as muscular tonus and force as well as pressure and muscle kinetic load. Among the selected studies, 17 used clinical examination such as inspection/palpation, manual ROM, muscle tests, neurological tests and other clinical tests. EMG evaluation and MIDI data were the most represented associated types of assessment. The study identifies and classifies musculoskeletal methods of assessment related to piano playing in the published literature and highlights the need for further research on groups either similar or more specific such as harpsichord or organ players.

BACKGROUND

Playing-related musculoskeletal disorders (PRMDs) are by definition musculoskeletal disorders that were found in 39% of professional and university student instrumentalists, and are described as weakness, pain or other symptoms related to performing on a musical instrument.[2] Numerous terms describe musicians' musculoskeletal disorders, however, the syntagm 'playing-related musculoskeletal disorder' (PRMD) seems to cover most appropriately the music-specific types of work-related disorders.[3]

Piano performance was chosen for this study due to the fact that pianists experience musculoskeletal problems[4] more often than cellists, guitarists or organists.[5] Pianists ache with a variety of injuries that may come directly from practicing and/or performing,[6–8] including muscular pain syndromes, tendinitis, tendon entrapment, nerve entrapment, focal dystonia, and many other issues.[9] Neck, shoulder, right elbow, upper back and lower back are the most common sites of discomfort or pain for pianists.[10] The most frequent problems reported by pianists are tendinitis, blisters and spasms.[11] Performance-related musculoskeletal injuries lead not only to loss of practice and rehearsal time but frequently to loss of income.[12]

Pianists can perform the same movement through various combinations of individual joint movements and muscular activities.[13] An understanding of the various and highly refined muskoloskeletal motion patterns and postures in piano playing may allow for the development of prophylactic strategies.

A few authors have emphasized the need for an appropriate musculoskeletal assessment in order to minimize risk and favor optimal performance. However, there are no specific protocols for assessing diseases relating to various types of motion and posture.[2, 5] This study aims to identify and classify musculoskeletal methods of assessment in the published research on pianists. The results may be of interest for physiotherapy and further research; it could also have an impact on careers in piano performance, teaching strategies and clinical examination.

MATERIALS AND METHODS

Research Strategies

A systematic literature search was performed on the Cochrane, PubMed and CINAHL databases using the following terms and combinations: [piano or pianist] AND [motion or movement] OR [posture or postural] OR [musculoskeletal]. Additionally, the key journal on performing arts medicine and therapy, the Medical Problems of Performing Artists (MPPA), was interrogated with the following terms: "piano," "pianist," "movement," "motion," "posture," and "musculoskeletal." After the first step, 13.534 papers found by the database searches were excluded based on titles and abstracts, the inclusion/exclusion of the remaining papers being decided after full reading. 121 papers were assessed for eligibility, eligible papers being studies which used a cross-sectional study design to gather information and meet the inclusion/exclusion criteria.

Selection of Studies

The following inclusion criteria were applied:

- The study was about the motion and posture of pianists in the context of a musculoskeletal assessment. Studies assessing neurologically aspects of the pianists' movement, motion and/or posture were excluded, except for focal hand dystonia, a disorder characterized by involuntary movements, twisting, abnormal postures and co-contraction of antagonist muscles, frequently in a task-specific context, prevalence in pianists being relatively high with about 1-2% of performers being affected. Only studies assessing musculoskeletal methods for assessing focal dystonia in pianists were included.[14]
- The study was empirical and quantitative. Reviews and qualitative studies, interviews and dissertations were excluded.
- The study was published between July 1989 and August 2019.
- The study was written in English.
- The study was focused on assessing the pianists and not the piano.
- The study was done on piano/keyboard-related performance.
- Questionnaires were not the only form of assessment used, but were combined with other types of assessment.

Based on the chosen research procedure, 45 studies fullfilled the selection criteria (see Table 1). No ethical review was necessary since the present study was not clinical and not experimental.

Analysis

The classification for the selected studies is based on the Schemmann et al. (2018) study[1] to which the category *Combined with Other Assessments* and the subcategories *MIDI Data* and *Neurological Tests* were added as follows:

1. Biomechanical measurements which include kinematics, kinetics, muscle activity/response, joint range of motion (ROM), MIDI data and other types of assessment;
2. Clinical examination (inspection/palpation, ROM, muscle tests, neurological tests and other types of assessment);
3. Self-report assessments;
4. Combined with other assessments.

RESULTS

A total of 13.646 citations were retrieved. Abstracts and papers were assessed for eligibility in several stages as outlined in Table 2. The most frequent reason for exclusion was papers featuring research on musicians or instrumentalists that were not pianists (*n*=13.575).

The methodological limitations identified in a majority of papers were lack of informed consent procedure description (*n*=58), inadequate reporting of reliability and validity of the outcome measures (*n*=14), lack of statistical significance, and inadequate acknowledgement of study limitations (*n*=23).

The 45 studies selected are listed in Table 2 along with all assessment types in use as well as their respective combinations. Detailed information about the studies is presented in three categories: biomechanical, clinical examination and self-report. A special subclassification was made for MIDI data because of its frequency and importance as an assessment method for pianists. Simoultaneous measurements of finger and wrist joint movement is essential during piano performance.[15]

BIOMECHANICAL MEASUREMENTS

Measurement of Kinematics

45 studies were included in this review. 21 studies measured motion, movement or posture, assessed by 2-dimensional (2-D) or 3-dimensional (3-D) kinematic analysis.

Spector and Brandfonbrener (2005) videotaped (by standard digital video camera) patients' hands with musician's dystonia and combined the assessment with the "Frequency of Abnormal Movements arm dystonia disability scale" (FAM) and the "Burke-Fahn-Marsden scale" (BFM).[16]

Differences in kinematics and kinetics of the upper-limb movements were investigated by Furuya et al. (2010) while the subjects were pressing a key with two different touches: pressed and struck. The devices used were: two 2-D position sensor systems, a sound-level meter and a stereo-sound amplifier.[17] Furuya et al. (2012) measured kinematics in the sagittal plane (position sensor cameras) and muscular activities (EMG) of the upper extremity (anterior *deltoid*, posterior *deltoid*, *triceps brachii*, *biceps brachii*, *flexor digitorum superficialis* and *extensor digitorum communis*) during repetitive piano keystrokes.[18]

Several studies used an accelerometer for kinematic data. Chen et al. (2011) used four accelerometers combined with EMG for measuring physiological tremors in the vertical direction of the right-hand digits (*flexor digitorum superficialis* and *extensor digitorum communis*). All subjects conducted two contralateral resistance protocols with the left hand in the nongrip and grip conditions.[19] A wireless 3-D accelerometer was used by Clemente (2014) to measure and analyze the head and cervical posture of piano players during musical performance. The 3-D accelerometer was incorporated in a special pair of glasses used by the subjects.[20] De Manzano et al. (2010) recorded the head movements using a 3-axis accelerometer, combined with EMG, MIDI-data, self-report questionnaire as well as cardiovascular and respiratory measurements.[21] A 3-D accelerometer and empirical-mode decomposition in combination with a Hilbert transform was used by Lee et al. (2014) for obtaining the instantaneous frequency and amplitude of subjects' tremor.[22] In a further study (2015) the authors focused on the 3-D accelerometer signals combined with EMG and clinical examination.[23]

Fernandes and de Barros (2012) used 3-D retro-reflective markers combined with grip strength and anthropometric measurements as well as a hydraulic dynamometer. The grip-strength measurements employed a Digiflex hand and finger exerciser.[24]

Sakai et al. (1996) adapted the Expert Vision System for measuring the finger and wrist joint motion. This video-based passive marker system was used during the piano playing of the subjects.[15] Further on (2006), the authors used a video-based passive marker detection system (Expert Vision System) which is able to track the 3-D motion of the reflective markers.[25] Furuya et al. (2011) used a video-based passive marker detection system (Expert Vision System) which consists of four video cameras, a video processor and a system able to track in 3-D the motion of reflective markers. Additionally, hand span as well as range of motion were also assessed.[26]

Kaufman-Cohen et al. (2018) investigated joint kinematics (wrist and elbow angles) with a 3-D motion capture using passive reflective markers, a six-camera high-speed motion analysis system (Qualisys Medical AB) combined with anthropometric measurements, the "Standardised Nordic Questionnaires" (SNQ), self-report and a validated appendix for Upper Extremities.[6]

Kilincer et al. (2019) investigated lateralization and motor asymmetry using kinematic 3-D sensor from the electromagnetic tracker (TrackSTAR ascension Technology) attached to the index finger.[27]

Wristen et al. (2006) used a high-speed motion capture technology (six-camera digital infrared-camera system) that captured index finger motions during performance.[28] An optoelectronic computerized system (Smart system) that detected 3-D motion of the relative joint positions and fingers of the right hand by six infrared-sensitive device cameras was used by Ferrario et al. (2007).[29] Ferrarin (2008) examined pianists with focal dystonia using an optoelectronic motion capture system (SMART system) for 3-D kinematic data, combined with EMG, inspection of the upper-limb movements, self-report, neuroimaging and hematochemical testing.[30] Massie-Laberge et al. (2019) used a kinematic passive infrared motion capture and a questionnaire about how body movements relate to musical structure. They used a 17-camera Qualisys motion capture system for motion data and a video camera to record the performances.[31]

The wrist dynamic motion was measured by Sugawara (1999) using the Greenleaf Medical System (containing WristSensor Gloves and dual-axis sensors) supplied with a goniometer and a self-report questionnaire.[8] Tominaga et al. (2016) recorded time-varying joint angles of fingers using a custom-made glove and MIDI data.[32]

The "Adapted Postural and Repetitive Risk-factors Index" (APRRI) was adapted by Yee et al. (2002) who combined the data with the "Upper Body Musculoskeletal Assessment" (UBMA) and self-reporting,[33] the UBMA being a comprehensive set of clinical evaluations.

O'Shea and Moran (2019) studied while the pianists were performing the role of attentional effort using Motor Imagery with iPad 3, Tobii T60 eye-tracking system combined with an EMG armband, a self-report questionnaire and the "Borg Rating of Perceived Exertion Scale-CR10" (BRPES). A Cedrus response pad was used afterwards in order to test finger motor-function.[34]

Measurement of Kinetics

Six of the studies focused on instrumental assessments for data such as forces, muscle pressure and internal loads. Wolf et al. (1993) used Harding's 2-D finger computer model to measure forces in the joints and tendons of the right index finger.[35] The tendon and joint forces determined from a free-body force analysis of each of the phalangeal segments was studied by Harding et al. (1989). The subjects' fingertip strike-force was measured with a force transducer. Also the tendon activation moments as function of the joint flexion angles were determined with a bow-string model.[36]

Inui and Ichihara (2001) assessed finger tapping of the subjects using a force plate connected to strain gauges.[37] A four miniature strain-gauge force transducers to monitor the striking forces of the tapping fingers was used by Aoki et al. (2005). Additionally, they measured the maximum isometric pinch force of the fingers with a self-made strain-gauge force transducer and the maximum grasp force of the right hand using a grasp-force dynamometer.[38]

Measurement of Muscle Activity or Response

All the assessed muscles with EMG are mentioned in Table 5. Grieco et al. (1989) made a vocational electromyographic analysis of the trunk, shoulder and arm during performance, supplied by general anthropometric parameters and self-report.[39] Further on, Gohl et al. (2006) analyzed the median and ulnar neuropathies by using the Cadwell Sierra LT electromyograph and stimulator (EMG) combined with measurements of the skin temperature at the wrist (digital thermometer), active range of motion, manual muscle testing as well as neurological testing and self-reporting.[40]

Wristen et al. (2006) used an eight-channel EMG system for the muscle activity in the back/shoulder, parts of the hand and arm, and the masseter muscle of the jaw. Also, electrogoniometers were used for measuring the motion range of the hand span.[41] The activity of eight arm and shoulder muscles with EMG was measured by Yoshie (2008), combined with MIDI signals, electrocardiogram, a sweat-rate meter and self-reporting.[12]

Oikawa et al. (2011) assessed the wrist positioning and wrist muscles activity with a surface EMG, an electrogoniometer connected to EMG, and manual-resistance muscle tests.[42] The muscular activities in the focal dystonia pianists' hands was recorded by

Furuya et al. (2018) with a surface electromyograph. Additionally, finger dexterity was measured by MIDI sensors implemented beneath all piano keys.[43] Honarmand et al. (2018) recorded surface electromyography of the back-extensor muscles. Also, they ran the isometric back extension test and used self-reporting.[44]

The activity of eight intrinsic and extrinsic finger muscles was recorded by Oku and Furuya (2019) using EMG and MIDI data from a piano synchronized with EMG signals.[45]

MIDI DATA

A number of studies used a connectivity standard (Musical Instrument Digital Interface or MIDI) to succeed in transferring digital-instrument data.[46] Furuya and Altenmüller (2013) studied the finger tapping of pianists with Focal dystonia. They recorded MIDI data using a custom-made script in LabView.[14] The MIDI-based analysis and a self-report for assessing the musician's dystonia in pianists was used by Van Vugt et al. (2014).[47] Spector et al. (2014) assessed the temporal unevenness in scale playing using also a MIDI-based analysis and self-reporting.[48]

OTHERS

Chen et al. (2000) measured the pain threshold of latent myofascial trigger-points of bilateral *extensor digitorum communis muscles* using a pressure algometer.[49] The ankle stability in musicians was studied by Rein et al. (2010) using the Biodex Stability System and, additionally, a goniometer (for ROM), a tuning fork (for the vibratory sensibility of the lower leg), EMG and self-reporting.[50] Sakai and Shimawaki (2010) used a simple posterior-anterior radiography of the affected hand with the thumb and the little finger abducted. They measured also the hand span and the length of the thumb, middle and little finger.[7] Baadjou et al. (2015) assessed finger mobility by digital photography of hands and questionnaires such as "Short Questionnaire to Assess Health-enhancing physical activity" (SQUASH), "Dutch Musculoskeletal Questionnaire" (DMQ), "Disability Arm, Shoulder, Hand questionnaire" (DASH), "Short Form-12" and "Visual Analog Scale" (VAS).[51]

CLINICAL EXAMINATION

Among the selected studies, 17 used clinical examination as follows: inspection/palpation, manual ROM and muscle, neurological or other clinical tests. Muscle stretch reflexes, pathologic reflexes (Hoffman and Babinski reflexes), special tests (Tinel's sign and Phalen's test) and Adson's maneuvers were included in the range of neurological tests. Table 4 covers the clinical assessment for all of the 17 studies mentioned.

Wristen (2000) set motion pattern norms (which considered the biomechanical, environmental and morphological constraints of the pianists' performance) that were formatted into checklists for future qualitative biomechanical analyses of individual players' technique.[9]

Yoshimura et al. (2006) analyzed the risk factors for playing-related pain in students and used extensive upper arm and hand anthropometric measurements along with a battery of bilateral upper-extremity performance tests (ROM), isometric strength, rotation speed, and hand span measured with a digital photographic device. The hand volumes were measured using the displacement method.[52] Furthermore, Yoshimura (2008) conducted the same study, this time on piano teachers, using anthropometric measurements of the upper arm and hand, bilateral upper-extremity performance tests, VAS and digital photography of the hands for finger mobility.[53]

Wilson et al. (1993) measured biomechanically hand size and shape, active range of motion and passive flexibility.[54] Lee (2010) used Wagner's method for passive span of fingers' measurement device and adapted it for biomechanical measurements of the hand and arm.[55]

SELF-REPORTING ASSESSMENTS

Table 3 presents the additional self-reports that were used in the musculoskeletal assessment. The present review did not cover general information such as demographic data,[39,40,48,50,52] playing background and/or playing habits,[6,8,39,40,48,52] playing experience and professional status,[40] hand dominance,[40] computer time,[40] sport activities[50] and enjoyment of school subjects.[48] The questionnaires targeting psychological status[8,39,52] and subject awareness regarding Cumulative Traumatic Disorders were also not being taken into consideration.[8]

DISCUSSION

The research on musculoskeletal assessment requires movement measurements using motion-capture devices and electromyography. Computational analysis in areas such as robotics, signal processing, multivariate analysis and machine learning can also be used for force sensors and data analysis.[13]

Most (73.33%) of the above-mentioned 25 studies (dated July, 1989 to August, 2019) were written from 2006 to 2019, which suggests a growing interest in research on musculoskeletal assessments on pianists during piano performance. 50% more publications in this field were published from 2010 to 2019 (equal to the output from 1989 to 2009), while literature predating 1993 is almost inexistent.

The research studies reviewed here are significantly different in terms of their objectives, variables, instruments and measures employed, as well as the type of data-analysis performed. Most published studies were designed with clinical rehabilitation in mind; music teachers were co-opted in very few of them.

Two previous studies reported that pianists' PRMD's occurred most frequently at the hand and forearm muscles,[56,57] the wrist being especially susceptible to injury.[8] Of the fingers, the index and the middle finger were the two most examined.[29] The EMG-recorded muscles are presented in Table 4. The most frequent (35.71%) EMG muscle assessment looked at the forearm muscles, especially *extensor digitorum superficialis* and *flexor digitorum superficialis* (23.8%).

However, different studies investigated other muscles and their results are significant for future research. For example, investigations of the mechanics of *ankle sprains* in musicians are necessary in order to evaluate work-related injuries in instrumentalists.[50] Grieco et al. (1989) reported that the trunk and the neck were the sites that generated the most frequent, serious and prolonged problems among young pianists.[39] Further documentation is needed in order to validate the results,[52] to address the pianists' playing position as part of the evaluation process,[40] as well as to correlate among changes in pressure pain threshold and the duration of repetitive muscle contraction.[49]

For further research it may be important to note that the instruments reported in the selected studies were validated and tested for reliability. For instance, the optimization analysis technique used by Harding et al. (1989) can be used to provide data on finger positions that minimize forces in digital tendons and joint during piano performance. Alternatively, he proposed a stop-action video recording technique for finger positions during performance; the data could be entered into the finger-force modeling program so as to determine tendon-tension magnitudes.[36]

Sakai et al. (1996) reported the feasibility of the method developed in his study and it would be a useful addition to the assessment methods currently avaible.[15] The reliability and validity of the methods implemented by Gohl et al. (2006) in the procedure has been proven by empirical evidence.[40] The methodology proposed by Fernandes and de Barros (2012) is sufficiently sensitive to detect motion patterns and finger-coordination differences between pianists and non-pianists.[24] The wireless 3-D accelerometers can be a helpful tool to evaluate both dynamic and static body biomechanics.[20] The pressure algometer developed by Fischer has proven to be a reliable and a valid way to measure the pain threshold of an MTrP.[49] Yoshie (2008) used a validity and reliability scale: the "anxiety thermometer" confirmed by Houtman and Bakker (1989). Also, he stated that the MIDI technology has actually been shown to be effective in quantifying movement impairment caused by the overuse syndrome or focal dystonia.[12]

Yoshimura (2006) states that VAS is a reliable and a valid approach for measuring pain.[52] Honarmand et al. (2018) used a valid and reliable Persian translation of the "Cornell Muscular Discomfort Questionnaire" (CMDQ).[44] In addition, the "Frequency of Abnormal Movements arm dystonia disability scale" (FAM) developed for the objective and quantitative clinical assessment of musician's dystonia may be useful for pianists. A reliable and valid scale could be combined with the FAM scale to broaden the former's scope. Also, the results for the FAM scale could be reinforced by repetition with more examiners and the relationship between FAM scores and the level of examiners' expertise could be determined simultaneously (Spector and Brandfonbrener 2005).[16]

Spector et al. (2014) used MIDI data as a validated measure of motor performance, relevant in a musical setting. However, the additional questionnaire used has not yet been validated and there remains the possibility of a recall bias.[48] Also, the UBMA is a relatively new measurement tool and there is currently no published normative data.[33]

Peroneal reaction time is a stable parameter which is reliable for repeated measurements, independent of the time of measurement.[50] Also the Biodex Stability System is a reliable tool for assessing neuromuscular control by quantifying the ability of a person to maintain dynamic postural stability on an unstable surface.[50]

Yee et al. (2002) demonstrates that the test-retest reliability for the "Adapted Postural and Repetitive Risk-factors Index" (APPRI) was highly effective. However, it is also possible that the APRRI may have been too complicated of a measure to score by including the dynamic posture of several joints and body parts. A more specific measure of postural control to areas of discomfort as self-reported by the subject may be worth taking into consideration for further research. For example, a part of the APRRI could focus on the wrist and elbow joints of the right arm. Also, it may be helpful to include in the APRRI a measure of repetitiveness and muscular tension.[33]

Likewise, determining the most important methodological limitations in previous literature can help further studies investigate hypotheses derived from such limitations.

Sugawara (1999) mentioned that, in terms of accuracy of the measurement, there might have been a slight deviation during the calibration process or during the fitting of the gloves. Also, the pocket that houses the optic fiber on the glove interfered with stabilizing the arm of the goniometer which normally remains in a fixed position. Due to the fact that, to some subjects, the gloves were too small or slightly too big, their range of motion for the session may have deviated from the normal range of motion.[8]

Van Vugt et al. (2014) mentioned that there was no control for the amount of time a subject partook in each of the therapies and that objective measurements of task-specific motor performance were only gathered on a subsample of subjects (<50% of the total number included in the study). The subjective measurement scales were not previously validated.[47]

Some studies reported, as a limitation, that they assessed just one hand or just the fingers. Kaufman-Cohen et al. (2018) reported that the main limitation of his study is that joints other than the elbow and wrist were not monitored, so that the compensation techniques were not recorded. Also, little attention was payed to control the differences between participants' height and its impact on kinematics or to having all participants playing at the same tempo, which could have had some effect on the fragment being played, hand position, or muscle tension.[6]

Lee (2010) recorded only the scale in thirds with the right hand alone.[55] Further, Lee et al. (2014) did not include the difference between the hands that are more involved in motor control (right hand in pianists) and the contralateral hand, and did not investigate whether the handedness plays a role.[22] Oku and Furuya (2019) did not compare between the right and the left hands of the patients because the hand affected by focal dystonia differed across the patients. The authors included subjects with symptoms manifested at only one finger. Further studies are therefore needed to investigate whether the present classification applies to patients whose multiple fingers are affected by focal dystonia. Other performing tasks besides scales and arpeggios can also trigger the symptoms and could be investigated.[45]

Tominaga et al. (2016) did not cover all possible patterns of fingering such as the transitions between the index and middle fingers. The movement independence of fingers depends on fingering. Also, he assessed only key-striking movements.[32]

Furuya and Altenmüller (2013) reported that the current testing procedure assessed not only the characteristics of the dystonic symptoms, but also results from biomechanical constraints. The issue could be solved by collecting data only from patients with no history of botulinum-toxin injection and adding the biomechanical measurement proposed by Furuya and Altenmüller.[14]

3-D motion capture cameras represent a significant investment, are expensive, difficult to use, and require a fixed installation.[20] Yet, some of the studies that used a 3-D kinematic analysis, did not exploit the device at full capacity. Fernandes and de Barros

(2012) used a 3-D kinematic analysis, however only rotations in the sagittal plane were analyzed.[24] The sagittal plane was reported as a limitation in Harding's 2-D finger model, together with *only the fingers' examinations,* or *just male subjects*.[35]

A number of studies were the first to implement new procedures. Sakai et al. (2006) marks a starting point for the use of a video-based passive marker detection system for pianist's hand and wrist.[25] Wristen et al. (2006) are the first to apply motion-capture technology in order to study pianists. High-speed motion-capture technology allows for detailed examination of the pianists' motions. Use of high-speed motion analysis can help piano teachers identify potential motion problems in pianists' technique.[28]

Furuya et al. (2011) mark a starting point for the use of a video-based passive marker detection system for hand and wrist in piano performance. Additional advances in computer technology and software, as well as the inclusion of additional piano techniques, should be studied further.[26]

Yoshie (2008) is the first to have systematically checked how the activity of musicians' arm and shoulder muscles can be elevated during stressful performances.[12] Hand and arm weights were measured by Lee (2010) after a brief session of weight-relaxation training, an innovative procedure.[55] Chen et al. (2011) was the first to describe differences in pianist motor control in the cross-transfer of motor overflow with physiological tremor.[19]

MacRitchi et al. (2013)[58] and Teixeira et al. (2015)[59] found that the pianists' movements depend on the underlying structure of the musical excerpt and on the technical level thereof. The variations in head position found by Massie-Laberger et al. (2019) are strongly associated with the structural features of the piece or with the physical constraints of the instrument.[31]

A variety of music examples, from a basic keyboard passage (44.82%) to a technically demanding piano score were used for subject performance in the selected studies (see Table 6).[20,28,31,41] Basic keyboard passages include scales, arpeggios and/or chords. The practice of scales is relevant for pianists and piano students as scales are basic elements of the musical architecture in classical, jazz, rock and pop music.[48]

The requested task was performed either *staccato* or *legato*, or both, with one or both hands for the melody/music excerpt. The tempo was strictly measured with a metronome,[6,12,15,18,25,26,30,34,39,42,43,45,47,48,55] or requested to be either a constant[25,32] or increasingly[16,33] faster, or not controlled at all.[7,8,16,17,20,21,28,29,29,31,35,41,44,49] The time frame was from 1.5 minutes[41] to more than 5 hours.[44]

Various characteristics of the instrument such as brand and model, year of construction, vertical versus coda instrument and anthropometrics may be important, because the joint kinematics may change when using different pianos.[6] The majority of the included articles used a digital piano, with two exceptions: a Bechstein grand pianoforte[29] and a 7/8 piano keyboard.[41] The dimension of the Bechstein piano limited the position of the cameras used for movement reading while more complex biomechanical models (up to 19 markers per hand) have been used for the analysis of single finger motions only without musical performance.[29] Wristen et al. (2006) used a 7-inch smaller keyboard, a 7/8 piano keyboard (Steinbuhler & Company) that can be fitted into a grand piano in place of a conventional-size keyboard. The musical instrument should be carefully chosen as this variable could result in misleading results by alteration of various data such as different camera positions, greater finger markers and more.[41] Further research may focus on studies that correlate repertoire, technique and practice habits with physical discomfort.[60] Moreover, it could select a wider set of musical pieces to allow for a better identification of the characteristics of each group.[29]

In addition, a better definition of what represents the typical participant profile for the different branches of this type of research could provide more streamlined data. In the 45 studies reviewed so far, participants had a wide variety of musicianship level, from university beginner students to consecrated concert pianists. Even though greater proficiency should lead to more effortless and more efficient keystrikes,[35] age is an important risk factor for pain.[53] Studies on piano teacher/piano student pain at different levels[29] and its relation with intrinsic characteristics (age, race and nationality), performance and/or practice habits, teaching hours,[61] and so on, could be developed further.[53]

Most studies recruited piano students at university level. The absence of studies on first-class concert pianists is attributable to difficulty of access, recruiting a large enough number of such musicians being practically not possible. However, further research could aim for more concert pianists, as the total unitary kinetic energy and the unitary kinetic energy of extraneous movements of concert pianists is significantly larger for both, hand and fingers.[29]

Studies that take into consideration different nationalities are also relevant for further studies. Furuya et al. (2006) stated that the rate of PRMD was >10% higher with Japanese pianists than the figure reported in Western countries.[62]

CONCLUSIONS

The present survey shows that despite of increasing interest in this field of research, the empirical data is still subject to serious limitations. The present review of musculoskeletal studies did not asses the validity of the results. Suggestions for future research may include biomechanical assessment, clinical examination and self-reports which could be useful to the medical-care system as well.

Future studies may use a standardized design for physical assessment, valid and reliable measurement tools, as well as appropriate statistical tests of association.[61] Furthermore, musculoskeletal assessments should be evaluated in a way that guarantees the reliability and the validity of the observations made. Moreover, there should be more studies on the relationship between piano performance musculoskeletal measurements and the quality of the performance. A standard protocol that should include the description of the procedure, instructions and possible outcomes may be taken into consideration. The present review may be useful to research in the study of musculoskeletal-assessment quality and impact thereof on different health indicators and/or performance.

TABLE 1. Selection of papers for review

Systematic literature search:

Cochrane: 11.998 findings
CINAHL: 1020 findings
PubMed: 463 findings
Medical Problems of Performing Artists Journal: 165
Total records identified through database searching: 13.646

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Eliminate non piano-specific, not focusing on physical assessment, eliminate papers on the basis of all exclusion criteria + study design: 13.534 papers eliminated

↓

112 included citations
Retrieve and examine full papers

↓

Eliminate duplicates and the studies on the basis of all exclusion criteria + study design : 52 papers eliminated

↓

45 papers
Scored for methodological quality

TABLE 2. Overview of All Types of Assessment and Their Combinations Used in the Selected Studies

Reference	Population: *n* type of pianist (RR)	Instrumented Biomechanical Measurement						Clinical Examination					Self-Report	Combined with Other Assessments
		Kinematics (2D + 3D)	Kinetics	Muscle activity / response (EMG)	ROM (instrumented)	Others	MIDI Data	Inspection/Palpation	ROM (manual)	Muscle tests	Neurological test	Other		
Aoki et al. (2005)[38]	10/10		X											
Baadjou et al. (2015)[51]	31/ 132					X							X	
Chen et al. (2000)[49]	40/65					X								
Chen et al. (2011)[19]	12/24	X		X										
Clemente (2014)[20]	17/17	X												
de Manzano et al. (2010)[21]	21/21	X		X			X						X	Cardiovas-cular and respiratory measures
Fernandes and de Barros (2012)[24]	11/25	X	X									X		
Ferrarin (2008)[30]	3/18	X						X					X	Neuroima-ging and hemato-chemical testing
Ferrario et	19/19	X												

al. (2007)[29]														
Furuya and Altenmüller (2013)[14]	17/29						X							Custom-made script in LabVIEW
Furuya et al. (2010)[17]	7/7	X	X											
Furuya et al. (2011)[26]	5/10	X							X			X		
Furuya et al. (2018)[43]	20/60			X			X							
Gohl et al. (2006)[40]	19/38			X					X	X	X	X	X	
Grieco et al. (1989)[39]	117/ 117			X								X	X	
Harding et al. (1989)[36]	4/4		X											Combined with a bow-string model analyser of the joint flexion angles
Honarmand et al. (2018)[44]	10/10			X						X			X	
Inui and Ichihara (2001)[37]	10/33		X											
Kaufman-Cohen et al. (2018)[6]	15/15	X										X	X	
Kilincer et al. (2019)[27]	40/80	X												
Lee (2010)[55]	12/12											X		
Lee et al. (2014)[22]	12/31	X												
Lee et al. (2015)[23]	11/21	X		X										
Massie-Laberge et al. (2019)[31]	10/10	X											X	
Oikawa et al. (2011)[42]	14/28			X						X		X		

Oku and Furuya (2019[45])	13/35					X	X							
O'Shea and Moran (2019)[34]	15/15	X											X	BRPES
Rein et al. (2010)[50]	30/60			X	X	X					X	X	X	
Sakai and Shimawaki (2010)[7]	220/ 262													Radio-graphs
Sakai et al. (1996)[15]	10/10	X												
Sakai et al. (2006)[25]	10/10	X												
Spector and Brandfonbrener (2005)[16]	8/26	X				X								FAM and BFM scales
Spector et al. (2014)[48]	30/30						X						X	
Sugawara (1999)[8]	3/18	X				X							X	
Tominaga et al. (2016)[32]	7/7	X					X							
van Vugt et al. (2014)[47]	54/54						X						X	ADDS
Wilson et al. (1993)[54]	4/18				X					X		X		
Wolf (1993)[35]	8/8		X				X							
Wristen (2000)[9]	-											X		
Wristen et al. (2006)[28]	1/1	X												
Wristen et al. (2006)[41]	2/2			X	X									
Yee et al. (2002)[33]	33/33	X					X	X	X	X	X		X	
Yoshie (2008)[12]	12/12			X			X						X	ECG, Sweat rate meter

Yoshimura (2008)[53]	47/56					X			X			X	X	
Yoshimura et al. (2006)[52]	35/35				X	X						X	X	Displace-ment method

FAM = Frequency of Abnormal Movements arm dystonia disability scale, BFM = Burke-Fahn-Marsden scale, BRPES = The Borg Rating of Perceived Exertion Scale-CR10, ADDS = Arm Dystonia Disability Scale
VAS = Visual Analog Scale, STAI = State-Trait Anxiety Inventory, ECG = electrocardiogram

TABLE 3. Self-Reports Regarding the Musculoskeletal System

Reference	Outcome of the Self Report
Baadjou (2015)[63]	SQUASH (Wendel-Vos, 2003) DMQ (Hildebrandt, 2001) - to assess musculoskeletal complains DASH (Beaton, 2001) - to assess musculoskeletal disability Short Form-12 Health Survey (Aaronson, 1998) - to assess physical and mental health
de Manzano et al. (2010)[21]	A subset of the Flow State Scale to rate the flow dimensions according to the test manual (Jackson & Eklund, 2004)
Grieco et al. (1989)[39]	PRMD (occurrence, site and characteristics of any musculo-skeletal disorders) introduced in a specially developed questionnaire made by the author
Honarmand et al. (2018)[44]	GHQ-12 (Dresch MdPS-LaV, 2008) and CMDQ (Hedge, 1999)
Kaufman-Cohen et al. (2018)[6]	SNQ (Kuorinka, 1987) and a validated appendix for Upper Extremities (similar to SNQ) focused on reviewing the presence of pain in the muscles of the arm, elbow, forearm, palm and each of the fingers (Ratzon, 2008)
Massie-Laberge et al. (2019)[31]	3 Questions (made by the author) about the pianists' perception of how they move in relation to the musical score
O'Shea and Moran (2019)[34]	VMIQ-2 (Roberts, 2008) to measure the ability to form mental visual and kinaesthetic images of movements BRPES (Borg, 1982) as subjective measure

	of exertion during movement A post-experiment Likertstyle questionnaire
Rein et al. (2010)[50]	Medical history (ankle sprain, injuries of the skeletal system and neuromuscular or neurological disease (made by the author)
Spector et al. (2014)[48]	Medical history (made by the author)
Sugawara (1999)[8]	Feedback of the WristSensor Gloves
van Vugt et al. (2014)[47]	Extended version of the questionnaire used before (Jabusch 2005) about dystonia symptoms and, additionally, questions about piano playing and the relation with the therapy (before the therapy)
Yee et al. (2002)[33]	SOPA-R (Jensen, 1989) to measures pain attitude SF-36 (Ware, 1993) to measure both physical functioning and mental health
Yoshie (2008)[12]	STAI (Spielberger, 1970) to measure types of anxiety
Yoshimura (2008)[64]	VAS to quantify pain intensity[65] in response to four question (used also in Yoshimura 2006)
Yoshimura et al. (2006)[52]	PRMD (type, history, location, duration, onset, severity, frequency, contributing factors) using: VAS, body chart instrument (developed by Zaza, 1998)

GHQ-12 = General Health Questionnaire, CMDQ = Cornell Muscular Discomfort Questionnaire, SNQ = Standardised Nordic Questionnaires, VMIQ-2 = Vividness of Movement Imagery Questionnaire-2, BRPES = Borg Rating of Perceived Exertion Scale-CR10, SOPA-R = Survey of Pain Attitudes-Revised, SF-36 = Short-Form Health Survey, SQUASH = Short Questionnaire to Assess Health-enhancing physical activity, DMQ = Dutch Musculoskeletal Questionnaire, DASH = Disability Arm, Shoulder, Hand questionnaire

TABLE 4. Musculoskeletal Clinical Examination of Pianists in the Selected Studies

Anatomical Area	Musculoskeletal Clinical Examination	Author
Neck and head	Active ROM	Gohl et al. (2006)[40]
Upper extremities in general	Manual muscle testing for all major muscle groups; Sensory assessment with both light touch and pain/pin prick assessment; Muscle strech reflexes; Pathologic reflexes: Hoffman reflex	Gohl et al. (2006)[40]
	Length measurements; Active ROM	Yoshimura (2008)[64]
	Length measurements	Yoshimura et al. (2006)[52]
	Length measurements	Kaufman-Cohen et al. (2018)[6]
	Manual resistance test of the *extensor carpi radialis brevis* and *flexor carpi ulnaris* muscles	Oikawa et al. (2011)[42]
	Biomechanical measurement of hand and arm adapted from Wagner's method	Lee (2010)[55]
Lower extremities in general	Pathologic reflex: Babinski reflex	Gohl et al. (2006)[40]
	Vibratory sensitivity of the lower leg measured with a tuning fork; Romberg test; ROM of the ankle measured with a goniometer	Rein et al. (2010)[50]
Shoulder girdle and Shoulder joint	Active ROM	Gohl et al. (2006)[40]
Elbow	Active ROM	Gohl et al. (2006)[40]
	Rotation by active and passive movement	Wilson et al. (1993)[54]
Wirst	Active ROM; Tinel's sign and Phalen's test	Gohl et al. (2006)[40]
	Wrist circumference	Yoshimura (2008)[64], Yoshimura et al. (2006)[52]
	ROM, rotation speed, isometric and pinch strength measured with HPM Basic	Yoshimura et al. (2006)[52]

	Elements of Performance XII System	
	Wrist angle measured with an electrogonimeter	Oikawa et al. (2011)[42]
	Radial and ulnar abduction by active movement	Wilson et al. (1993)[54]
Hand and fingers	Active ROM	Gohl et al. (2006)[40]
	Hand volume and span; Index finger diameter	Yoshimura (2008)[64]
	Hand volume measured using a displacement method	Yoshimura et al. (2006)[52]
	Palm breadth, thickness and circumference; hand breadth and circumference; index finger length;	Fernandes and de Barros (2012)[24]
	ROM, maximum and minimum angle of abduction	Furuya et al. (2011)[26]
	Hand breadth, length of the third finger, length of the hand at the third finger, angles between fingers at maximum aperture	Grieco et al. (1989)[39]
	Hand span and the length of the third finger	Kaufman-Cohen et al. (2018)[6]
	ROM; Hand size, shape and width; Passive flexibility; Maximum interdigit span, maximum flexion, extension and rotation of the selected joints – active and passive measurements; Metacarpophalangeal joint movement and active thumb flexion	Wilson et al. (1993)[54]
	Hand span with electro-goniometers	Wristen et al. (2006)[41]

TABLE 5. Overview of the Selected Studies Using Surface EMG and the Recorded Muscles

Study	Chen et al. (2011)[19]	de Manzano (2010)[21]	Ferrarin (2008)[30]	Furuya et al. (2012)[18]
Facial muscles		ZM and CS		
PL and PB				
Back-extensors muscles				
LE				
Trapezius				
Deltoid				Right side of AD and PD
TB			X	Right
BB				Right
BR			X	
Forearm muscles				
APB				
ADM				
DI				
EDC	Right		X	Right
ECR				
FCU			X	
FDS	Right		X	Right
EP			Brevis and longus	
FP			Longus	

Lee et al. (2015)[23]	Grieco et al. (1989)[39]	Furuya et al. (2018)[43]
	X (including LM and IM as the main back extensors)	
	Right	
	Right and left upper trapezius	
	Right	
	Right	
Finger flexors and extensors of the forearm	Right epicondyle and epitrochlea	
		X
		X
	Right 1 DI	1 DI
		X
		X

Yoshie (2008)[12]	Wristen et al.	Rein et al.	Oku and Furuya (2019)[45]	Oikawa et al. (2011)[42]
	MM			
		Muscle bellies		
UT bilaterally	UT bilaterally			
Long head bilaterally				
Long head bilaterally				
	Flexors and extensors			
			B. H.	
			B. H.	
			1 DI, 2DI, 3 DI, 4 DI at B.H.	
X			B.H.	
				Brevis
X				X
			B. H.	

ZM = Zygomaticus major, CS = Corrugator supercilii, LE = Lumbar erector, UT = Upper trapezius, TB = Triceps brachii, BB = Biceps brachii, APB = Abductor pollicis brevis, DI = Dorsal interosseous, 1 DI = First dorsal interosseous, ADM = Abductor digiti minimi, EDC =

Extensor digitorum communis, EDS = Extensor digitorum superficialis, FDS = Flexor digitorum superficialis, ECR = Extensor carpi radialis, FCU = Flexor carpi ulnaris, AD = Anterior Deltoid, PD = Posterior Deltoid, BR = Brachioradialis, LM = Longissimus muscles, IM = Iliocostalis muscle, EP = Extensor pollicis, FP = Flexor pollicis, PB and PL = Peroneus longus and the peroneus brevis, MM = Masseter muscle, B. H. = Both hands.

TABLE 6. Musical Piece, Melody or Excerpt used in the Selected Studies

Author	**Musical Piece, melody or excerpt chosen**
Chen et al. (2000)[49]	Familiar fast pieces (voluntarily selected by the subject)
Clemente (2014)[20]	Free repertoire, followed by a piece with a score previously chosen by them or directly asked by the teacher to play (e.g. Liszt's Hungarian Rhapsody no. 6)
de Manzano et al. (2010)[21]	Complete piece or a complete movement of a larger cycle (voluntarily selected by the subject)
Ferrarin (2008)[30]	A scale performed symmetrically with the two hands in inward direction
Ferrario et al. (2007)[29]	16 measures of a Minuet by Bach
Furuya et al. (2010)[17]	Right-hand keystroke of the C3 key by the middle finger
Furuya et al. (2011)[26]	Octave and C major chord
Furuya et al. (2012)[18]	Right-hand repetitive and simultaneous keystrokes of the E4 key by the thumb and the C5 key by the little finger
Furuya et al. (2018)[43]	17 successive strikes of 5 adjacent piano keys (C, D, E, F, G) within a range of one octave
Grieco (1989)[39]	Exercises from Hanon, also each subject performed an unseen passage (Scott Joplin's 'Elite Syncopation'), and then one or two passages from the subject's repertoire
Honarmand et al. (2018)[44]	A song for 10 minutes, free repertoire for 5 hours, followed by the identical song played by the subject at the beggining
Kaufman-Cohen et al. (2018)[6]	Praeludium I, in C, by J. S. Bach
Lee (2010)[55]	Short excerpt of a "scale in thirds" exercise from Cortot's Rational Principles of Pianoforte Technique (1989) and an excerpt from Chopin's Etude no. 1, op. 10
Massie-Laberge et al. (2019)[31]	Medtner Sonata Reminiscenza op. 38 (mes. 253-274), Chopin 4th Ballade (mes. 152-160), Chopin's Impromptu (mes. 43-51)
Oikawa et al. (2011)[42]	An octave (G3-G4) with the right thumb and little

	finger
Oku and Furuya (2019)[45]	Two-octave C-major scale, successive strikes of five adjacent keys bidirectionally; To strike five nonadjacent separate keys bidirectionally ("arpeggio")
O'Shea and Moran (2019)[34]	Four music scores: two easy (one for the right-hand and one for the left-hand) and two complex (one for the right-jand and one for the left-hand). It comprised extracts from Hanon's The Virtuoso Pianists (Easy; Schirmer, Vol. 925) and Exercise 34a from Brahms' 51 Exercises for piano (Complex; Schirmer, Vol. 1600)
Sakai et al. (1996)[15]	A scale and a chord pattern
Sakai et al. (2006)[25]	An octave and a chord pattern (C major chord)
Spector and Brandfonbrener (2005)[16]	All music excerpts were chosen by one investigator (A. G. B.)
Spector et al. (2014)[48]	Scales (C major scales) over two octaves (C3-C5) with both hands separately
Sugawara (1999)[8]	Not mentioned
Tominaga et al. (2016)[32]	8 note melody (G-E-G-D-F-E-F-D) within a range of one octave with the right hand
van Vugt et al. (2014)[47]	Ascending and descending scales (C major scales) over two octaves, with the subject's affected hand
Wolf (1993)[35]	Specific passage from Mendelssohn's Song Without Words (op. 19, no. 2)
Wristen et al. (2006)[28]	Chopin Scherzo in B-flat Minor op. 31 and an excerpt from the second movement from Judith Lang Zaimont's Suite Impressions, entitled "Jazz Waltz"
Wristen et al. (2006)[41]	The first 1.5 minutes of the Tchaikovsky Piano Concerto in B-flat Minor, op. 23
Yee et al. (2002)[33]	A chromatic scale, major scales, a familiar piano piece, an unfamiliar piece - Beethoven, Polonaise Opus 89 in C (Complete Edition of All His Works: For Piano, Little Pieces. Long Island, NY, Edwin F. Kalmus, 1971), sight-read and then play a difficult piece of music - Babbitt M.: Playing for Time. (11 Piano Music in Twentieth Century America. Chapel Hill, NC, Hinshaw Music, Inc., 1979)
Yoshie (2008)[12]	A-flat major arpeggio combined with G-sharp minor arpeggioss
Yoshimura (2008)[53]	Chord (B-C#-G#-B)

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