Assessing 2D and 3D Motion Tracking Technologies for Measuring the Immediate Impact of Feldenkrais Training on the Playing Postures of Pianists

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ABSTRACT

The Feldenkrais Method of somatic education has become popular with pianists for improving ease of motion and musculoskeletal health. This thesis contains three studies investigating motion-tracking technologies as means to objectively assess the impact of Feldenkrais training on pianist posture. The first study investigates the accuracy and reliability of Dartfish 2D motion tracking software. Results indicate that Dartfish tracking error is within +/- 0.25 centimeters. The second study uses Dartfish to track head, shoulder, and spine positions of 15 pianists during performance before and after receiving a Feldenkrais Functional Integration Lesson. Comparisons of pre- and post-test measurements indicate no group trends in posture change. However, intriguing changes to movement quality in the head and torso were observable for two participants. The third study compares tracking quality of Dartfish and the Microsoft Kinect for the head, shoulders, and arms of four pianists attending a weeklong Feldenkrais workshop. Results reveal frequent tracking errors with the Kinect sensor, making it unsuitable to measure the impact of somatic training on pianist posture.

Keywords: pianist posture, motion tracking, motion capture, Dartfish, Kinect, somatic training, Feldenkrais method, piano pedagogy

RÉSUMÉ

Cette thèse présente trois études qui examinent l'efficacité des technologies de suivi du mouvement pour mesurer objectivement l'effet de la méthode Feldenkrais sur la posture des pianistes. La première étude évalue la précision et la fiabilité de la fonction de poursuite de mouvement du logiciel Dartfish. Les données indiquent que l'erreur de mesure n'est pas supérieure à +/-0.25 cm. La deuxième étude utilisait Dartfish pour suivre le mouvement de la tête et le torse des 15 pianistes avant et après une leçon de la méthode Feldenkrais. Les données indiquent que les mesures moyennes du groupe ne varient pas significativement après le traitement. Pourtant, on observe des changements intéressants dans les caractéristiques des mouvements de la tête et du torse pour deux participants. La troisième étude compare la qualité de la technologie de suivi de mouvement entre Dartfish et Kinect de Microsoft. On a constaté que la qualité de la poursuite de mouvement de Kinect est inférieure à celle de Dartfish. Le Kinect n'est pas un outil efficace pour mesurer l'effet de la méthode Feldenkrais sur la posture des pianistes.

Mots-clés: posture, piano, poursuite de mouvement, Dartfish, Kinect, somatique, Feldenkrais method

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INTRODUCTION

Playing piano is one of the most complex feats of motor control that human beings can accomplish (McPherson & Gruhn, 2002). Mastery of the instrument involves over a decade of dedicated, daily practice to refine and reinforce the connections between the auditory, visual, and motor cortices of the brain, which must coordinate seamlessly to allow a perfomer to play with control and expression (Bangert & Altenmüller, 2003; Bangert, Häusler, Altenmüller, 2001; Bangert et al., 2006). The many hours of continual practice involved can place formidable demands on the body. Recent research has revealed high prevalence rates for the development of playing-related pain amongst professional musicians, including pianists (Zaza, 1998; Cayea & Manchester, 1998, Dawson, 2002; Brandfonbrener, 2009). Theories about the development of playing-related pain often implicate poor postural alignment as one of the important risk factors (Cailliet, 1990; Brandfonbrener, 1997; Allsop & Ackland, 2010; Dommerholt, 2010). Therefore, many pianists have turned to somatic training approaches, such as the Feldenkrais Method, to help them discover more comfortable and sustainable movement and posture strategies. Unfortunately, despite the abundance of subjective evidence demonstrating somatic training can improve postural alignment and allow musicians to move more freely, there is a paucity of objective, scientific research demonstrating the impact of somatic training on musician posture and movement. This thesis explores the efficacy of Dartfish and Kinect motion tracking technologies as means of objectively measuring the playing posture and movement of pianists in particular. Obtaining quantitative data about the positioning of pianists' bodies during performance using these technologies could allow researchers to objectively evaluate if there is an appreciable difference in movement and posture characteristics before and after somatic training interventions. Three research studies are presented that investigate the suitability of

these two technologies as posture measurement tools in the context of live piano

performance. The first study tests the reliability and accuracy of Dartfish video-based

measurement in a controlled lab setting. The second study explores the use of Dartfish in a

repeated measures study examining posture and movement characteristics of pianists before

and after a Feldenkrais Functional Integration Lesson. The third study compares Dartfish and

Kinect tracking results of pianists' performances from before and after a weeklong

Feldenkrais workshop. Results from these studies are presented and discussed in terms of

how motion tracking technologies could best be incorporated in future studies assessing the

impact of somatic training on the movement and posture of pianists.

CHAPTER 1: LITERATURE REVIEW

Reputable music schools and training organizations are increasingly incorporating somatic education methods into their programs to help students improve postural alignment and movement quality (Schiff, 2014; Stewart, 2010b; Stewart, 2015). Misaligned posture and restricted movement habits are often implicated in the development of playing related pain (Cailliet, 1990; Brandfonbrener, 1997; Allsop & Ackland, 2010; Dommerholt, 2010), or are cited as factors in inexpressive playing (Neuhaus, 1967; Fink, 1992; Taubman, 1995). Somatic practitioners often report differences in the postural alignment and movement characteristics of their students after attending somatic training sessions (Rosenthal, 1987; Mayers & Babits, 1989; Nelson, 1989), and practitioner websites are littered with student testimonials purporting improvements to playing quality, playing related pain, and freer movement (Goldansky, 2008; Stewart, 2010a; Fraser, 2015; Boyd, 2015; Johnson, J., 2015). However, there is little scientific evidence that visible changes in posture occur immediately as a result of somatic training interventions (Jain, Janssen & DeCelle, 2004; Schlinger, 2006). In the following review I present literature that contextualizes the need for objective measurement in somatic training research with musicians and explore how measurement approaches from the field of kinesiology could be applied using available 2D and 3D motion tracking technologies to make such objective measurement possible with pianists.

This literature review contains five sections: The first section outlines how somatic training became associated with musicians by exploring factors contributing to a greater appreciation for the importance of body awareness in music pedagogy and performance culture over the past few decades. The second section describes three popular somatic training methods: the Alexander Technique, Body Mapping, and the Feldenkrais Method, and explains their significance in music pedagogy. Since the Feldenkrais Method will be

investigated in later research papers in this thesis, a separate section is included to discuss this particular somatic method in more detail. The remainder of section two explores the limited body of scientific research on somatic training outcomes, and discusses how quantitative measurement of posture is underexplored in the current literature. The third section describes approaches to measuring posture that have been used in the fields of kinesiology and ergonomics and discusses how these approaches could be applied in the context of piano playing. The fourth section describes two movement tracking technologies that could be utilized as accessible means to track and measure pianists' movements during live performances for the purposes of quantitatively comparing posture and movement characteristics from before and after somatic training interventions. The first technology examined is video-based analysis software called Dartfish. The second is the Microsoft Kinect depth sensor. In the final section I propose research questions to investigate the suitability of these technologies for quantification of pianistic posture and movement that will be answered by three separate studies.

1.1 The Significance of Posture and Movement in Piano Pedagogy

Since traditional pedagogical approaches tend to limit conceptions of posture to maintaining an upright and somewhat rigid playing position (Prieur, 1994), somatic training methods have become incorporated into music education as a supplementary form of pedagogy to improve musicians' posture and movement. The following section explores these issues in more detail. First, an overview of how piano posture is presented in historical and modern pedagogical literature is presented. Next, pedagogical literature on the role of posture in the etiology of playing-related pain and expressive playing technique is presented to illustrate changing attitudes about total body awareness that have become more prevalent in piano pedagogy in the last few decades.

1.1.1 Traditional views of posture and movement in piano pedagogy. From the time that the earliest written treatises on the art of keyboard playing began to appear, piano pedagogues have been concerned with teaching students to sit "properly" at the piano. In fact, Carl Czerny believed that "the movements of the body have so great an influence on piano-forte playing, that a good and graceful position must be the first thing to which the Pupil's attention should be drawn," (Czerny, 1839, p. 1). Many authors of treatises on keyboard playing, such as C. P. E. Bach (Bach, C.P.E, 1949, originally published 1753, rev. ed. 1787), Couperin (Couperin, 1716), Leschetizky (Brée, 1997, originally published in 1902), Hummel (Hummel, 1827), and Bártok and Rechaufsky (Bartók and Reschofsky, 1950, originally published 1913), outline their recommended sitting posture early in their volumes (Gerig, 2007). Although the details of optimal bench height and distance of the player from the keyboard vary among authors, they seem to agree that it is preferable for a student to maintain a still, upright stance with the forearms roughly level with the piano keys. The various descriptions emphasize the importance of maintaining such a posture continually while playing, and they frequently caution against slouching. Today, similar descriptions of piano posture appear at the beginning of modern piano method books (Bastien, J. & Bastien, J. S., 1985; Barden, Kowalchyk, & Lancaster, 2009; Vogt & Bates, 2001; Curie, 1985; Fletcher, 2012). Just like the historical treatises, modern method books seem to place greater importance on how the position looks externally rather than on how the student feels while playing. They do not explore how body position might influence execution and control during playing, and stillness seems to be valued over pliability. Furthermore, modern method books do not reinforce lessons about playing posture at later points in the volume. It seems that piano posture is often treated as an incidental issue to be dealt with quickly at the beginning of study in order to make way for the more important subject of hand and finger

technique. Although the traditional descriptions of posture found in method books offer a convenient starting point for introducing a pupil to the instrument, they are often oversimplified and tend to overlook any exploration of total body involvement during keyboard performance. This has been criticized by some who attribute the proclivity of many students to play rigidly or develop musculoskeletal problems in part to their adherence to the tenets of fixed, erect posture introduced to them from their earliest lessons (Newman, 1984; Prieur, 1994).

        1.1.2 Posture as a factor in playing quality and playing related pain. Some manuals on piano pedagogy afford little importance to issue of playing posture, moving on quickly from issues related to sitting to focus more extensively on the positioning of the hands and fingers (Last, 1985). However, other pedagogues have emphasized the importance of total body incorporation into piano playing, and have shown a greater interest in exploring how body awareness could improve technique and playing quality (Neuhaus, 1967; Fink, 1992; Prieur, 1994; Taubman, 1995). This emerging concern for body awareness in music performance stems, in part, from concerns that excess tension in the trunk and limbs, and misaligned posture during playing inhibits expressive control at the instrument. It is widely held among piano pedagogues that addressing issues of excess tension in the neck, arms, and body during playing can help students improve their technical control, while freeing them to shape the music more expressively (Wheatley-Brown, Comeau, & Russell, 2014). For example, in his book *What Every Pianist Needs to Know about the Body,* Thomas Mark discusses how learning proper mechanical use of the body will help liberate pianists from excess tension in the joints and muscles to free them to play more securely and expressively (Mark, 2003). Similarly, Barbara Lister-Sink's popular DVD series *Freeing the Caged Bird: Developing Well-Coordinated, Injury-Preventive Piano Technique* (1996, 2008), teaches

students how to achieve suppleness in their movement by focusing on step-by-step lessons on how to use the body based on principles of biomechanics, with the goal of improving technique quality (Osada, 2009). These and other pedagogues have focused their efforts on developing methods for reducing body tension to promote improved artistry at the piano.

Prolonged misaligned or rigid postures are frequently cited as factors in the development of playing-related musculoskeletal disorders (PRMDs) in both the medical and performing communities (Cailliet, 1990; Brandfonbrener, 1997; Allsop & Ackland, 2010; Dommerholt, 2010). Over the last two decades, studies have confirmed high prevalence rates of PRMDs for professional instrumentalists and students, raising awareness that playing-related pain is common amongst professional musicians (Zaza, 1998; Brandfonbrener, 2009). Some evidence suggests prevalence rates are especially high for music teachers and conservatory students (Dawson, 2002) and pianists are in the high-risk group amongst their fellow instrumentalists (Cayea & Manchester, 1998; Dawson, 2002). PRMDs constitute an urgent problem in music pedagogy, since research has shown that PRMDs can severely impact musicians psychologically (Zaza, Charles, Muszynski, 1998; Bialocerkowski, McMeeken, & Bragge, 2004; Kenny & Ackermann, 2015), and can also impact a musician's ability to coordinate their fine motor skills and posture during performance (Fry, Hallett, Mastrioanni, Dang, & Dambrosia, 1998; Daenen, Roussel, Cras, & Nijs, 2010; Steinmetz, 2009, Steinmetz, Seidel, Muche 2010). Alarmingly, research suggests music students often lack strategies for addressing playing-related pain and professional teachers are often uninformed or confused about how to best help students when PRMDs develop, despite desiring to help (Quarrier, 1995; Redmond & Tierman, 2001; Spahn, Richter & Zschocke, 2002; Britsch, 2005). Increasing awareness of the prevalence of PRMDs and their serious impact on both student and professional musicians has motivated many to seek pedagogical

alternatives to the issue of body-use in keyboard performance, since traditional approaches to piano pedagogy lack specific knowledge and strategies to address these issues.

      1.1.3 Conclusion. Although posture has remained an important issue in piano pedagogy since the earliest treatises on keyboard technique were written, some modern day pedagogues take issue with static and rigid approaches to sitting, since maladaptive posture is cited as one of the potential causes of PRMDs and inexpressive playing. The growing concern for body awareness in music pedagogy created a need for new pedagogical strategies, since traditional approaches to music pedagogy do not equip music students and teachers with effective strategies to deal with issues pertaining to improved body use or playing-related pain.

1.2 Somatic Training Methods

      Musicians' interest in somatic training methods, such as the Alexander Technique (Alexander, 1932), the Feldenkrais Method (Feldenkrais, 1981), and Body Mapping (Conable, 2009), has increased in response to a growing concern for body awareness strategies in music pedagogy. This section begins with an overview of the Alexander Technique and its offshoot, Body Mapping, which are two somatic training methods popular amongst musicians. This is followed by a more detailed analysis of the Feldenkrais Method of somatic education, which will be the primary intervention of interest in this thesis. Next, I present an overview of subjective evidence for the outcomes of somatic methods in case studies and testimonials, with a subsequent review of the scientific research conducted on somatic training methods thus far. The closing section discusses the value of measuring posture and movement quantitatively as a way to objectively examine the potential impact of somatic training on pianists.

1.2.1 Overview of somatic training methods. The word *somatic* comes from the ancient Greek word *somatikos,* meaning "of the body" (Harper, 2015). Somatic training methods are constructed around the principle that the mind and the body are inextricably linked, and that improving functionality of the body will confer not only physical benefits, but psychological and emotional benefits as well (Feldenkrais, 1964). The various somatic methods have crafted techniques to elicit a more refined awareness of the total body, and to improve body use by helping people learn to replace maladaptive movement habits with ergonomic alternatives. It is theorized that as new approaches to movement become habitual through practice of these methods, quality of life and musculoskeletal health will improve (Eddy, 2009). Although each somatic method has a unique set of practices and theoretical foundations, they share a common objective to help individuals move with greater ease by helping them attain awareness of the integration of various parts of the body. Somatic practitioners use various combinations of therapeutic touch, diagrams, verbal directives, exercises, and manipulation of joints to help individuals reconfigure habits of motor-control that mediate posture (Spire, 1989; Conable, 1995; Alcantara, 1997; Ginsburg, 1999; Mark, 2003). In the following sections I will describe three of the most popular somatic approaches in more detail.

1.2.1.1 Alexander Technique and Body Mapping. Of the three methods to be discussed, the Alexander Technique was the first to be formulated. The Australian actor Frederick Matthias Alexander (1869–1955) developed this technique in response to difficulties he experienced with vocal projection, which could not be explained by doctors. He developed a set of principles about healthy ways to use the body through a process of self-exploration. His discoveries helped him to recover from his vocal problem and return to acting. His transformation was so dramatic that he was motivated to continue to refine and

eventually teach his method. Registered Alexander Technique practitioners who complete an intensive, four-year training program continue to teach the method today (http://www.thealexandertechnique.net/courses/). During Alexander Technique sessions students may be given verbal directives about ergonomic ways to move or receive therapeutic touch from the practitioner. Generally, Alexander teachers seek to guide individuals to achieve a more comfortably aligned posture, (particularly in terms of the head's connection to the spine), through the use of imagery and specific movements (Conable, 1995). Alexander Technique theorizes that by consciously inhibiting engrained movement patterns and postures and deliberately replacing them with ergonomic alternatives, the new approaches will become habitual over time, allowing students to enjoy a more free and comfortable use of their body (Alexander, 1932).

Body Mapping is an offshoot of the Alexander technique and similarly emphasizes the role of conscious inhibition of posture and movement habits so that new ways of moving can be consciously executed and gradually assimilated into healthier habits. William and Barbara Conable initially developed this method to help musicians prevent or recover from playing-related pain and discomfort. William Conable is a cello professor at Ohio State University School of Music. He began to develop Body Mapping in his work with cello students, using formative elements from the Alexander Technique. Barbara Conable is an Alexander Technique teacher. Together, the two developed Body Mapping as a comprehensive form of anatomically based somatic education (Andover Educators, 2013). In this approach, an individual's body map is considered to be their internal perception of the shape and size of their body in space, and their functional understanding of how joints and muscles move together anatomically (Conable, 2009). Proponents of Body Mapping believe that when a person's body map is accurate they will move with ease and will have a lower

risk for developing musculoskeletal problems. Unfortunately, individuals do not always clearly understand how the joints in their body are constructed and many people function with inaccurate body maps. In theory, inaccurate body maps can lead to restricted and awkward movement, joint stiffness, muscle fatigue, and even musculoskeletal disorders. For instance, many people mistakenly believe that the arm attaches to the torso at the area typically referred to as the shoulder. A student of Body Mapping would be taught that the clavicle is truly the first bone of the arm, and that the arm actually attaches to the torso at the sternoclavicular joint at the front of the body. Individuals who learn about the role, location, and function of the sternoclavicular joint are often able to move their arms more freely because they have a clearer mental representation of the true biomechanical functioning of that region of their body. Body mapping teaches correct body-use with diagrams, models, illustrations, and palpations of structures on the body to help people become more conscious of how the various structures work together during movement. Body mapping can be studied independently using DVD lessons, or taught by a licensed Andover Educator (Andover Educators, 2013).

1.2.1.2 The Feldenkrais Method. Moshe Feldenkrais (1904–1984) was a physicist, engineer and Judo master who first began developing his method of somatic training in response to a knee injury received playing soccer (Feldenkrais, 1981). Over the course of his life he applied his extensive knowledge in the fields of physics, anatomy, psychology, and neuroscience to expand his method, which he eventually used to help many individuals with neuromuscular problems, including many children with cerebral palsy (Fox & Korentayer, 1980). The theoretical basis of the Feldenkrais method is fundamentally different from Alexander Technique and Body Mapping. Whereas the latter two focus on identifying problematic movement habits or incorrect anatomical conceptions and replacing them with

ergonomic alternatives through conscious attention and effort, the Feldenkrais Method puts greater emphasis on unconscious motor learning. Feldenkrais theorized that human beings begin a process of motor-learning apprenticeship as babies, gradually learning to move and balance by receiving proprioceptive feedback from interacting with the environment (Feldenkrais, 1981). This type of motor learning is largely unconscious and evolves as individuals develop motor control solutions to successfully survive in their environment, further refining them through proprioceptive feedback. Feldenkrais believed that this process of motor learning is blocked or muted in many adults, and that specific types of controlled movement could awaken it by helping the brain incorporate proprioceptive feedback into modified motor plans that more fully integrate various components of the body. In fact, Feldenkrais teachers refer to their clients as "students" to emphasize that the individual is undergoing a learning experience as they explore movement possibilities rather than experiencing a mechanical adjustment like one might receive at the chiropractor.

Feldenkrais teachers help people explore a variety of new ways to move during lessons. They promote motor learning by manipulating the conditions of proprioceptive feedback so that central nervous system can experience novel learning situations. For instance, work is often done in a lying position to allow antigravity muscles that normally keep people balanced while standing experience movement with gravity working in a different plane. Many of the movements also require students to differentiate the direction of their movement from the direction of their gaze. For instance, a student may be asked to turn their head to the left while moving their eyes to look to the right. Feldenkrais practitioners communicate with the nervous systems of their students by guiding them through one of two contrasting modalities of controlled movement aimed at facilitating motor learning: Awareness through Movement (ATM) and Functional Integration (FI). ATM lessons involve

student-directed movement and require a Feldenkrais teacher to verbally instruct a group of

students through a series of progressive movements designed to help students explore the

many ways various parts of their body can integrate to achieve a desired movement goal,

such as rolling over, or sitting up (Feldenkrais, 1990). Students are directed to focus on the

quality of the movement, not the size or speed, and are cautioned to move smoothly, without

force. During ATMs, students are encouraged to focus on becoming aware of how the

movements feel in their own bodies as the goal, instead of attempting to stretch or force the

body into positions that are uncomfortable (Ginsburg, 1999, p.4). Contrastingly, FI lessons

involve practitioner-directed movement. The student is not responsible for moving their own

body during these one-on-one lessons; they must relax and allow the practitioner to gently

move the joints and muscle tissue while they are in a lying position. Gravity has a different

effect on the body when a student is lying down, allowing the nervous system of the

student's body to experience the movements carried out by the practitioner in a new

environmental condition. The practitioner seeks to communicate with the central nervous

system of the student directly through touch to help it learn new movement possibilities. The

teacher will often become aware of joints with restricted movement that constitute "blind-

spots" in a student's nervous system, and will try to move their bodies in such a way that the

brain will "wake-up" to reintegrate that area of the body into coordinated movement.

Although Feldenkrais students might become aware of habits, tendencies, or asymmetries in

their posture and movement through the process of ATM or FI, this is not the primary goal of

Feldenkrais lessons. The act of exploring new possibilities for movement can cause

unconscious changes to the way the brain integrates parts of the body to control posture and

goal-directed movement. Students can receive Feldenkrais lessons from Certified Feldenkrais

Practitioners who have completed a four-year accreditation and training program

(http://www.feldenkrais.com/professional-training).

        1.2.2 Somatic training approaches in music pedagogy. Somatic training methods

are incorporated into many injury prevention and technical training methods for musicians.

For example, the celebrated injury recovery approach developed by Dorothy Taubman

incorporates somatic training methods as a core aspect of therapeutic intervention (Taubman,

1995). Today, her method continues to be used by high calibre performing musicians and is

taught at the Goldansky Institute (http://www.golandskyinstitute.org/), which is renowned for

its Summer Symposium featuring performances, lectures, and private lessons at Princeton

University. Many prestigious music-training institutions now make Alexander Technique

lessons available to students. For example, Tanya Bénard is an Alexander Technique teacher

serving on the faculty of the Royal Conservatory of Music in Toronto, where she delivers an

Alexander Technique program for musicians she developed in 2006 (The Royal

Conservatory of Music, n.d). Similarly, Lauren (Lori) Schiff is an Alexander Technique

teacher and trumpet player on faculty at the Juilliard School who coaches sessions with

music students. She also teaches the Alexander Technique at the renowned Aspen Music

Festival (Schiff, 2014). Body Mapping and the Alexander Technique are the central somatic

methods explored by Thomas Mark in his celebrated book, *What Every Pianist Needs to*

Know about the Body (Mark, 2003). In this book, pianists can find detailed anatomical

diagrams accompanied by descriptive visualization strategies designed to increase

understanding of how joints, muscles, and posture alignment best function to promote free

use of the body during playing. Mark also teaches a six-hour course overviewing this

material in various cities in the United States and Canada (Mark, 2015). These examples

illustrate how Body Mapping and Alexander Technique have become important aspects of

musical training, especially among reputable performing institutions that cater to the most promising of music students.

The Feldenkrais Method has also become associated with music pedagogy. In fact, some Feldenkrais practitioners have gained notoriety for their work with musicians specifically, helping many develop freer expression and recover from playing-related pain. For instance, Anat Baniel, trained psychologist and Feldenkrais practitioner, teaches her own method evolving the work of Moshe Feldenkrais, which has been incorporated into music programs at the Tanglewood Music Centre and the San Francisco Symphony (Spire, 1989; Baniel, 2012). Individuals can train in Baniel's method at the Anat Baniel Method Centre in San Rafael, California (http://www.anatbanielmethod.com/). Aliza Stewart is a certified Feldenkrais practitioner specializing in work with musicians.

She regularly teaches seminars and workshops at various music schools, notably the Mannes School of Music and the Julliard School (Stewart, 2015). She also works as an annual resident at the Marlboro Music Festival, which is artistically directed by international piano superstar, Mitsuko Uchida (Marlboro Music, 2015), and the Yellowbarn Music School and Festival, which is associated with the Manhattan School of Music. Uri Vardi, a professional cellist, and his wife Hagit Vardi, a professional flautist, are Feldenkrais practitioners offering specialized training for musicians at the University of Wisconsin and workshops around the world (http://www.harmoniousmovement.com/). Finally, Alan Fraser is a Feldenkrais practitioner specializing in work with pianists who regularly offers workshops in Europe and North America on Feldenkrais techniques for the piano (Fraser, 2012). His approach extends Feldenkrais' principles of motor learning to his understanding of piano technique, helping pianists diversify their control of dynamics, voicing, and tone colour, while liberating a more secure technique at the instrument (Fraser, 2010; Fraser, 2003/2011).

1.2.3 Conclusion. Alexander Technique, Body Mapping, and the Feldenkrais Method have become closely associated with music pedagogy. The Alexander Technique and Body Mapping focus on helping individuals identify and consciously replace maladaptive movement habits with ergonomic alternatives. Contrastingly, the Feldenkrais Method focuses on exploring new movement possibilities and awakening the central nervous system to a more receptive state to promote unconscious motor learning. All three methods have become well respected in music pedagogy, and are heavily incorporated into various popular approaches to piano technique that are intended to help prevent or rehabilitate playing related pain.

1.3 Evidence of Somatic Training Outcomes for Musicians

The body of research on the benefits of somatic training is small, and most of the available studies have not studied musicians. Most evidence linking somatic training to improvements in musculoskeletal pain or music performance quality comes from subjective sources, such as testimonials or practitioner accounts. In this section I will first present examples of subjective and qualitative evidence describing reported outcomes of somatic training. Next I will review the findings from existing scientific research conducted on somatic training as a therapeutic interventions for musculoskeletal pain and review the few studies examining somatic training outcomes for musicians. Finally, I will review research investigating the impact of somatic training on issues related to posture to support the proposition that quantitative measurements of posture variables could offer a more objective way forward in somatic training research.

1.3.1 Qualitative evidence and testimonials. Musicians tend to speak positively about their experiences with somatic training. Practitioner websites are littered with testimonials of people who insist that their playing improved (Goldansky, 2008; Stewart,

Alexander Technique by Rosenthal (1987) discusses case studies of a violist, a violinist and a pianist suffering from upper extremity pain. The practitioner describes how all three previously incapacitated performers were able to return to playing after three Alexander Technique sessions, although a disclaimer was put forth that such results are not guaranteed. Some practitioners also report differences in their students' posture alignment after somatic training. For instance, Mayers and Babits (1989) include before and after photos of a singer in their article on the Alexander Technique in order to illustrate that the singer appears to be in a more natural position following their training. Although these examples of testimonials and practitioner-reported results convey pertinent details about the experiences of individual clients, they do not constitute research-based evidence of somatic training outcomes, and offer little to contextualize the results in terms of expected outcomes for musicians in general.

      1.3.2 Research on somatic training outcomes. Although the theoretical foundations of most somatic methods claim to be rooted in scientific theories of motor control, neuroplasticity, and motor-learning (Feldenkrais, 1966; Buchanan & Ulrich, 2001; Nichols, 2004; Ginsburg, 2009; Doidge, 2015), the body of scientific research investigating the outcomes of somatic training in both musician and non-musician populations is very small, and ultimately our understanding about the mechanisms behind any positive outcomes from somatic training remains almost exclusively theoretical (Jain, Janssen & DeCelle, 2004). In the following subsections I outline research on somatic training as a therapeutic intervention for musculoskeletal pain, followed by research on the somatic training outcomes for musicians.

      1.3.2.1 Research on somatic training as a therapeutic intervention for musculoskeletal pain in non-musician populations. To date, the small body of research that

exists on somatic training methods has focused on assessing their suitability as therapeutic interventions for musculoskeletal disorders in non-musician populations. For instance, Little and colleagues (Little et al., 2008) conducted a randomized control trial examining the effectiveness of Alexander Technique lessons, massage therapy, and a doctor's prescription of exercise along with behavioral counseling from a nurse in the treatment of chronic or recurring lower back pain. A total of 579 participants with back pain were randomized into the following groups: 144 to standardized care, 147 to massage therapy, 144 to six one-on-one Alexander Technique lessons, and 144 to 24 one-on-one Alexander Technique lessons. Half of the participants in each of these groups were randomly assigned to receive an additional prescription of exercise from a doctor. Individuals' health-related quality of life was assessed using the Roland Morris disability scale, which measures the number of activities impaired by pain and the number of days with pain. They found that individuals who took part in exercise coupled with Alexander Technique, but not massage, continued to have less back pain at a one-year follow-up. They also found that participants who received six Alexander Technique lessons plus exercise achieved 72% of the effect of 24 Alexander Technique lessons without exercise. This suggests that although massage may be effective for reducing low back pain in the short-term, Alexander Technique training can confer long term benefits for pain reduction. The results seem to indicate the long-term benefits can be bolstered or reinforced by exercising, suggesting that the prescription of exercises and a moderate number of Alexander Technique lessons could be a cost-effective way to treat low back pain. In a similar study, Yardley and colleagues (Yardley et al., 2010) examined low-back pain patients' attitude toward medical perscriptions of Alexander Technique lessons or an exercise program for the management of their symptoms. Following on the results of the previous study by Little and colleagues (2008), the research team created a questionnaire

based on the Theory of Planned Behaviour (see Ajzen, 1991 for information regarding this theory) to assess the attitudes and expectations of patients about Alexander Technique as a treatment for their back pain. This questionnaire was completed by 183 people randomly assigned to Alexander Technique lessons, and 176 assigned to exercise prescription. Data was also collected from semi-structured interviews with 14 individuals assigned to Alexander Technique and 15 assigned to exercise, before the intervention began. Post-intervention, 15 of those interviewed completed another semi-structured interview. Responses to the questionnaire demonstrate that attitudes toward both treatments were positive before the treatment began, but became more positive only for the Alexander Technique group. Many of the interviewed patients felt they could manage pain better as a result of Alexander Technique lessons. Individuals also reported fewer obstacles to practicing AT than to exercising, since it could be practiced at almost anytime or location, and because it involved the role of a supportive teacher. The results of this study suggest that when AT is administered from a personable practitioner at no cost to the individual, individuals are motivated to participate and have a favorable attitude toward its prescription for low back pain.

A few studies have examined the suitability of the Feldenkrais Method as a therapeutic intervention for musculoskeletal disorders. For instance, Kendall, Ekselius, Gerdle, Sörén, and Bengtsson (2001) compared fibromyalgia patients' reported pain, ability to balance, and lower extremity function before and after completing either a fifteen-week intensive Feldenkrais program or a 15-week group-based pain education and swimming pool therapy program. At the conclusion of the study it was found that participants in the Feldenkrais group improved in their balance and lower extremity function when compared with the pool group, but the improvements were not maintained at the six-month follow up.

Also, neither group showed statistically significant changes in reported pain or muscle

fatigue. However, questionnaire responses revealed that participants in the Feldenkrais group

felt better equipped to handle pain symptoms following treatment and were more satisfied

with treatment overall than the pool group. In a randomized control study, Lundblad, Elert &

Gerdle (1999) compared the Feldenkrais method with traditional physiotherapy as

interventions for neck and shoulder pain in ninety-seven female office workers randomly

assigned to undergo either sixteen weeks of Feldenkrais training, physiotherapy, or no

intervention. It was found that the Feldenkrais group reported significantly fewer complaints

about neck and shoulder pain and decreased disability during leisure time post-intervention.

The physiotherapy group reported no changes and the control group's complaints increased.

However, no significant differences were noted in any group using the self-reported scale

measurements for pain, indicating that there was not a measurable impact on pain intensity in

any of the groups. Similarly, Malmgren-Olsson & Bränholm (2002) compared the effects of

Basic Body Awareness Training (BAT), the Feldenkrais Method and conventional

physiotherapy on health-related quality of life, self-efficacy of pain management, and pain

reduction in 78 patients with non-specific musculoskeletal disorders. Participants in the

Feldenkrais and BAT groups each underwent 20 group therapy sessions while the duration of

treatment for the physiotherapy participants was established according to the

recommendations of their physiotherapist. It was found that there were no statistically

relevant differences in health-related quality of life and pain reduction for any of the groups.

However, participants in the Feldenkrais and BAT groups demonstrated improved self-

efficacy of pain management compared to the physiotherapy group, and the improvements to

self-efficacy remained stable after one year. Further statistical analysis of their results

confirmed that the Feldenkrais Method and BAT had a slightly more positive influence on

psychological well-being and pain when compared with physiotherapy (Malmgren-Olsson, Armelius, B., & Armelius, K., 2001). The researchers also noted that individuals with poor self-image and higher levels of pain were more likely to have a positive treatment outcome than individuals with good self-image and less pain. This observation is compelling since it suggests that the suitability of somatic training as a treatment for musculoskeletal pain may depend more on the psychological condition or personality of an individual and less on the nature of their specific diagnosis. Taken together, the results of the studies assessing the Feldenkrais Method and the Alexander Technique as therapeutic interventions for musculoskeletal disorders do not seem to point strongly to a relationship between somatic training and improvement of acute pain symptoms. However, all seem to clearly indicate that participants with musculoskeletal pain often reap psychological benefits from participation in somatic training, and often feel more empowered to continue treatment plans that incorporate somatic training compared to traditional treatment plans involving physiotherapy.

 1.3.2.2 Studies on somatic training outcomes for musicians. Some isolated studies with musicians have focused on assessing improvements to performance quality. For instance, Valentine and colleagues investigated the quality of performance in both high and low stress situations in twenty-five music students before and after receiving 15 Alexander Technique sessions, or undergoing no intervention (Valentine, Fitzgerald, Gorton, Hudson, & Symonds, 1995). It was found that the Alexander Technique group improved in comparison with the control group in measurements of overall quality of performance technique and musicianship, based on judgements by a blind panel of music experts. However, the improvements were only noted in low stress performing conditions. Another study by Valentine and Williamon (2003) at the Royal College of Music in London examined the impact of neurofeedback and Alexander Technique training on performance

quality in a sample group consisting of string, keyboard and wind players, and vocalists. Eighteen musician participants were randomly assigned to receive 30-minute Alexander lessons once a week for 12 weeks (n=10), or to undergo 10 sessions of neurofeedback training over 6-8 weeks (n=8). Music performances were video recorded before and after the training, and the videos were randomly ordered and assessed by experts external to the college. The results indicated that participants receiving neurofeedback training gave noticeably improved musical performances post-training when assessed by independent expert musicians. The Alexander Technique group demonstrated no significant improvement in performance quality. In a similar study by Wong (2015), ten pianists were assigned to receive a fifty-minute somatic training lesson in Body Mapping, the Alexander Technique, or the Feldenkrais Method. They were video recorded performing a C major scale, measures 1-22 of *Für Elise* by Beethoven, and Schumann's *Wilder Reiter.* Video recordings of the performances were sent to a panel of eight music experts who were asked to identify which performances they believed occurred post-somatic training based on musical quality, and to rate the performances from 1 to 7 on a number of performance quality factors, such as tempo consistency, expressivity, rhythmic accuracy, and tone quality. It was found that the post-somatic training clips tended to be rated slightly better on all measures of musical performance quality except tempo consistency, but that these results were statistically insignificant for all performance factors except tone consistency. Williamson and colleagues attempted to quantitatively investigate aspects of performance quality by measuring the key timing and velocity of pianists playing four-octave scales, hands separately on MIDI keyboards before and after receiving three to five sessions of Alexander training (Williamson, Roberts, & Moorehouse, 2007). It was found that some participants played the scales more evenly (with less variation in key velocity) after receiving Alexander training,

although the size of the sample group is undisclosed, and therefore the significance of these results is unclear. These three studies demonstrate first attempts to investigate the relationship between somatic training and music performance quality. As of yet, the body of research is too small to put forth conclusions, but early indications seem to suggest that any potential changes in musical performance quality immediately after short-term exposure to somatic training are likely subtle, and are likely to vary extensively from performer to performer. Future studies may require the more objective techniques to measure various specific aspects of performance quality, and would benefit from recruiting more participants or investigating long-term somatic interventions.

Two studies have attempted to objectively examine the impact of somatic training on various physical and psychological experiences of performing musicians. For instance, Mozeiko's (2011) mixed-method study investigated the impact of 12 weeks of Alexander Technique training on 51 female violinists. Participants were divided into an intervention group and a control group using rating scales and interviews to learn about participants' experiences of pain, body awareness, executive functioning, and playing experiences. Results provided significant evidence for improvement in body awareness for the intervention group, but no significant improvement in pain symptoms for either group. The second study used surface electromyography (sEMG) to detect if differences in the variability of trapezius muscle activation during violin playing were detectable after Body Awareness Therapy (BAT), and it was found that there were no notable differences in pre and post test readings of muscle activation (Fjellman-Wiklund, Grip, Andresson, Karlsson, & Sundelin, 2004). Taken together, the studies illustrate that while some researchers have taken important first steps to scientifically investigate somatic training outcomes for musicians, ultimately the body of research has not yet lead to any clear conclusions. Improvements to future research

methodologies will be required to learn more about somatic training outcomes for musicians (Schlinger, 2006).

       1.3.3 Posture as a Dependent Variable in Somatic Training Research. It is interesting to note that the studies mentioned in the previous two sections generally investigated variables relating to pain, muscle tension, psychological factors, or performance quality. Few have set out to examine the impact of somatic training on externally visible characteristics of posture. Given the appropriate measurement tools, assessing the impact of somatic training on externally visible variables relating to posture and movement of pianists seems logical, considering that most somatic methods seek to alter or diversify movement habits and skeletal alignment as a central mechanism to improve health and functioning. For instance, a core theoretical principle of the Feldenkrais Method is that controlled movement of the body, either through a student's careful attention in Awareness through Movement exercises, or a practitioner's guided movements in Functional Integration, can create a condition for motor leaning in the central nervous system ideal for learning new ways to use the body (Ginsburg, 2009). Moshe Feldenkrais (1965) clarifies this idea in the following quote given in an interview with Helen and Richard Schechner:

       The state of the cortex is directly and legibly visible on the periphery through

the   attitude, posture, and muscular configuration, which are all connected. Any

       change in the nervous system translates itself clearly through a change of

attitude,   posture and muscular configuration. They are not two states but two

aspects of the same state. (p. 114)

In accordance with Feldenkrais's theory that the body and mind exist as one system, attentive practitioners look for changes in students' posture, movement, and muscle tonus as evidence

that lessons have promoted changes in the motor control mechanisms of the central nervous system (Buchanan, 2001). This type of external observation is so central to the method that Feldenkrais himself maintained that quantitatively measuring aspects of posture would be useful if technologically feasible, since it could help give objective evidence of the impact of motor learning learning on the outward carriage of individuals as a result of his method (Feldenkrais, 1966).

Although there are only a few scientific studies investigating the impact of somatic training on posture and movement are few, initial research on the topic is promising. For instance, the previously mentioned studies on performance quality by Valentine and Williamon (2003) and Wong (2015) both incorporated a methodological component which used rating scales to examine practitioner or expert reported differences in posture characteristics from before and after somatic training interventions. For instance, in the study by Valentine and Williamon (2003) the posture of a subset of participants was rated before and after the Alexander Technique sessions using a rating scale that examined ten categories of Alexander Technique goals for movement and posture developed by the practitioner who rated participants in the study. In comparison with the neurofeedback participants, the Alexander Technique participants demonstrated great improvements in seven out of ten categories of Alexander Technique movement and posture goals, indicating that through one to one training, Alexander training can help students make noticeable postural improvements. The clearest improvements in posture were noted for singers. The results of this study are important because they constitute the first scientific evidence that Alexander Technique can visibly impact posture in musicians. However, future studies should use multiple raters and construct a rating scale using more input from multiple experts to avoid bias. In the study by Wong (2015), a panel of eight somatic training practitioners rated the

body usage of participants in the video recordings of participant performances of scales, *Für Elise* and *Wilder Reiter* from before and after the somatic training interventions. Raters used a seven point scale that allowed them to assess the quality of body usage from "very good usage and coordination" to "severe misusage" for different regions of the body. Statistically significant improvements were noted only for head and neck usage, although raters tended to rate body usage as slightly better after the somatic interventions for the other areas of the body as well.

A study by Kutschke (2010) on the impact of Alexander Technique training on non-musicians offers additional evidence that somatic training can impact posture of the head and neck. This study measured the neck and shoulder alignment, range of motion, and muscle activity in healthy non-musicians after participating in 20 Alexander Technique sessions over eight weeks. The Alexander Technique sessions were 45 minutes long and participants attended three sessions a week for the first month, then two sessions a week for the second month. The author hypothesized that Alexander Technique sessions might result in observable improvements to neck and shoulder mechanics, since many Alexander lessons focus on improving the connection of the head to the spine. sEMG measurements indicated muscle activity in the neck and shoulder altered after the Alexander training and photographic measurements of forward head posture improved significantly for intervention participants, especially during sitting and typing tasks. These results support the theoretical claim that AT can positively influence posture, especially of the head and neck. The fact that these improvements were observed in asymptomatic individuals suggests that AT may have a strong preventative value for musculoskeletal pain of the neck and shoulders.

Further evidence that the Alexander Technique can influence posture comes from a series of studies by Cacciatore and colleagues (2005, 2011). In the first study, Cacciatore,

Horak and Henry (2005) conducted a detailed case study that scientifically documented a 49-year-old woman's improvement in automatic postural coordination after Alexander technique training during treatment for low back pain. She received a 45-minute Alexander training session once a week for six months. Her posture was evaluated monthly for four months prior to the training and for three months after the training. Post-training, it was found that the patient's automatic postural coordination was improved, illustrated by her improved balance. Measurements of her body positioning revealed improvement in symmetrical alignment in the body. The woman also experienced improvements in her back pain. These results provide scientific evidence that long-term Alexander treatment can have a positive impact on body alignment, and that it may be a viable treatment option for chronic pain syndromes that may be related to postural imbalances. In a subsequent study, Cacciatore, Gurfinkel, Horak, Cordo and Ames (2011) investigated whether or not certified Alexander Technique teachers modulate axial postural tone (APT) better than subjects with no Alexander Technique experience. The researchers simultaneously performed a 10-week longitudinal study of the APT of individuals with low back pain who were receiving Alexander Technique lessons. The researchers assessed APT by measuring the resistance of the neck, trunk and hips during slow, torsional rotation in a standing position. Modulation of APT was measured by comparing this resistance to muscle activity levels using sEMG. It was found that Alexander Technique teachers modulated APT better at all rotational points when compared with matched control subjects. The low-back pain sufferers who received Alexander Technique training experienced reduced stiffness in turning compared to controls after 10 weeks. These results suggest that postural muscles function differently after long term Alexander Technique training and that even short-term training can positively influence mobility. These findings are especially important considering that Gurfinkel, Cacciatore,

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Cordo, Horak, Nutt, & Skoss (2006) found that postural tone is dynamically modulated in healthy adults, and that dysfunction in APT modulation can manifest as stiffness. These studies provide compelling initial evidence that somatic training could impact motor control strategies for posture and reduce muscle stiffness. The results warrant further investigation.

      1.3.4 Conclusion. Most of the evidence supporting the use of somatic training to improve playing quality or pain symptoms comes from subjective sources, such as testimonials and practitioner reported case studies. Much of the existing scientific research on somatic training has focused on assessing musculoskeletal pain symptoms or health related quality of life, and has yet to provide conclusive results. However, some initial research on both musicians and non-musicians has provided promising evidence that somatic training can influence postural control in individuals. This suggests that comparing external measurements of playing postures from before and after somatic training interventions could offer a promising way forward in research seeking to objectively examine the outcomes of somatic training with pianists. Since visual assessments of posture are an important diagnostic and evaluation tool in somatic training practices, it makes sense for researchers to objectively measure posture as a dependent variable in somatic training research.

1.4 Measuring Posture Quantitatively

      In order to compare the posture of pianists from before and after somatic training interventions, it is necessary to construct specific measuring protocols for specific body positions of interest. Researchers in kinesiology and related fields have devised various rating scales and measurement protocols to assess distances or angles between specific points of the body in order to quantify posture. In this section I review the various ways posture variables have been defined and measured in kinesiology literature. First I present studies that call into question the reliability of rating scales used to categorize or diagnose posture

characteristics during visual assessments, affirming an urgent need for more objective

measurement procedures. Next I present the strengths and limitations of various solutions

researchers have devised for measuring postural alignment and positioning of the head,

shoulders, and spine. Finally, I discuss factors researchers must consider when selecting

posture variables and devising measurement protocol for methodologies investigating the

impact of somatic training interventions in the context of live piano performance.

1.4.1 Limitations of visual assessment scales. Some researchers have used

qualitative visual assessments or rating scales to measure aspects of body positioning.

Generally these are Likert-style scales that contain diagrams or descriptions of posture for

each scale degree that have been created based on theoretical standards of healthy

positioning of the head, shoulders, and spine. In this method of measurement, raters must

choose the diagram or description that best coincides with the posture exhibited by the

participant. It is often used in research in clinical or occupational settings (Li & Buckle,

1999; Watson & Mac Donncha, 2000; Takala et al., 2010). Sometimes visual assessments of

posture are conducted from photographs or videos of participants (Fortin, Ehrmann,

Feldman, Cheriet & Labelle, 2011). Although posture rating scales are cost-effective and

easy to implement in large-scale studies using photographs or videos, research has called into

question the validity of visual assessments of posture from photos. For example, it was found

that the visual assessments of cervical and lumbar lordosis in photographs had poor inter-

rater reliability amongst a group of 28 clinical practitioners (Fedorak, Ashworth, Marshall,

and Paul, 2003). Similarly, Aitken (2008) found that the inter-rater reliability of visual

assessments of forward head posture were "poor" to "fair" amongst groups of both laypeople

and osteopathic students or professionals. Interestingly, ratings were more consistent among

first-and second-year osteopathic students compared with more experienced professionals.

Silva and colleagues found that physiotherapists' assessment of forward head position, side-flexion, and head extension in still photographs of 40 healthy subjects using a four-category scale had poor reliability, and did not correlate with angular measurements taken from the same photographs (Silva, Punt, & Johnson, 2010). Research clearly indicates that visual assessments of posture quality vary widely, even among trained professionals. These studies highlight the need for more objective approaches to posture measurement for research purposes.

1.4.2 Defining measurement protocol for posture variables. In the absence of qualitative descriptions or rating scales, researchers desiring to measure posture quantitatively face the difficult task of choosing which parts of the body will be measured, and how to determine the criteria for defining healthy or maladaptive posture. In this subsection I present various approaches to defining posture for quantification that have been applied in research in kinesiology or related fields. First I discuss the strengths and limitations of plumb lines and symmetry as models of ideal posture. Next I explore various approaches to defining posture variables in the head, shoulders, and spine, respectively.

1.4.2.1 Plumb lines and symmetry. One popular method for quantifying posture is the use of plumb lines that can be drawn through points at the head, shoulders, hips, knees, and ankles to verify that important structural joints are vertically arranged in such a way that the body can balance freely. This principle is frequently used in chiropractic, physical therapy, and somatic training assessments, and has been used as a criterion for assessing posture quality in resting positions in research (Krasnow, Chatfield, Barr, Jensen, & Dufek, 1997; Kendall, McCreary, Provance, Rodgers & Romani, 2005). However, the usefulness of straight plumb lines as a diagnostic criterion for posture has been questioned, and evidence shows that for healthy individuals, the points of balance at the ear, shoulder, hip, knee, and

ankle generally deviate considerably from a straight line in standing positions (Woodhull, Maltrud, & Mello, 1985). Research has also shown that the posture of highly trained dancers also tends to follow a zig-zag pattern instead of a straight line, even though plumb-line criteria are routinely used to assess the quality of a dancer's posture (Woodhall-McNeal, Clarkson, James, Watkins, & Barrett, 1990). Similarly, postural symmetry in the right and left sides of the body in the anterior and posterior views has been used as a standard representing postural health for diagnostic purposes, since it has been assumed that healthy bodies have similar resting positions for corresponding parts of the body on the right and left side. However, research has demonstrated that asymmetry is normally observed in the resting positions of the pelvis, shoulder, and trunk of healthy individuals (Ferreira, Duarte, Maldonado, Bersanetti & Marques, 2011). This raises questions about the suitability of using symmetry as a baseline criterion for healthy posture in research applications. These examples from research appear to indicate that the theoretical criteria for good posture established by vertical plumb lines or lines of symmetry are rarely found in natural examples of human posture.

1.4.2.2 Forward head position. Characteristics of head posture have been investigated in more detail compared to other areas of the body. For instance, many studies have measured forward head position in the sagittal plane by measuring the angle formed between a line passing from the C7 vertebra through the ear tragus, and a horizontal line passing through C7 while an individual is sitting or standing. Similarly, the angle formed between a horizontal line passing through the ear tragus and the line connecting the ear tragus, and the outer canthus of the eye has been used to assess the angle of the head at the atlas occipital joint. Research using these measuring methods points to a correlation between smaller angles of forward head position (occurring when the head is held further away from

the body), and higher incidences of musculoskeletal pain in office workers (Szeto, Straker &

Raine, 2002). Similarly, adolescents with neck pain have been found to have smaller angles

of forward head position than their no-pain peers (Ruivo, Pezarat-Correia & Carita, 2014).

There is also evidence that individuals with shoulder overuse injuries are likely to hold their

heads further forward (Greenfield et al., 1995). Although many studies investigating

correlations between forward head position and musculoskeletal pain have suffered

methodological shortcomings (Silva, Sharples & Johnson, 2013), more recent studies of

better quality have demonstrated statistically significant differences in forward head angle

between pain and non-pain groups (Yip, Chiu & Poon, 2008; Lau, Chiu & Lam, 2009; Silva,

Punt & Johnson, 2010). The results of these studies strongly suggest that more extreme

forward head positions are associated with musculoskeletal pain of the neck and upper back.

1.4.2.3 Shoulder position. Researchers have investigated the hypothesis that extreme

positions of the shoulder could be associated with higher incidences of musculoskeletal pain.

In some studies on shoulder posture, researchers have measured the horizontal and vertical

displacement of a point on the shoulder in relation to the C7 vertebra at the top of the spine

in order to determine if the shoulders are elevated or rest substantially forward from the body

(Szeto et al., 2002). Alternatively, some studies have quantified shoulder positioning by

measuring the angle between a line connecting a marked point on the shoulder and the C7

vertebra and a horizontal line extending forward from the shoulder in the sagittal plane

(Raine & Twomey, 1997). Thus far, the evidence linking specific shoulder positions with

higher incidence of musculoskeletal pain is less compelling than that available for forward

head position, due in part to varying measuring protocol between studies, which often have

questionable inter- and intra- rater reliability (Peterson et al., 1997). However, Greenfield

and colleagues found a statistically significant correlation between higher shoulder elevation

and musculoskeletal pain symptoms (Greenfield et al., 1995). Furthermore, a study of 485 individuals presenting with occupationally related musculoskeletal pain, (comprising mostly of computer users and musicians), reported that 78% of participants had rounded shoulders (Pascarelli & Hsu, 2001). The authors speculate that the high number of participants testing clinically positive for posture-related neurogenic thoracic outlet syndrome could point to it being a key component in the progression of work-related musculoskeletal pain disorders. Due to the complexity of the shoulder joint and the difficulty of placing anatomical markers on a clearly visible external shoulder landmark, future research must refine measurement methods to more comprehensively understand whether or not certain tendencies in shoulder position correlate with musculoskeletal pain symptoms in the upper body.

  1.4.2.4 Spine curvature. Researchers have been concerned with measuring angles of spine curvature in the cervical, thoracic, lumbar, and sacral spine, since extreme angles of spinal curvature are thought to disrupt postural balance, putting unnecessary loads on muscles not designed to support the weight of the body in an upright stance. This hypothesis is supported by research showing that varying spinal curvature can alter how trunk muscle activation varies as individuals move through different curvatures of their spine (O'Sullivan et al., 2006). However, details about how certain characteristics of spinal curvature influence musculoskeletal health are not well understood, and diverging theories create confusion about whether or not certain spine postures have clinical advantages (Claus, Hides, Moseley & Hodges, 2009). For instance, researchers still disagree about whether a naturally kyphosed or lordosed curvature in the lumbar spine is healthier for seated posture, and how proper posture should be taught for the prevention of lower back pain (Pynt, Higgs & Mackey, 2001; Scannell & McGill, 2003; O'Sullivan et al., 2010). Caneiro et al. (2010) found that the nature of thoracic and lumbar curvature can significantly impact head positioning and muscle

activation in the neck and back. However, evidence also shows that structural abnormalities in cervical spine curvature are not correlated with higher incidences of neck pain, even though they are often considered to be the cause in clinical settings (Grob, Fraunfelder & Mannion, 2007). An interesting study investigated the perceptions of 295 physiotherapists from four European countries on the quality of different sitting postures in photos (O'Sullivan, K., O' Sullivan, P., O'Sullivan, L., & Dankaerts, 2012). Participants were asked to choose the best posture from nine different photographs picturing individuals seated in various erect or slouching positions. It was found that 85% of respondents rated one of two posture photos as best. However, the two most commonly chosen photos were very different, with one depicting a significantly more erect posture than the other. Furthermore, the perception of good posture in the photos varied according to the nation of origin of the physiotherapists. These examples illustrate that although the hypothesis that extreme spine angles and sitting posture can increase the risk for developing musculoskeletal pain still stands in clinical settings, research has not yet been able to establish criteria for spine posture that can be used confidently in diagnostic and assessment situations, and further study is warranted.

To further complicate matters, research also suggests that spine posture is highly variable for individuals in their day-to-day lives. This makes it difficult to ascertain whether or not changes to posture observed in a repeated measures experiment are taking place as a result of an intervention, or reflect natural fluctuations in spine positioning. For instance, Dunk and colleagues found poor repeatability of posture measurement of thoracic, cervical, and lumbar curves when measured using a vertical reference line in photographs taken at three sessions, with the first session conducted in the morning, and the second and third session taken a week later in the morning and afternoon (Dunk, Chung, Compton &

Callaghan, 2004). They repeated this study using angle measurements directly on the body instead of using a plumb line for reference to minimize error due to postural sway, but posture was still found to be highly variable between measurement sessions (Dunk, Lalonde & Callaghan, 2005). Contrastingly, Pownall and colleagues found that the posture measurements of eleven healthy men remained stable over the course of one week, but the consistency of posture variables in the sagittal plane was much lower than in the posterior or anterior view, reinforcing the observation that spine curvature is naturally variable (Pownall, Moran & Stewart, 2008). Researchers have also found that it is difficult to predict positions of spine segments in relation to one another, and that there is a high degree of variability of the location of spinal centre of gravity across different people (Grimmer-Sommers, Milanese, & Louw, 2008). This natural variability of spine posture makes it impractical to use angles of spine curvature taken from photos or radiographs to track changes in spine posture due to interventions. Furthermore, methods for measuring spine curvature vary significantly from study to study (Harrison, D.E., et al., 2000), often using different vertebrae as landmarks (Bernhardt & Bridwell, 1989; Harrison, Janik, Troyanovich & Holland, 1996). Some studies report results based on internal measurements of the spine from radiographic images and others from photographs with markers placed externally on the skin (Leroux et al., 2000). This variability in measurement protocol makes it very difficult to compare results about spine curvature across different studies. There is currently no standardized protocol for measuring spine curvature in research, and it is therefore up to the discretion of the researcher to determine the criteria for measurement.

1.4.3 Measuring Posture during Piano Performance. In the following section I discuss important aspects of posture research that should be taken into when examining pianist posture in research. First I consider factors impacting the selection of posture

variables for research with pianists and somatic training. Next I review research that reveals

diverging opinions about what constitutes healthy posture, making it difficult to establish

criteria for defining posture as good or bad, deteriorated or improved. Finally, I discuss

literature on the neuroplasticity of motor control strategies mediating posture to discuss the

various factors intrinsic to participants or the external environment that could influence

posture strategies during music performance.

1.4.3.1 Selecting posture variables for research on somatic training for pianists.

Reports on changes to posture and movement as a result of somatic training are often

descriptive, or non-specific, and tend to vary between individuals, making it difficult for

researchers to choose specific parts of the body to measure when looking for potential

changes that could be meaningful in the context of piano playing. However, since

practitioners frequently seek to improve alignment of points of balance in the head,

shoulders, and spine (Alexander, 1932; Feldenkrais, 1966, 1981; Mayers & Babits, 1987;

Monette Corporation, 2015) researchers could consider looking at aspects of head and torso

positioning first in initial investigations on somatic training with pianists. As the previous

section summarised, the definition of posture variables and their corresponding measurement

protocol have not been standardized in research, except in the case of forward head position.

Therefore, researchers interested in measuring changes to pianists' posture that may arise

from somatic interventions must carefully construct measurement protocol and select specific

posture variables according to their own needs and expertise. Since research has shown a

connection between forward head posture and musculoskeletal pain in the neck in computer

users, this position could be a good choice for measurement with pianists. However,

researchers should be cautious about extending conclusions from research on computer users

to pianists, since the two activities place different biomechanical demands on the upper body.

Although research associating elevated or forward shoulder positioning with musculoskeletal pain is not conclusive, piano teachers are often concerned with the elevation of shoulders during performance, since it might be an outward indication of excess tension or performance anxiety. Therefore, it would be useful to measure the vertical and forward displacement of the shoulders in respect to the spine as another posture variable of interest in the context of piano playing (Dommerholt, 2010). Extreme angles of spine curvature held statically at length have also been implicated as problematic in the posture of musicians, warranting research on the impact of somatic training on the vertebral positioning and spine curvature of pianists (Cailliet, 1980). Investigating these three regions of the body (the head, shoulders, and spine) would give a comprehensive overview of the vertical postural alignment of performing pianists, allowing researchers to examine if somatic training performance postures of the head and torso.

 1.4.3.2 The challenge of assessing posture quality. As discussed in the previous section, conflicting results and theories about the influence of specific postures on musculoskeletal health hinders researchers' ability to interpret whether or not posture changes following interventions should be considered improvements. Since research has been unable to conclusively establish if certain posture characteristics are clinically problematic, and since posture his highly variable, and specific to the individual, researchers must contend with the fact that it may be impractical, if not impossible, to apply universal criteria for assessing posture quality across all participants in a study. Researchers must also consider that differences in the size and shape of various body segments could make it difficult to compare anthropomorphic data across different participants. In the context of piano playing, definitions about what should constitutes ideal posture are even more ambiguous. Posture and movement habits vary considerably among many notable concert

pianists, making it impossible to define good posture based on playing quality. For instance, Arthur Rubinstein is noted for the erect yet supple nature of his posture, and his parsimonious movement of the torso (Plake, 2011). His seemingly effortless interpretations, especially of the works of Chopin, are admired as masterful. However, Glenn Gould's peculiar manner of sitting, with a very low seat, hunched back, face nearly touching the keys, and raised shoulders, did not seem to interfere with his ability to deliver virtuosic and original performances, even though he struggled with severe musculoskeletal pain during his lifetime (Bazzana, 2010). Furthermore, very little research has been conducted on the topic of good piano posture. One notable exception is the study of Mora, Lee and Comeau (2007), which created a visual feedback tool designed to help students improve their playing posture. In this study, researchers created a 3D model of good piano posture by using a Vicon optical-based motion tracking system to track the playing posture of a professional pianist who also had a long career as a licensed Feldenkrais practitioner. The posture model created from tracking the practitioner's live piano performance was integrated into software that allowed for the model to be overlaid onto videos of performing pianists. The bone lengths of the computerized, stick-figure model were customizable so that their length could be modified to match the size of the pianist in the videos. Students could then observe how their playing posture compared with that of the model frame by frame. Although this customizable model could be an excellent pedagogical tool, it was constructed based on the movement habits of only one adult pianist. The resulting model cannot be considered definitive, since other somatic trainers and pianists may have had different opinions about how best to sit. Furthermore, as previously discussed, the notion of establishing a universally imposed posture model may not be useful in assessing posture quality in research situations, due to the natural variability of posture within and between people. Postural sway and the natural

variability of spine curvature and head positioning in individuals throughout their daily lives present a serious obstacle for researchers attempting to use photographic methods to track changes to posture in repeated measures studies (Grimmer-Sommers, et al., 2008). At present, there are no definitive criteria for judging the quality of pianists' initial posture, making it difficult to judge if changes observed in post-intervention testing should be considered improvements or deteriorations. Unless future research is able to specify criteria that can definitively label certain postural observations as problematic, it is advisable that researchers investigating the impact of somatic training on pianist posture should look for changes to posture variables only, without applying criteria for whether or not the change should be considered better or worse. This will allow researchers to take a more objective first look at the possible influence of somatic training on posture in various areas of the body, instead of ascribing preconceived expectations based on opinions about posture quality that may not be well-founded in research.

1.4.3.3 Neuroplasticity of postural control. Evidence shows that posture is mediated by complex and highly adaptable motor control strategies in the central nervous system that can easily be influenced by factors intrinsic to the participant or their environment. This plasticity of postural strategies allows the central nervous system to respond efficiently to constantly varying conditions in the body and the environment, and to accommodate the demands of various types of tasks being performed (Krasnow, Monasterio and Chatfield, 2001). For instance, research shows that maintaining balance during walking, standing, and sitting requires cognitive resources (Lajoie, Teasdale, Bard & Fleury, 1993; Andersson, Hagman, Talianzadeh, Svedberg & Larsen, 2002), and that more complex cognitive tasks can increase postural sway in healthy individuals (Pellecchia, 2003). However, complex cognitive tasks were found to have less impact on the postural sway of professional gymnasts

compared with controls, suggesting that sensorimotor expertise achieved through training

may impact postural strategies used to maintain balance (Vuillerme & Nougier, 2004). The

cognitive demands required for maintaining balance in standing and walking appears to

increase with age, since it has been found that older individuals find it more difficult to

maintain their balance with cognitive or sensory interference (Shumway-Cook & Woollacott,

2000; Lacour, Bernard-Demanze & Dumitrescu, 2008). It has also been shown that

individuals use different posture control strategies to maintain their balance when

neuromuscular fatigue is induced in their low back extensor muscles, suggesting that the

central nervous system can change its postural strategy to circumvent the use of muscle

groups which may be fatigued (Wilson, Madigan, Davidson & Nussbaum, 2006). Individuals

have also been found to use different posture control strategies to maintain their balance

when they are expecting a balance perturbation compared to when the perturbation comes as

a surprise (Cordo & Nashner, 1982). These examples from motor control research illustrate

the complexity of motor control strategies mediating posture. Many different environmental,

biological, and cognitive factors can influence how the brain controls the orientation of an

upright body in space at any given moment. Researchers investigating the posture of pianists

must appreciate this complexity and consider how these factors could influence postural

control mechanisms in the brain and carefully control for variables such as age, level of

expertise, task type, and degree of task preparation when selecting pianists for participation.

The previously mentioned studies illustrating how motor control strategies for posture

can be influenced by attention and cognitive demands are particularly important to consider

when conducting studies investigating the impact of somatic training on pianist posture.

Researchers must consider that pianists may exhibit different postural characteristics

depending on the type of task they are performing, since different playing tasks have

different cognitive demands. For instance, when reading sheet music for the first time, pianists will direct their attention primarily toward the music, and much of the pianist's cognitive resources will be allocated to decoding the notes and symbols. However, during a memorized performance, the pianist executes complex motor control programs that have been refined through many repetitions. It would be interested to conduct studies to learn if pianists' cognitive resources could be more freely allocated to musical expressivity and if their brains are perhaps more responsive to auditory and proprioceptive feedback from the hands when playing from memory. It is common to observe performers swaying their bodies freely during memorized performances as they embody aspects of the musical phrasing. During the performance of technical exercises such as scales, their body may not move in a similar manner due to the lack of musical phrasing impulses. Differences in the cognitive and attentional demands of these contrasting tasks could result in very different motor control strategies for posture during performance. Therefore, researchers investigating posture of pianists must consider the type of performance activity that will be measured. It is not presently known to what degree piano posture depends on the type of playing activity being performed, and future researchers will require a better understanding of its significance when constructing methodologies to investigate somatic training outcomes.

  1.4.4 Conclusion. Although quantitative measurement of posture variables could be used to meaningfully compare pianists' body positioning from before and after a somatic training interventions, researchers must carefully select specific areas of the body to observe and determine how posture variables will be measured. Since somatic training has been purported to influence alignment of the head, neck, shoulders, and spine, researchers might best be directed to take anatomical measurements of distances and angles in these areas for initial investigations. Researchers must also consider that it is difficult to judge the quality of

specific postures due to conflicting opinions about the definition of healthy posture and the natural variability an individuals' posture day to day. Therefore, research comparing pre- and post-somatic intervention posture variable measurements should investigate only if differences are observable in the two sessions, without attempting to judge whether or not an improvement to posture has been observed. Finally, neurological control of posture is very complex, and can be influenced by many environmental, biological, and cognitive factors. Researchers must consider the high degree of neuroplasticity in motor control strategies of the central nervous system, and carefully control for factors such as participants' level of preparation of performance tasks to be used for testing. Since research has shown that posture control can be influenced by the cognitive demands of competing tasks, research on pianists should also explore body position in different types of playing tasks, such as sight-reading, technical exercises, and memorized performance.

1.5 Motion Tracking Tools for Quantitative Posture Measurement

Researchers must have access to measuring tools that can reliably and accurately track and measure pianists' bodies during live performance in order to compare quantitative measurements of posture from before and after somatic training. Advancements in computer and depth sensing technology have made it possible for researchers to track and measure aspects of human posture and movement quantitatively. In this section I review literature on various means of tracking and measuring human posture that have been used in kinesiology and discuss the strengths and limitations of various tools in the context of live piano performance. First, I dicuss the limitations of complex optical-based systems, such as Vicon, in live performance situations. Next, I review literature on two movement tracking technologies that could offer simpler, more portable, and more affordable alternatives to optical-based systems for quantitative movement tracking of pianists: Dartfish video analysis

software, and the Microsoft Kinect. Finally, I explore how these two technologies have been applied in posture and movement research and highlight important considerations for their use with pianists.

      1.5.1 Limitations of optical based tracking systems. Currently, 3D optical-based systems that require the use of reflective markers fixed to points of interest on participants' bodies are the most reliable type of tracking tool for quantitative analysis of human movement. Popular brand names of optical based tracking systems include Vicon and Optitrak. These systems consist of two or more cameras equipped with an array of infrared LEDs and infrared optical filters. The cameras detect the reflection of infrared light off of specialized reflective markers that can be positioned on anatomical landmarks on human bodies. Vicon cameras allow for high-resolution tracking, recording at a frame rate of anywhere from 120 to 1000 frames per second. Signals from the cameras are processed by an analog to digital converter, and accompanying software can be used to analyze coordinate positions of the tracked markers. This type of technology is capable of capturing small, fast movement, and has even been used to investigate detailed movement of the hands, wrists, and fingers of performing pianists (Sugawara, 1999; Holmquist, 2002; Furuya, Altenmüller, Katayose, & Kinoshita; Sakai & Shimawaki, 2010; Furuya, Flanders, & Soechting, 2011; Oikawa, Tsubota, Chikenji, Chin, & Aoki, 2011). Motion-capture studies using optical-based systems to investigate torso movements of musicians have focused on expressive gestures and cuing in ensembles (Luck, & Toiviainen, 2006; Goebl & Palmer, 2009, Thompson & Luck, 2011). Very little research has employed 3D motion-capture technology to gain a better understanding of postural alignment at the piano. One exception is the previously mentioned study by Mora, Lee and Comeau (2007), which used Vicon to track the body movements of a pianist who was modeling good playing posture. Although Vicon and

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similar systems make high resolution, accurate motion tracking possible, analysis can become very time consuming, since generally a great deal of post-processing is necessary to clean up data, especially if complex movements were tracked, or if too few cameras were used. Proper operation requires the use of trained technicians and a carefully controlled experimental set-up. These factors make the use of Vicon impractical in situations that require immediate data processing. In studies with pianists, the piano itself can act as an obstacle that prevents the infrared cameras from getting accurate reflections from the anatomical markers, and testing cannot be done using large acoustic pianos. Furthermore, the systems are usually not highly portable, and are best suited to semi-permanent installation in a laboratory setting where environmental variables, such as ambient lighting conditions, can be controlled. These factors restrict the usability of optical-based motion tracking technology when it comes to live music performance situations.

     1.5.2 Video-based 2D tracking with Dartfish. Video-based measurement software could offer a simple alternative to optical based systems for measuring posture variables in two dimensions in the context of piano performance. In this approach, anatomical points of interest are visibly marked on participants' bodies so that they can be tracked easily in videos either manually, or using tracking features that identify and follow a selected pixel colour. One such software is Dartfish, which was originally designed as a performance analysis and coaching feedback tool for professional athletes (Dartfish, 2015). It enables users to label video frames with commentary or drawings, and to make two-dimensional angle and distance measurements directly on video frames. It also allows for one to three videos to be compared side-by-side, and the user can slow videos down or zoom in on them to examine movement in greater detail. Dartfish software has been used to analyze performance in many applications. For example, it is used by the United States Tennis Association for coaching

education (Melville, 2014a), the Great Britain Canoe/Kayak Slalom team to give athletes

performance feedback (Wells, 2014), and by NASA to help scientists evaluate the

performance of space suits (Melville, 2014b). Recently, researchers have become more

interested in using the motion tracking capabilities of the Dartfish ProSuite software package

as a means of tracking human movement for quantitative data analysis. In this version of the

software, users can target an object of interest with a tracking marker, and the software will

search successive video frames for pixels of identical colour to those on the selected object,

allowing the tracking marker to follow the object of interest as the video plays. 2D Cartesian

coordinates of the object can be exported directly to a Microsoft Excel document if the user

establishes a point of origin and known reference distance on the opening frame. Dartfish can

analyse videos created using regular video cameras, and the software has an easy to learn

interface, making it an attractive tool for music researchers interested in analyzing movement

in live performance situations.

    1.5.2.1 Dartfish in posture and movement research*.* Researchers have used Dartfish

to quantitatively measure posture for a variety of different purposes, including the

assessment of sitting posture of subjects with postural backache (Womersley & May, 2006),

the assessment of a sit-and-reach test for hamstring flexibility (Mier, 2011), the influence of

neck pain on neck flexion during a reaching task (Constand & MacDermid, 2013), the

thoracic posture of rugby players (Bolton, Moss, Sparks, & Venter, 2013), standing posture

in asthmatics after diaphragmatic and aerobic breathing training (Shaw, B., & Shaw, I.,

2011), and comparing the impact of strength and stretch interventions in range of motion in

dancers (Wyon, Smith & Koutedakis, 2013). Dartfish has also been used in a few

applications with musicians. For instance, its slow-motion and multi-video playback features

provide an important component of Riley's multi-modal feedback system for helping

students learn how to move their hands more efficiently (Riley, Coons, Marcarian, 2005; Riley, 2009/2010/2011). The Dartfish semi-automatic tracking function has been used to track the bow movements of violinists to compare the bow trajectories of student and professional violinists (Deutsch, 2011). Finally, the Dartfish angle and distance measuring tools have been used to analyze the posture of a singer by measuring variables in still frames taken from videos of the singer in order to measure postural changes in response to a physiotherapy intervention (Staes, Jansen, Vilette, Coveliers, Daniels & Decoster, 2006). This example is particularly pertinent because it illustrates the potential for Dartfish to be used as a tool to quantitatively evaluate posture in repeated measures studies of a similar construction with pianists undergoing a somatic training intervention.

1.5.2.2 Accuracy and reliability of Dartfish motion tracking for analysis of live piano performance. Although quantification of posture using Dartfish motion tracking could offer a way forward in assessing the impact of somatic training on pianists, to date, Dartfish has not been used to export coordinates from continuous motion tracking data in order to analyze posture and movement habits during live music performances. Most studies that have used Dartfish to measure posture variables have examined stable sitting and standing postures and have taken measurements manually at fixed time intervals to calculate the average value for various positions (Pownall et al., 2008). With proper experimental set-up, studies using video-based software to measure posture variables in individual video frames using anatomical markers as reference points have confirmed fair to high inter- and intra-rater reliability, especially when measurements are taken in the sagittal plane (van Niekerk, Louw, Vaughan, Grimmer-Sommers, & Schreve, 2008; Grimmer-Sommers et al., 2008; Perry, Smith, Straker, Coleman, & O'Sullivan, 2008; Ferreira et al., 2010). It has also been shown that postural measurements made from external markers in photographs using

software like Dartfish correlate well with measurements taken from radiographs of the skeleton (van Niekerk et al., 2008). Although most studies using this measurement procedure reported good inter-rater reliability for their particular Dartfish measurement protocols, these reports do not comment on the accuracy and reliability of Dartfish when using the motion tracking feature to collect data continuously throughout a video. Single-frame analysis is not ideal for examining posture during piano performance, since pianists tend to move their torso intuitively while playing. Furthermore, the way a pianist sits while at rest is not necessarily representative of their posture habits during performance.

Therefore, researchers interested in using Dartfish to quantitatively investigate posture and movement habits during performances should first assess the reliability of the automatic tracking tool. One study investigated the accuracy of the Dartfish motion tracking feature by comparing it to the highly reliable Vicon 3D tracking system (Eltoukhy, Asfour, Craig, & Thompson, 2012). In this study, researchers tracked movement of a participant performing a simple squatting movement with Dartfish and Vicon simultaneously, and found that the difference between tracked objects' trajectories was about +/- 5 mm between the two systems, with magnitudes of differences in marker position ranging from -10 to +20 mm depending on the anatomical marker and the axis of movement examined. In this study, researchers used basler video cameras to minimize distortion of video images during exposure. Although this paper provides researchers with a good initial representation of the overall accuracy of Dartfish and its potential as a human movement quantification tool in research, it does not comment on the repeatability of Dartfish tracking results among various software users. Future studies should investigate the repeatability of tracking results across multiple measurers, and conduct further testing to learn how accurate Dartfish can track using standard complimentary metal oxide semi-conductor (CMOS) video cameras.

1.5.3 Depth-sensor tracking with Microsoft Kinect. The Kinect sensor was initially developed by Microsoft to allow people to control video games using gestures, circumventing the need for hand-held controllers, and allowing for a more immersive gaming experience. The Kinect apparatus contains a regular RGB video camera and a depth-sensing camera that projects a dense array of structured infrared light points into the room in order to create a depth image of objects in front of the sensor. Both cameras have a 640×480 pixel resolution, record at 30 frames per second, and are functional in any ambient lighting condition, although Microsoft cautions about using the sensors in direct sunlight (Microsoft, 2015a). A front-mounted sensor collects infrared beams reflecting from objects in order to create a depth of the area in front of the sensor. The device is equipped with on-board software that identifies body-parts by shape, and tracks their location in three dimensions. More detailed descriptions of the tracking process and the software operation can be found in the overviews of Duffy (2010) and Hadjakos (2012). The main difference between Kinect motion tracking and marker-based optical systems, (such as Vicon), is that the Kinect software predicts the likeliest position of the skeletal points it is searching for based on shapes it detects using the infrared sensor instead of measuring the precise location of markers placed by the researcher. Once a sensor has determined a familiar human shape, such as a round head, it searches for expected body parts based on algorithms containing anthropomorphic information on the size and shape of human beings, which was compiled through extensive testing and programming. Cartesian coordiates of skeletal positions are made with the Kinect unit as the origin of the coordinate system, with the z-axis increasing positively away from the unit, the x-axis increasing to the left of the unit, and the y-axis extending upward (see figure 1, chapter 5). These predictions are made continuously as the sensor records at a rate of thirty times a second.

1.5.3.1 Benefits of markerless motion tracking. Researchers have been interested in finding applications for Kinect in human movement studies since its release in 2010 because it does not require the use of anatomical markers for tracking. Although more complex optical-based systems of motion tracking are accurate and reliable, the necessity of fixing spherical or reflective markers to the body can significantly interfere with the participants' natural movement habits, and can easily become detached during data collection. This is a particularly important issue in research on live piano performance. Since Kinect sensors do not require the use of anatomical markers, pianist subjects may wear comfortable clothing during testing and do not have to perform with cumbersome markers attached to their bodies, allowing for more natural performance conditions. Furthermore, the risk of moving or misplacing markers during testing is a considerable source of potential error in repeated measures tests using marker-based systems. For example, any protruding anatomical markers would have to be removed to allow the participant to lie down comfortable for studies involving Feldenkrais Functional Integration lessons. Great care would have to be taken to ensure that the placement of the markers in the post-intervention measurement is exactly identical to their placement in the pre-test measurement. Should the Kinect be found to have a high enough resolution for the quantification of posture variables, it could offer a markerless, portable, and affordable solution to these problems for researchers interested in using motion capture to assess the impact of somatic training on the posture and movement of pianists.

1.5.3.2 Kinect in rehabilitative and music research. Researchers recognized the potential for the motion tracking and gesture identification capabilities of Kinect to be applied in rehabilitative research soon after its release in 2010. Some of the earliest research contributions using the Kinect involved the development of video games to help patients and

physicians track and monitor progress in rehabilitative exercise regimens prescribed for individuals with injuries or motor disabilities (Chang, Chen, and Huang, 2011; Lange, Chang, Suma, Newman, Rizzo and Bolas, 2011; Roy, Soni & Dubey, 2013; Neri, Adorante, Brighetti & Franciosi, 2013; Sun, Liu, Wu & Wang, 2014; Tseng, Lai, Erdenetsogt & Chen, 2014). Some more advanced Kinect software are designed to give live feedback to the patient about the quality of the movement, letting them know when a movement is done incorrectly, and showing them how it could be improved (Zhao, Espy, Reinthal & Feng, 2014; Zhao, Feng, Lun, Espy & Reinthal, 2014). Researchers in music were also quick to explore many promising applications for the Kinect or similar depth cameras technologies after their release. For instance, researchers developed pedagogical software for the Kinect that allows musicians to improvise musical sounds and harmonic progressions using gestures in order to help train auditory skills (Sentürk, Lee, Sastry, Daruwalla, & Weinberg, 2012). Another software enables performers to control sound parameters of a live performance with hand gestures in front of the infrared motion sensor, which feels natural to the performer and is aesthetically pleasing to an audience (Brent, 2012; Yang & Essl, 2012). Kinect sensors were also used to unobtrusively track the head and bow movements of string ensemble performers in order to gain information about patterns of expressive gesture and cuing between ensemble members (Hadjakos, Großhauser, & Goebl, 2013). Finally, Hadjakos (2011/2012) demonstrated that Kinect sensors can be used to reliably track the position of a pianist's head, shoulders, and arms from a perspective above the keyboard during virtuosic performance. These studies illustrate the diversity of research applications for the Kinect that quickly evolved across various fields of study as researchers recognized the potential for markerless motion tracking to revolutionize research methodologies in a variety of disciplines.

1.5.3.3 Kinect for human movement quantification. Recently, researchers have become interested in determining if the Kinect could be used to obtain quantitative measurements of human movement to track changes as a result of various training or rehabilitative interventions, or to compare movement characteristics in different populations. In order to assess the accuracy of Kinect tracking, many studies have compared Kinect tracking data with data simultaneously captured using 3D optical based systems, such as Optitrack (Webster and Celik, 2014), Optotrak (Tao, Archambault and Levin, 2013), MediaLab (Fernández-Baena, Susíin, and Lligadas, 2012), Codmotion (Alnowami, Alnwaimi, Tahavori, Copland, and Wells, 2012), and Vicon (Clark et al., 2012), showing generally good concurrent validity between the two types of systems. The degree of measurement error found between systems varies widely from study to study, and depends largely on the method used to calculate error. Analyses that make use of data filters to remove outlying data points resulting from tracking errors will generally report much better results (Clark et al., 2012; Tao et al., 2013). The degree of error calculated also depends on the speed, size, and plane of observation for the movement tested. For example, the exercises and diagnostic arm movements prescribed for stroke victims that were tested by Webster and Celik (2014) are very large, slow, and simple. In this context, the Kinect resolution is adequate to quantitatively evaluate exercise performance. However, more research will be required to determine if the Kinect has a high enough resolution to investigate faster, or more complex movements.

The error found in Kinect measurements can be attributed to a variety of factors. One source of error is the Kinect's pose estimation system, which has been shown to incorrectly identify poses more frequently than other, more detailed systems, especially in the sagittal plane, or in positions where one joint position might occlude another (Obdržálek, Kurillo,

Ofli, Bajcsy, Seto, Jimison, & Pavel, 2012). Some evidence suggests that tracking is more reliable in the frontal plane as opposed to the sagittal plane (Obdržálek et al., 2012; Huber et al., 2014) and that accuracy diminishes as the unit is moved farther away from the object (Alnowami et al., 2012; Dutta, 2012; Pedro & Caurin, 2012). The repeatability of Kinect results is better for objects centered in the frame, and the standard deviation of results increases predictably in the periphery of the image and as the distance of the object from the Kinect increases (Pedro & Caurin, 2012). Multiple studies have provided evidence that a proportional bias exists in the size of some Kinect tracking measurements, especially in the sternum region (Obdržálek et. al, 2012; Clark et al., 2012; Tao et al., 2013). The Kinect also appears to track more reliably in the x and y-axes compared to the z-axis, and error tends to vary between different joint positions or angles (Pedro & Caurin, 2012; Webster & Celik, 2014). Based on the results of these studies it can be concluded that the suitability of the Kinect as a quantitative measuring tool for human movement depends on the type of movement being investigated, the software solutions developed for data collection, and data collection procedures.

Overall, the body of research conducted to date indicates that while Kinect is less precise in comparison with optical-based tracking systems, it has sufficient accuracy for assessing characteristics of human movement in some cases, such as rehabilitative games, or tracking the progress of rehabilitative exercise. The validity of the Kinect has been tested for joint positions, distance traveled by specific skeletal points, and joint angles in various planes in various studies. Although it is difficult to make a precise estimate of the Kinect accuracy due to the diversity of data collection and analytical procedures used throughout the studies, Obdržálek summarizes the literature by generalizing that the Kinect could be considered to have a joint localization accuracy in the range of 1 to 4 cm at a distance of 1 to 4 meters

(Obdržálek et. al, 2012). Accuracy for angles is harder to generalize, but might be conservatively estimated to be within 5 and 13 degrees, when major tracking errors are filtered out (Fernández-Baena et al., 2012). Even though these levels of error are higher than those of marker based systems, the Kinect may be suitable for quantitative measurement in some applications, depending on the data collection strategy, the variable being measured, and the quality of software customization. For instance, Scano and colleagues compared joint position data of reaching movements tracked in the sagittal plane from the Kinect and a passive motion capture system (Scano, Caimmi, Malosio and Tosatti, 2014). Errors were found within an acceptable range for the assessment of upper limb movement quality, and that the results were precise enough to determine Parkinson's disease patients from the healthy subjects in the testing group. A particular successful example is that of Kusaka and colleagues, who were able to devise a detailed anthropomorphic algorithm for more precisely estimating pose and measuring joint angles that kept error under 10 degrees at all times (Kusaka, Obo, Botsheim, and Kubota, 2014). Using this method they were able to detect differences in the size of shoulder and arm angles in a person with hemiplegia before and after a therapeutic intervention. This study was extended to track arm and shoulder angles in seven elderly people undergoing five consecutive days of therapy, and results showed no significant change in any maximal angle. A similar study could be done to investigate if the Kinect could be used as a portable, simple to use, unobtrusive, and affordable motion tracking tool for the purposes of assessing the impact of somatic training on posture in the context of piano playing. However, as this review indicates, the potential for tracking errors is high when using the Kinect, and the suitability of the technology for human movement quantification will depend on the quality of software, and the nature of the movement being investigated.

1.5.4 Conclusion. Although accurate, the immobility, and complex data preparation and analysis procedures involved with 3D optical-based tracking systems limits their suitability in live performance situations. Dartfish and Kinect could serve as simple, portable and affordable alternative movement tracking technologies for measuring posture variables in pianists before and after somatic training interventions. Applications of these two technologies in posture and rehabilitative research have been promising, suggesting that testing in live performance situations with pianists warrants further study. The primary benefit of Dartfish is that motion tracking can be done in digital videos recorded by regular cameras, which can easily be placed in performance situations. The primary benefit of the Kinect is that motion tracking does not require visual markers to be placed on the body, which may fall off, move, or interfere with natural movement during piano performance.

1.6 Research Problems

1.6.1 Summary of literature review. Through the review of literature I have attempted to make evident that although somatic training interventions have become closely associated with music pedagogy as strategies to improve body awareness, improve playing quality, and address playing-related pain issues (Fox & Korentayer, 1980; Stewart, 2010b; Vardi, 2015), most evidence for their effectiveness in these applications come from subjective sources, such as testimonials (Goldansky, 2008; Stewart, 2010; Fraser, 2015; Boyd, 2015; Johnson, J., 2015) or practitioner reported case studies (Rosenthal, 1987; Mayers & Babits, 1989; Nelson, 1989). The body of scientific research on somatic training outcomes is small, and most of the existing studies have focused on outcomes pertaining to health-related quality of life or musculoskeletal pain, with few conclusive results (Lundblad et al., 1999; Malmgren-Olsson & Bränholm, 2002, Little et al., 2008; Yardley et al., 2010). Interestingly, research investigating the impact of somatic training interventions on posture

and movement habits have not been prioritized, even though somatic training seeks to

directly impact patterns of body-use as a mechanism to improve health and functioning, and

despite the fact that somatic trainers often look for visual indications of change in posture

and movement patterns as evidence that somatic lessons are having an effect. Some initial

studies have provided evidence that patterns of postural muscle recruitment are different in

individuals who have undergone somatic training compared to controls (Cacciatore et al.

2005; Kutschke, 2010; Cacciatore et al., 2011). This evidence suggests that somatic training

could be found to have a measurable impact on posture, and that repeated measures studies

comparing posture characteristics of musicians from before and after somatic lessons could

provide new and important information about somatic training outcomes in musicians.

Valentine and Williamon (2003) conducted this type of repeated measures study with a small

group of musicians by assessing aspects of posture and body use from before and after

Alexander Technique training sessions. However, the measurement procedure was somewhat

biased since body-use was measured by the same practitioner who developed the rating scale.

Furthermore, research has called into question the reliability and repeatability of posture

measurements made using visual assessments or rating scales (Fedorak, Ashworth, Marshall,

and Paul, 2003; Aitken, 2008; Silva, Punt, & Johnson, 2010). Ultimately, it is difficult to

draw meaningful conclusions from the results of studies using subjective measurement tools.

Using motion tracking technologies to quantitatively measure posture variables in repeated

measures studies could offer a meaningful way forward in the field of research on somatic

training with pianists. Therefore, I will investigate both Dartfish video-based movement

tracking software and the Microsoft Kinect as accessible motion tracking tools to objectively

compare posture measurements from before and after somatic training interventions. In the

following section I will establish three research problems to be investigated in this thesis that will lead to a better understanding of the suitability of these technologies for this purpose.

1.6.2 Research problem 1: Reliability and repeatability distance and angle measurements using Dartfish motion tracking. As I presented in the literature review, Dartfish and similar software has already been used in marker-based procedures to quantitatively measure posture in relatively stable seated or standing positions by collecting manual measurements from a few selected frames (van Niekerk et al., 2008; Grimmer-Sommers et al., 2008; Perry et al., 2008; Ferreira et al., 2010). Although these studies reported good levels of accuracy and reliability, these reports cannot be applied to measurement procedures involving the motion-tracking feature of Dartfish. Since pianists' positioning at the piano tends to be dynamic, changing according to the musical and technical demands of the playing task, researchers should consider examining continuous tracking data from complete performances. Measuring seated piano posture from continuous tracking data will help give a more accurate depiction of average positioning, and allow us to examine characteristics of body movement in the context of live performance.

Eltoukhy et. al (2012) compared the Dartfish tracking of anatomical markers to the highly reliable Vicon 3D optical-based system during a simple squatting movement, and found that the difference between tracked objects' trajectories was about +/- 5.0 mm between the two systems, with magnitudes of differences in marker position ranging from -10 to +20 mm depending on the anatomical marker and the axis of movement examined (Eltoukhy et al., 2012). This paper provides researchers with a good initial representation of the overall accuracy of Dartfish and its potential as a quantification tool in research on human movement. However, Eltoukhy and colleagues generated the Dartfish measurements from a single measurement session, and therefore they are unable to comment on the consistency of

results for a given measurer, or between different measurers using the same trac[...]

procedure on the same video. This information is vital to understanding how ac[...]

reliable Dartfish is for studies that would use multiple measurers, or compare m[...]

across different trials. Furthermore, Eltoukhy and colleagues used scientific Basler cameras

to minimize lens distortion. Presently, it is not clear if Dartfish can accurately and reliably

track objects in videos generated from more accessible CMOS video cameras, which are

easier for researchers to access. Before it can be determined if Dartfish is a suitable tool for

quantitatively measuring pianists' performance postures from before and after somatic

training outcomes, researchers must learn if Dartfish tracking results are adequately accurate

and reliable to permit comparisons across different measuring sessions, and if the results are

reliable across different measurers.

   To address this problem, we (my research supervisors and I) propose to answer the

following four questions:

1. Are tracking results of markers reliable (repeatable across different software

  users) for distance measurements using the tracking procedure employed in

  our study?

2. Are distance measurements attained using the Dartfish tracking procedure

  accurate?

3. What is a good estimate of combined total error for distance and angle

  measurements made using our tracking procedure?

4. Is tracking smooth and consistent across measurers for movements that occur

  in simultaneously in the x and y-axes?

Answering these four questions will allow us to determine whether or not any differences

observed in the Dartfish measurement of pianists' postural variables from before and after

somatic interventions can be considered outside the range of measurement error for the tool using our tracking procedure. These questions should be answered prior to analysing tracking data with live pianists.

We propose the following hypotheses in response to our research questions:

1. The repeatability of results using the tracking feature has not yet been assessed in previous research. However, since previous studies showed good inter-rater reliability for manual measurements taken at specific frames, we hypothesize that results achieved using the tracking tool are likely to be repeatable within at least 0.5 centimeters, especially among trained users (Staes, et al., 2006; van Niekerk et al., 2008; Pownell et al., 2008).

2. We hypothesize that a small discrepancy will be found between actual distance measurements and Dartfish distance measurements, since there are many sources of potential systematic error (such as camera lens distortion), and random error (such as manually positioning the origin of the coordinate system). However, since Eltoukhy et al. (2012) found about an error of about 0.5 between Dartfish and Vicon and Dartfish trajectories, it is likely that the error in our study will not exceed 0.5 centimeters.

3. We hypothesize that combined total error from the reliability and accuracy measurements may slightly exceed the 0.5 centimeters found by Eltoukhy et al. (2012) because their assessment of error did not take into account reliability across different measurers.

4. We hypothesize that Dartfish will be able to smoothly track movements occurring simultaneously in both axes, since it has been successfully used to analyze complex movements in other contexts, including golf swings

(Wright, 2008) and trajectory of bow movements of string players (Deutsch, 2011).

1.6.3 Research problem 2: Using Dartfish to measure posture variables of pianists before and after a Feldenkrais Functional Integration lesson. 2D video-based motion tracking software, including Dartfish, has been used to take quantitative measurements of posture for a variety of purposes in human kinetics research (Womersley & May, 2006; Mier, 2011; Shaw, B., & Shaw, I., 2011; Constand & MacDermid, 2013; Bolton et al., 2013). However, researchers have not yet explored the use of Dartfish as a posture measurement tool with musicians. Dartfish could offer a good alternative to complex optical-based systems 3D tracking systems for measuring piano posture, since data analysis can be done on videos filmed with regular video cameras that can easily be positioned in live performance situations.

Therefore, this study aims to investigate the suitability of Dartfish 2D software as a possible objective measuring tool for comparing quantitative measurements of posture variables from before and after a somatic training session, specifically, a Feldenkrais Functional Integration (FI) lesson. Our second study seeks to answer three main questions:

1. Will our experimental set-up allow for posture measurements to be taken accurately and reliably across testing sessions with live pianists using Dartfish tracking?

2. Are common posture changes noted across a group of pianists after a single FI lesson?

3. Are significant posture changes evident for any particular participants after a single FI lesson?

Based on existing research, we present the following hypotheses:

1. Research has demonstrated that Dartfish is a convenient method for 2D posture measurement when measured manually from individual video frames (Staes, et al., 2006; van Niekerk et al., 2008; Pownell et al., 2008), and our reliability testing (Beacon et al., 2015a) indicated that Dartfish tracking results are highly repeatable and accurate using our data collection protocol for tracking balls on a fixed rail. We hypothesize that the usability and accuracy found will extend to situations with live pianists.

2. We hypothesize that no trends in changes to posture will be noted in the group after one Feldenkrais lesson due to the variability of posture between different individuals, and the natural variability of an individual's posture from day to day (Dunk et al., 2004/2005; Grimmer-Sommers et al., 2008).

3. We hypothesize that specific change to some posture variables might be noted for some individuals, since somatic practitioners and their students often report differences in alignment or movement quality after minimal exposure to the method (Fox & Korentayer, 1980; Mayers & Babits, 1989; Stewart, 2010 a; Stewart, 2010b; Vardi, 2015; Boyd, 2015).

1.6.4 Research problem 3: Using Kinect to measure posture variables and track movement of pianists before and after a weeklong Feldenkrais-focused piano technique workshop. In the literature review I demonstrated that although the markerless tracking capabilities of the Kinect make it an attractive option for studying the posture of pianists unobtrusively during live piano performance (Hadjakos, 2011/2012), its suitability as a quantitative measurement tool for posture must be examined on a case-by-case basis (Obdržálek et al, 2012), and software must be customized for collecting data in the situation at hand (Clark et al., 2012; Tao et al., 2013). In order to determine if the Kinect could be

used to quantify pianist posture to investigate somatic training outcomes, software engineering students at the University of Ottawa modified the Kinect software to track pianists seated in the sagittal plane, allowing for the measurement of head, shoulders, spine, and hip positions, which are of interest to somatic trainers (Payeur, et al., 2014). Quantifying the changes in the location of these anatomical positions in space could give valuable information about characteristics of alignment during performance. We tested this software and the Kinect sensor in a pilot test during which a pianist was asked to play a short musical excerpt while purposefully maintaining different exaggerated posture positions, including a neutral spine position, and extremely swayed back or hunched postures (Payeur, et al., 2014). The results of this pilot study demonstrated that the average x, y and z coordinates of the head, shoulder centre, right shoulder, and lower spine position tacked by the Kinect reflect expected differences in position when comparing the tracking of exaggerated slouched or sway-backed postures with neutral postures during piano performance (Payeur et al., 2014). However, since our pilot study did not compare Kinect tracking results with a baseline measurement made using a measurement tool known to be reliable, it is unclear how closely the Kinect tracking reflected the actual movements of the pianist, and therefore whether the average differences reported reflect the detection of postural change, or artifacts of the tracking process. Furthermore, the differences between the neutral and exaggerated postures measured are likely much more pronounced than any expected differences resulting from real somatic training interventions, and it is not clear from our pilot research if the resolution of the Kinect allows for the detection of small changes in postures of the head and shoulders across measurement sessions. The first two research papers of this thesis demonstrated that Dartfish is an accurate and reliable tracking tool in the context of live piano performance, and is therefore suitable to serve as a tool to take baseline measurement for comparison with

Kinect tracking results (Beacon, 2015a; Beacon, 2015b). By comparing tracking results from

Dartfish and Kinect it will be possible for us to determine if the Kinect has a high enough

resolution to track body positions during live performance in order to meaningfully compare

posture variables of pianists from before and after somatic training workshops.

Therefore, the aim of our study is to assess the suitability of the Kinect as a

quantitative measurement tool for assessing the impact of somatic training on the posture of

pianists using the current software solution developed by engineers at the University of

Ottawa. We intend to compare Kinect tracking results to 2D baseline measurements taken

with Dartfish. Our research seeks to answer two main questions:

1. How well do time plots of *x* and *y-axis* coordinates data tracked by the

   Kinect match baseline plots obtained using Dartfish when tracking live

   pianists?

2. Do Dartfish tracking results show differences in posture variables of pianists

   from before and after a weeklong Feldenkrais training workshop, and if so,

   do Kinect tracking results reflect the same differences?

In response to these questions, we present the following hypotheses:

1. Since the time plots in our initial pilot study with the Kinect showed

   evidence of many tracking errors (Payeur et al., 2014), we hypothesize that

   the time plots of coordinate data from the Kinect will contain frequent

   tracking errors in comparison with Dartfish, which was demonstrated to

   reliably track body positioning of pianists in the previous two studies of this

   thesis (Beacon, 2015a/2015b).

2. We hypothesize that differences in posture variables will likely be

   measurable for some individuals, since a weeklong exposure to somatic

training is likely to have a more profound impact on posture and movement

habits compared to a single intervention as was tested in the second study in

this thesis (Beacon, 2015b). However, it is likely that if any differences are

found, they might only be reflected in the Dartfish results, since the

possibility of frequent tracking errors in the Kinect could impact average

posture value calculations, resulting in discrepancies in measurements

between the two systems.

CHAPTER 2: METHODOLOGY

I have constructed the following three methodologies to answer the research questions posed at the end of the previous chapter, which aim to evaluate how Dartfish and Kinect motion tracking technologies might best be used in repeated measured studies comparing pianist posture from before and after somatic interventions. Results from the three studies will constitute a first, exploratory attempt to using readily available movement tracking technology to objectively measure the impact of somatic training on playing posture.

2.1 Study 1: Reliability and Repeatability of Distance and Angle Measurements using Dartfish Motion Tracking

2.1.1 Design. The following methodology examines the accuracy and repeatability of Dartfish motion tracking software by comparing multiple software users' measurements of polystyrene balls sliding on an aluminum rail in video recordings taken with a regular, CMOS video camera.

2.1.2 Apparatus. We fixed two polystyrene balls (identical to anatomical markers we intend to use on pianists in subsequent studies) onto screws twenty centimeters apart on top of a sliding aluminum rail (see figure 1). The aluminum rail was clearly marked with a ruler system etched using a milling machine with a digital read-out system and equipped with glass scales with a resolution of 0.01 mm. We mounted the aluminum rail to a tripod equipped with a crank mechanism to adjust the height of the apparatus. We recorded video data with a CMOS Sony HD handy-cam (HDR-XR260V, 8.9 megapixels). A floor grid system, floor markers, carpenter's square, and plumb bob were used to ensure that the slider and camera were square and positioned perpendicular to one another. We used a carpenter's level to ensure the cameras and aluminum rail were level.

2.1.3 Procedure. We carefully leveled and positioned the camera was carefully at a right angle to the aluminum slider at height of 94 centimeters and a distance of 158 centimeters. The aluminum rail was also levelled. In the first video, we recorded the two balls mounted on the aluminum rail sliding left through a range of fifteen centimeters. The sliding movements were generated by hand. In a second video, we repeated the sliding test at a height exactly one centimeter above the original reference test, confirming the one-centimeter vertical displacement of the aluminum slider using a digital calliper. In a third video, we recorded the hanging polystyrene ball seen on the right side of figure 1 as it was swung once to the left and right.

2.1.4 Measurement. Four measurers (two with prior experience, and two without prior experience) used Dartfish software to track the two Styrofoam balls throughout their horizontal sliding-movement in the first video, three times each. First, the measurer placed an origin marker in the video at the visible point marked clearly on the centre of the tripod. Next, they established a reference distance of fifteen centimeters by dragging a distance-measuring tool the full length of the visible 15-centimeter ruler marks etched on the aluminum. Finally, the measurers positioned circular tracking markers over the two balls and carefully monitored them as the video played at half speed to ensure that the markers remained precisely positioned over the image of the balls in the video. The data table tool was used to export the x and y coordinates of the tracked balls for each of the three measuring trials.

The same tracking procedure was used for the second video to track the horizontal ball movements at a height one centimeter higher than reference, but due to limited access to research volunteers, data from only two measurers (one experienced, one inexperienced)

completed three tracking trials for this portion of data collection. Similarly, only three users

tracked the trajectory of the swinging ball in the third video.

2.1.5 Analysis. The following sections describe how we estimated the reliability and

accuracy of measurements of the ball positions calculated using the coordinates generated by

Dartfish.

2.1.5.1 Reliability. In order to determine threshold of measurement error for distance

and angle measurements made using our Dartfish tracking procedure, we calculated the mean

horizontal distance and standard deviation of the distance between the two balls mounted on

the aluminum rail for each of the three tracking trials completed by each measurer. We used

the standard deviation across measurers to calculate a measurement error. We defined the

measurement error in terms of a percentage chance that the measurement will be within a

selected error range (calculated using the area under the normal curve). We then

trigonometrically analyzed the measurement error determined from this method to estimate

the error for angle measurements calculated from line segments formed from three tracked

points.

2.5.1.2 Accuracy. In order to determine how accurately Dartfish tracking represents

actual distances in the *x*-axis, we subtracted the average difference between the four

measurers' tracked measurements of the horizontal distance between the two balls on the rail

from the known distance of 20 cm. In order to determine how accurately Dartfish tracking

represents actual, known distances in the *y*-axis, we calculated the difference between the

height of the ball markers in the videos taken at reference height and one centimeter above

reference height for each of the three tracking trials of two of the measurers. We subtracted

the average difference of ball height in videos one and two from the known height difference

of one centimeter to determine how close the tracking measurements came to the actual

vertical displacement between video one and two. We used data from only two measurers in the *y*-axis calculation because only two research assistants were available to complete the tracking for this portion of data collection.

2.2 Study 2: Using Dartfish to Measure Posture Variables of Pianists Before and After a Feldenkrais Functional Integration lesson

2.2.1 Design. The following repeated measures study aims to investigate the suitability of Dartfish software as a quantitative measuring tool for examining the posture of pianists from before and after somatic training interventions. Dartfish motion tracking software is used to measure posture variables of the head, shoulders, and spine in videos of piano performances recorded before and after the pianists received a thirty-minute Feldenkrais Functional Integration (FI) lesson.

2.2.2 Participants.

2.2.2.1 Pianists. Sixteen pianists (12 female, 4 male, age range 14 to 55, with a mean age of 27) responded to email advertisements administered through the Ontario Registered Music Teachers' Association and posters placed in the University of Ottawa (see appendix A). All participants had achieved a minimum playing level of Grade 10 in the Royal Conservatory of Music. Mean number of reported hours per week spent practicing at the time of testing was 9.4, and the average age that piano lessons commenced was 6.6 years. None of the participants had previous experience with the Feldenkrais method, but four had minimal past exposure to the Alexander Technique. Two of the participants reported past problems with playing-related musculoskeletal pain in the arms, and two reported lower back problems attributed to acute injuries unrelated to piano playing. Participants were informed that the study sought to investigate the influence of Feldenkrais FI on pianists, without specifically mentioning movement or posture as objects of study. We obtained ethics approval from the

University of Ottawa prior to data collection and all participants signed consent forms (see appendix B).

        2.2.2.2 Playing requirements. As I discussed in the literature review, research has shown that posture recruitment strategies can be influenced by the cognitive demands of competing tasks (Lajoie et al., 1993; Andersson et al., 2001; Pellecchia, 2003). Therefore, we were interested to take postural measurements of participants' bodies during a variety of playing tasks, since cognitive processing of posture may differ depending on the type of playing activity the pianist is doing. We asked participants to perform the following three playing tests in the given order:

    a. C major contrary-motion scale in sixteenth notes (quarter note=80 bpm), beginning on middle C and extending the full range of the piano, repeated 4 times

    b. The 'A' section of *Für Elise* by Beethoven (measures 1-22), with repeats, from memory

    c. An eight-bar sight-reading piece in the style of a Gavotte

We informed participants of the playing tasks a minimum of two weeks in advance, and we asked them to rehearse the C major scale at the required tempo and to prepare *Für Elise* from memory. We chose the C-major contrary motion scale as a playing test because of its symmetrical construction, which would allow for similar movements to be examined on both sides of the body in the anterior view. It is a simple technical test which all advanced pianists would be able to perform confidently. We chose measures 1 to 22 of *Für Elise* as the piece to be played from memory since it is well known and easy to memorize. This portion of the piece is very technically simple and has a smooth, flowing texture that would be easy for advanced players to interpret expressively. The score we used is available from IMSLP Petrucci Public Domain Music Library (Faiman, 2003). We chose the first and second sight-

reading examples from page four and eight respectively of the grade four sight-reading

preparation material from the syllabus of the Associated Board of the Royal Schools of

Music (Johnson, T., 2001). We chose pieces in the style of a Gavotte to maintain metric and

rhythmical consistency between the testing sessions. We permitted the participants to

examine the pieces without playing for up to a minute before performance.

2.2.3 Set-up.

2.2.3.1 *Anatomical markers.* We cut round stickers approximately two-centimeters in

diameter from red kinesiology tape to create the markers for the outer-right canthus of the

eye, the right ear tragus, right anterior acromioclavicular joint (shoulder), back of right

elbow, right olecranon process (side of elbow), lateral epicondyle of humerus (top of

forearm), and ulna styloid process (wrist) (see figure 1, chapter 4). We mounted the small red

stickers on larger green stickers as a background to ensure the markers would remain visibile

against participants' skin. We provided participants with sleeveless black sports tops prior to

testing to ensure markers remained unobstructed in the videos. We securely fixed strong, flat

magnets of a five-millimeter diameter to the C7, T4, T8, and T12 vertebrae of each

participant using medical tape. We mounted white, polystyrene balls to magnetic bases one-

centimeter long, allowing them to be positioned precisely over the appropriate vertebrae over

top of the participant's clothing. This magnet system allowed us to remove the spinal

markers for the FI lessons of participants, and subsequently reposition the markers in

identical anatomical positions for the second testing session. A medical student positioned all

anatomical markers to ensure they were placed accurately and consistently. Our choice of

anatomical points of interest was informed by a study by Pownall and colleagues (2008)

which examined the consistency of standing and sitting posture in eleven men over the

course of a week. Their protocol permits the measurement of head and shoulder position in

relation to the C7 vertebra, which is clearly visible at the base of the neck and therefore easy to mark. They also marked the T4, T8, T12, and L5 vertebrae, allowing researchers to examine spine position in the cervical, thoracic, and lumbar regions.

2.2.3.2 Experimental set-up. We recorded video data with two Sony HD HandyCams, (HDR-XR260V, 8.9 megapixels) set to record at a frame rate of 60i (capturing 30 frames per second). We mounted them on Manfrotto tripods and positioned them so that the lens was perpendicular to the participant's right shoulder for the sagittal view and perpendicular to the participant's back for the posterior view. We mounted a dark coloured curtain behind the performers to maximize contrast with the white-spherical, anatomical markers placed on the spine. We positioned a set of 1000-watt spotlights perpendicular to participants approximately four meters away to ensure marker visibility. We adjusted the heights of the video cameras and their distance from the piano individually for each participant and retained these measurements for the second recording session. We also recorded the participants' preferred piano bench height and the distance of the piano bench so that the positions could be retained for each testing session. Pianists performed the playing tests on a Yamaha upright piano.

2.2.4 Procedure. We conducted testing was completed at the University of Ottawa Piano Pedagogy Research Laboratory. Once all anatomical markers were positioned and the heights of the cameras and piano bench had been recorded, we asked participants to perform the three playing tests while being video recorded in the sagittal and anterior views. Following the pre-test performance, we removed the spherical magnetic markers from the spine while the flat magnets beneath the clothing and the Kinotape markers remained in their original positions. We then escorted participants to an adjoining room where they immediately received a 30-minute FI lesson, which was video recorded for reference.

Although the content of each FI lesson varied according to the specific needs of each participant, each FI lesson involved a similar set of body movements focusing on the neck and upper back while participants were positioned on their sides and backs. After the FI lesson, we replaced the spinal markers over the magnets, and rerecorded the playing tests in the same manner as the previous session. Alan Fraser conducted all the Feldenkrais FI lessons for the study. Fraser is the author of *The Craft of Piano Playing* (2003, 2nd Edition 2011, also in DVD), *Honing the Pianistic Self-Image* (2010) and *All Thumbs: Well-Coordinated Piano Technique* (2012). He is also a professor of piano at The University of Novi Sad, Serbia. Fraser is a certified Feldenkrais practitioner who has been conducting Feldenkrais sessions with pianists for 24 years and is renowned for his piano technique workshops delivered in universities across North America and Europe.

2.2.5 Measurement.

2.2.5.1 Dartfish tracking procedure. We cropped the videos of playing test performances so that each video clip began with the first note of the performance and ended with the performers placing their hands back on their lap. We then shortened the video clips and imported them into the Dartfish software. I trained two research assistants to track the markers in the videos by using an analyzer tool to position a circular tracking marker around the object of interest in the video frame. One of the trained assistants or I tracked each marker once. All markers were tracked at a "medium speed" setting, which searches 10% of the video for identically coloured pixels. Although the tracking markers generally stay over the objects of interest as they move, they tend to gradually slip from their centered position, or occasionally jump to another part of the video with similar colouring. Thus, the movement tracking process can only be characterized as semi-automatic, and it was necessary to track the videos in slow motion, and often stop video playback to reposition markers that may have

slipped. The software users in this study ensured that the markers remained centered over the objects in the video throughout the tracking by using the frame-by-frame scrolling, zoom, and slow-motion playback functions.

Dartfish automatically records the coordinate position of tracked markers according the pixel position on the screen. In order to export the coordinates in distance units, the software user must establish a known reference distance in the videos, and mark a desired point of origin for the Cartesian coordinate system. For sagittal view videos we marked the width of the piano bench next to the person's right leg as a reference distance. For anterior view videos we marked the length of the bench as a reference distance. We placed the origin for the Cartesian coordinate system over a green tab marked for reference on the back of the piano bench for all saggital view videos. We marked the origin of the coordinate system as the centre of the buttocks at the point where it meets the seat for anterior view videos. Measurers generated x and y coordinates by linking the tracked objects to columns in the Dartfish data table tool and exporting the automatically generated coordinates to Excel.

2.2.5.2 Measurement of posture variables. Table 1 presents the posture variables we chose and the justification for their measurement.

Table 1
Description of measurement of posture variables for Dartfish tracking

Variable	Description of measurement	Justification for measurement
Head region		
(i) forward head angle (°)	Angle formed between a horizontal line passing through the C7 spinous process and a line connecting the C7 process to the ear tragus	Found to be a good indicator of forward head position (Raine &Twomey, 1997; Pownall et al., 2008; Ruivo, et al., 2014). A smaller cervical angle has been associated with increased forward head position and neck pain in computer users (Szeto et al., 2002).
(ii) head height (cm)	Height of the ear-tragus marker above the origin of the Cartesian coordinate system	Not previously found in literature. A simple way to determine if a person is sitting more or less erectly overall between testing sessions.
Shoulder region		
(iii) shoulder protraction angle (°)	Angle formed between a line connecting a point on the shoulder and the C7 vertebra and a horizontal line extending forward from the shoulder in the sagittal plane	Gives information about the degree of protraction (forward rounding) in the shoulders (Raine & Twomey, 1997). Measured here according to the procedure of van Niekerk et al. (2008).
(iv) vertical and horizontal shoulder displacement (cm)	Difference between the *y*-axis value of C7 and the right shoulder	A mode of measurement used by Szeto et al., (2002) to investigate shoulder elevation and shoulder protraction separately.
Spine region		
(v) origin-C7 angle (°)	Angle formed between the x-axis and a line joining C7 to the origin of the coordinate system at the back of the piano bench	Not previously found in literature. Used here to represent the angle of forward inclination of participants as they play.
(vi) T4 angle (°)	Angle formed between the C7, T4, and T8 vertebral markers	Used in Pownall et al., 2008. Gives an indication of curvature in the upper thoracic region of the spine.
(vii) T8 angle (°)	Angle formed between the T4, T8, and T12 vertebral markers	Used in Pownall et al., 2008. Gives an indication of curvature in the lower thoracic region of the spine.
(viii) T12 angle (°)	Angle formed between the T8, T12, and L5 vertebral markers	Used in Pownall et al., 2008.Gives an indication of the curvature in the lower thoracic/upper lumbar regions of the spine.
(ix) height of vertebral markers (cm)	Height of spine markers (C7, T4, T8, T12, L5) above the origin of the Cartesian coordinate system	Not previously found in literature. Used here to give information about changes in vertical positioning in certain regions of the spine.

2.2.6 Analysis.

2.2.6.1 Comparing posture variables. We calculated the mean value of each posture

variable from tracking data collected every three video frames for each playing test. We

subtracted the average values of the pre-test from those in the post-test in order to determine

if there were any differences in the average values between the two sessions. Based on the

results of the first study in this thesis, we considered differences greater than 0.5 cm and 2.5

degrees outside of the range of measurement error for the Dartfish measurement procedure.

2.2.6.2 Examination of time-plots. We plotted the posture variable measurements against time in Microsoft Excel to get a visual representation of how the movement of various parts of the body progressed across a performance. We qualitatively compared pre- and post-test time plots individually to assess if any significant differences in movement patterns were visible for any posture variables. We looked for significant differences in range, pattern, or smoothness of movement, and made note of any time plots that had noticably different characteristics in pre- and post-test tracking. Deutsch (2011) used plots of this type generated from Dartfish data to visually represent different characteristics in bowing patterns of professional and amateur violinists.

2.3 Study 3: Using Kinect to measure posture variables and track movement of pianists before and after a weeklong Feldenkrais piano technique workshop

2.3.1 Design. The following methodology examines the suitability of the Kinect motion sensor as a tool for quantitatively tracking the body positioning of pianists for comparing posture variables from before and after somatic training. We used the Kinect sensor to track the body movements of four pianists during performances of scales at the beginning and end of Alan Fraser's weeklong Piano Technique workshop. We compared the tracking results and posture from the Kinect to benchmark coordinate data obtained using Dartfish video-based motion tracking software.

2.3.2 Participants.

2.3.2.1 Pianists. We recruited four professional piano teachers (three female, one male; ages = 24, 29, 50, and 51) from among participants in Alan Fraser's weeklong piano technique institute at the University of Ottawa, taking place July 14−19, 2014. All participants had achieved a minimum of a bachelor degree in music, studying piano. Two had attended prior institutes of Alan Fraser, but had no long-term experience with the

Feldenkrais method. The other two were new to the Feldenkrais method altogether. We obtained ethics approval prior to data collection and all participants signed consent forms.

2.3.2.2 Playing requirements. We asked participants to play three repetitions of a C major contrary-motion scale, starting on C4 and extending to the lowest and highest octave of the piano in sixteenth notes, at approximately eighty beats per minute. We did not require participants to play with a metronome. We chose this test because it is symmetrical. It requires similar movements on both sides of the body simultaneously and does not require any torso rotation. Furthermore, pianists move primarily by leaning toward and away from the piano bench in the x and y axis during this type of scale. Their bodies remain almost stationary in respect to the camera (the z axis). Since the pianists' torso moves primarily in one plane, we can compare 2D data from Dartfish with the 3D data from the Kinect for single-plane posture variables. Scale performances have been used as convenient test to investigate the influence of somatic training on musicians in previous research (Williamson et al., 2007).

2.3.3 Set-up.

2.3.3.1 Anatomical markers. Prior to each recording session we fitted participants with red kino-tape markers on their right ear-tragus, right acromion process (top of shoulder), right olecranon process (elbow), and right ulnar styloid process (wrist), to permit accurate tracking with Dartfish. We marked the C7 vertebral process with a white, Styrofoam ball glued to a strong magnet taped to the skin with medical tape. We chose these points to correspond as closely as possible with the skeletal points tracked by the Kinect as summarized below in table 2. We provided participants with a tight-fitting, sleeveless sports top to ensure the view of the markers remained unobstructed by loose clothing. A medical student placed all markers to ensure accurate and consistent placement.

Table 2

Skeletal points tracked by Kinect and the corresponding body positions tracked using Dartfish

Kinect	Dartfish
Head	Ear-tragus
Shoulder centre	C7 vertebral process
Right shoulder	Right acromion process
Right elbow	Right elbow
Right wrist	Right wrist

Notes: See corresponding illustration in figure 1 in research paper 3

2.3.3.2 Experimental set-up. We recorded video data with a Sony HD HandyCam, (HDR-XR260V, 8.9 megapixels) set to record at a frame rate of 60i, (capturing 30 frames per second). We mounted it on a Manfrotto tripod to an appropriate height for each participant, which was retained for both pre- and post-test tracking sessions. We used a Kinect for XBox 360, which was equipped with an infrared depth-camera (640×480 pixels, 30 images per second) and an RGB camera (1280×1024 pixels, 10 images per second) to track the pianists' movement. Before the first recording of each participant, we positioned the video camera perpendicular to the right shoulder of the pianist and leveled it. The distance and height of the camera was recorded at this point and maintained for both recording sessions for each pianist. We placed the Kinect at approximately a 45 degree angle, approximately 1.5 meters to the front and right of participants, but found that we had to adjust the position of the Kinect frequently since the sensor was often unable to initiate tracking. Due to the inconsistency of Kinect tracking initiation, we were unable to keep the Kinect at a consistent height or position for all recording sessions.

2.3.4 Procedure. We collected all data at the University of Ottawa Piano Pedagogy Research Laboratory. Participants attended a six-day piano technique workshop with Alan Fraser. Fraser has achieved international renown for his piano technique workshops, which he conducts at universities across North America and Europe (http://www.pianotechnique.net/alanfraserinstitute/). Participants attended a one-hour private

piano lesson each day of the workshop, which involved exploring principles of the

Feldenkrais method to help develop ergonomic playing technique. Participants were also

permitted to observe other students' lessons and to attend daily lectures about the Feldenkrais

method and piano technique. All participants also attended an Awareness through Movement

(ATM) session each of the six institute days. The ATMs focused on exploring new

movement possibilities in the pelvis, shoulder, and spine. Somatic training workshops like

this offer a unique opportunity for researchers to study participants undergoing intense

exposure to a particular method, and previous research has investigated the impact of

bodywork modalities on musicians in workshop settings (Khalsa & Cope, 2006). We video

recorded the first scale performance of each participant on the first morning of the institute,

before workshop activities began. At the end of the institute, we recorded the same four

participants playing the same scale test a second time after they completed the final ATM

lesson.

2.3.5 Measurement.

2.3.5.1 Kinect tracking procedure. Software developers from the University of

Ottawa department of computer engineering modified the original motion-capture software

platform of the Kinect to track seated pianists from the sagittal view, since the normal

platform recognizes individuals in standing positions facing the camera (Payeur et al., 2014).

A research assistant manually initiated Kinect tracking as participants played the first note of

their scale, and stopped tracking when participant's hands left the piano at the end of the

exercise. The x, y, and z coordinates of the head, shoulder-centre, right shoulder, right elbow,

and right wrist were automatically exported to Excel files for analysis. The direction of the

axes of the coordinate system and an example of how the Kinect skeleton points would

correspond to a participant's body can be viewed in figure 1 in research paper 3 of this thesis.

2.3.5.2 Dartfish tracking procedure. I trained two research assistants to use the Dartfish software, and they completed all tracking of anatomical markers for this study. Anatomical markers were tracked in the videos using Dartfish TeamPro software, version 7.0, according to the previously described procedure (Beacon, 2015a). They set the reference distance to the diameter of the lowest ball marker on the spine (3.7 cm), and they marked the origin of the coordinate system at a point on the bench behind the participants. We clipped the videos prior to analysis so that each one began when the pianist played the first note of the exercise, and ended when they removed their hands from the piano.

2.3.6 Analysis.

2.3.6.1 Comparing Kinect and Dartfish time-plots. I rated the tracking performance of the Kinect based on how closely it matched the movement pattern depicted in the Dartfish reference plot using the rating-scale we devised, depicted in table 3 in research paper 3. Since the participants played three repetitions of the scale for each test, the *x*-axis time plots typically reflected three similar movement cycles as the participant moved their torso toward and away from the piano.

2.3.6.2 Comparing average posture values. We calculated the average values for the postural variables in table 3 for the pre and post-test recording sessions of each participant using the coordinate values reported by both tracking technologies. We measured forward head angle as depicted in figure 2 of research paper 3 for Dartfish data. We made the same measurement for the Kinect data, but the C7 was replaced by the position of the shoulder centre in the Kinect skeleton.

Table 3
List of single-plane posture variables for comparing Dartfish and Kinect tracking

Posture variable	Description of Dartfish measurement	Description of Kinect measurement.
(i) forward head angle	Angle formed between a horizontal line passing through the C7 spinous process and a line connecting the C7 process to the ear tragus.	Angle formed between a horizontal line passing through shoulder centre skeletal tracking point and a line connecting the shoulder centre to the head skeletal tracking point.
(ii) vertical displacement of head and the shoulder centre	Difference between the y-axis value of the ear-tragus and the y-axis value of the C7 vertebrae.	Difference between the y-axis value of the head and the y-axis value of the shoulder centre.
(iii) horizontal displacement of head-shoulder centre	Difference between the x-axis value of the ear-tragus and the x-axis value of the C7 vertebrae.	Difference between the x-axis value of the head and the x-axis value of the shoulder centre.
(iv) height of head above hips	Difference between the y-axis value of the ear-tragus and the origin of the coordinate system at bench level.	Difference between the y-axis value of the head and the y-axis value of the hip centre.
(v) height of C7 above hips	Difference between the y-axis value of the C7 vertebrae and the origin of the coordinate system at bench level.	Difference between the y-axis value of the shoulder centre and the y-axis value of the hip centre.

2.4 Conclusion

This chapter outlined the methodology of three studies that were designed to assess the suitability of Dartfish and Kinect tracking technologies for measuring the posture of pianists before and after somatic training interventions. In the following chapters I present three individual research papers that contain the analysis and results answering the research questions posed by the three studies.

CHAPTER 3:
RESEARCH PAPER 1

Reliability and repeatability of distance and angle measurements made using Dartfish motion

tracking

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Abstract

This study seeks to investigate the accuracy and reliability of the Dartfish video-analysis software's motion tracking feature to determine if it could be used to compare posture variables of pianists from before and after somatic training interventions in subsequent studies. Four software users tracked the movement of Styrofoam balls in three different videos. In the first video, we moved two balls mounted 20 cm apart horizontally through a distance of 15 cm on a sliding rail. We repeated this sliding test one centimeter higher in the second video. We compared the average and standard deviation of the tracked distance between the two balls for the sliding tests across users and compared the height of the balls as measured in video one and two. Results indicate that Dartfish tracking results are reliable to within 0.5 cm and accurate to within 0.4 cm. We estimate total analytical error to be at 0.5 cm (+/- 0.25 cm). A third video depicted another ball being swung slowly, left and right. The time-plots of the position of swinging ball in video three were indistinguishable across different software users in both the x and y axes. These results indicate that the estimated measurement error of Dartfish tracking is small enough to permit quantitative measurement of body postures of pianists to be used to compare performing postures from before and after somatic training interventions.

Keywords: Dartfish, motion tracking, posture, piano playing, somatic

LITERATURE REVIEW

Necessity of objective measuring tools for research on posture outcomes of somatic training with musicians

Most evidence that somatic training can improve postural alignment and movement habits in musicians comes from subjective sources, such as testimonials (Goldansky, 2008; Stewart, 2010; Fraser, 2015; Boyd, 2015; Johnson, J., 2015) or practitioner-reported case studies (Rosenthal, 1987; Nelson, 1989; Mayers & Babits, 1989). However, research on non-musicians has provided some initial evidence that participation in somatic training can impact muscle recruitment strategies in posture modulation (Cacciatore, Horak, & Henry, 2005; Cacciatore, Gurfinkel, Horak, Cordo & Ames, 2011) and positioning of the head and neck (Kutschke, 2010). Furthermore, studies on the impact of somatic training on musicians' posture by Valentine and Williamon (2013) and Wong (2015) provide initial indications that somatic training could lead to improvements in musician body usage. However, these two studies measured posture using somatic practitioner assessments of body-use using rating scales developed specifically for the studies. Research has called into question the validity of visual assessments of posture using rating scales (Fedorak, Ashworth, Marshall, & Paul, 2003; Aitken, 2008). As of yet no studies with musicians have attempted to quantitatively measure visible attributes of posture and movement from before and after somatic training. Studies using objective measuring tools to obtain quantitative data about body positioning could provide more reliable evidence of changes to posture and movement as a result of somatic training. Therefore, our study seeks to objectively track and measure the body positioning of performing pianists to determine if somatic training sessions influence aspects of their posture and movement, as has been suggested by evidence from testimonials and case-studies.

Dartfish as a tool for motion analysis

Dartfish video-based motion tracking software could be suitable as a tool for objectively measuring the body positioning of pianists to compare aspects of posture and movement from before and after somatic training interventions. It was originally designed as a performance analysis and coaching feedback tool for professional athletes. The software enables users to label videos with commentary or drawings, and to make two-dimensional angle and distance measurements directly on video frames. Up to three videos can be played side-by-side for comparison, and the user can crop, slow down, or zoom in on videos to examine movement in greater detail. These features have made Dartfish software an attractive option for coaches and researchers seeking to conduct detailed performance analysis of human movement. For instance it is used by the United States Tennis Association to help educate coaches about playing technique (Melville, 2014a) and the Great Britain Canoe/Kayak Slalom to give athletes performance feedback (Wells, 2014). Scientists at NASA have even used Dartfish to evaluate the performance of space suites (Melville, 2014b). Although Dartfish has primarily been used to analyze performance in sports, it has also been used to analyze the movement of instrumentalists in some instances. For example, Dartfish playback and side-by-side video comparison functions are used as central components of Riley's (2009) multi-modal feedback system for training ergonomic piano technique (Riley, Coons, Marcarian, 2005; Riley, 2010/2011). Deutsch (2011) used the Dartfish object-tracking function to track the bow movements of violinists in order to compare bow movement trajectories of student violinists and professional violinists. Finally, Staes et al. (2011) used the distance and angle measurement functions of Dartfish to measure posture variables of a classical singer from still photographs taken as individual video frames in order to assess the impact of physiotherapy on posture and alignment (Staes, Jansen,

Vilette, Coveliers, Daniels & Decoster, 2011). To date, researchers have not yet used the motion tracking feature of Dartfish to track and measure body positioning of musicians quantitatively.

Dartfish as a tracking tool for human movement quantification

Recently, researchers have become interested in using the motion tracking capabilities of the ProSuite version of Dartfish as a means of tracking human movement for quantitative data analysis of body positioning. This feature allows users to target an object of interest with a tracking marker, prompting the software to search successive video frames for pixels of identical colour so that the target can follow the object as the video plays. The 2D Cartesian coordinates of the tracked object can be exported directly to an Excel document if the user establishes a point of origin and known reference distance on the opening video frame. Since Dartfish tracks objects based on pixel colour, body positions of interest must be clearly marked with brightly visible anatomical markers to ensure accurate tracking takes place.

Dartfish has already been used to quantitatively measure posture for a variety of different purposes, including the assessment of sitting posture of subjects with postural back-ache (Womersley & May, 2006) the assessment of a sit-and-reach test for hamstring flexibility (Mier, 2011), the influence of neck pain on neck flexion during a reaching task (Constand & MacDermid, 2013), the thoracic posture of rugby players (Bolton, Moss, Sparks, & Venter, 2013) and standing posture in asthmatics after diaphragmatic and aerobic breathing training (Shaw, B., & Shaw, I., 2011). Dartfish and similar software has also been used in marker-based procedures to quantitatively measure posture in stable seated or standing positions, collecting manual measurements from a few selected video frames (van Niekerk, Louw, Vaughan, Grimmer-Sommers, & Schreve, 2008; Grimmer-Sommers,

Milanese, & Louw, 2008; Perry, Smith, Straker, Coleman, & O'Sullivan, 2008; Ferreira, Duarte, Maldonado, Burke, & Marques, 2010). These studies reported good inter-rater reliability for their particular Dartfish measurement protocols when measuring posture in stable standing and sitting positions. However, since these studies measured posture manually in individual frames, their accuracy and reliability reports cannot be extended to data obtained using the motion-tracking feature, which would be better suited to meaningfully examine the dynamic movements of performing pianists.

Accuracy and reliability of Dartfish tracking

Previous research has provided some initial evidence that Dartfish can generate accurate tracking data of human movement using the object-tracking feature. For instance, Eltoukhy and colleagues (Eltoukhy, Asfour, Craig, & Thompson, 2012) compared the Dartfish tracking of anatomical markers on a subject performing a simple squatting movement to tracking results obtained simultaneously with the highly reliable Vicon 3D tracking system. They found that the difference between tracked objects' trajectories was about +/- 5 mm between the two systems, with magnitudes of differences in marker position ranging from -10 to +20 mm depending on the anatomical marker and the axis of movement examined. These results provide researchers with a good initial representation of the overall accuracy of Dartfish as a tool for human movement quantification. However, Eltoukhy and colleagues generated the Dartfish measurements from a single measurement session, and therefore they are unable to comment on the consistency of results for a given measurer, or between different measurers using the same tracking procedure on the same video. Furthermore, Eltoukhy and colleagues used scientific Basler cameras to minimize lens distortion. Presently, it is not clear if Dartfish can accurately and reliably track objects in videos generated from more accessible CMOS (complementary metal-oxide semiconductor)

video cameras, which are easier for researchers to access. This information is vital to understanding the accuracy and reliability of Dartfish in studies using multiple measurers or when comparing measurements across different trials.

Research questions

Therefore, the first paper of this thesis seeks to answer the following four questions, which must be addressed prior to analysing tracking data with live pianists:

1. Are tracking results of markers reliable, (repeatable across different software users), for distance measurements using the tracking procedure employed in our study?

2. Are distance measurements attained using the Dartfish tracking procedure accurate?

3. What is a good estimate of combined total error for distance and angle measurements made using our tracking procedure?

4. Is tracking smooth and consistent across measurers for movements that occur in simultaneously in the *x* and *y*-axes?

Answering these four questions will allow us to determine whether or not any differences observed in the Dartfish measurement of pianists' postural variables from before and after somatic interventions can be considered outside the range of measurement error for the tool using our tracking procedure.

The following hypotheses are made in response to our research questions:

1. The repeatability of results using the tracking feature has not yet been assessed in previous research. However, since previous studies showed good inter-rater reliability for manual measurements taken at specific frames, it is hypothesized that results achieved using the tracking tool are likely to be

repeatable within at least 0.5 centimeters, especially among trained users (Staes, et al., 2006; van Niekerk et al., 2008; Pownell et al., 2008).

2. We hypothesize that a small discrepancy will be found between actual distance measurements and Dartfish distance measurements, since there are many sources of potential systematic error (such as camera lens distortion), and random error (such as the manual positioning the origin of the Cartesian grid). However, since Eltoukhy et al. (2012) found about an error of about 0.5 between Dartfish and Vicon and Dartfish trajectories, it is likely that the error in our study will not exceed 0.5 centimeters.

3. We hypothesize that combined total error from the reliability and accuracy measurements may slightly exceed the 0.5 centimeters found by Eltoukhy et al. (2012) because their assessment of error did not take into account reliability across different measurers.

4. We hypothesize that Dartfish will be able to smoothly track movements occurring simultaneously in both axes, since it has been successfully used to analyze complex movements in other contexts, including golf swings (Wright, 2008) and trajectory of bow movements of string players (Deutsch, 2011).

Answering these questions will permit researchers to understand the threshold of measurement error for Dartfish tracking so that they can confidently assess whether or not differences in posture variables measure with live pianists reflect measurable differences in body positioning, or if they should be attributed to sources of systematic or random error.

METHODOLOGY

Design

 The following methodology examines the accuracy and repeatability of Dartfish

motion tracking software by comparing multiple software users' measurements of

polystyrene balls sliding on an aluminum rail in video recordings taken with a regular,

CMOS video camera.

Apparatus

 We fixed two polystyrene balls (identical to anatomical markers we intend to use on

pianists in subsequent studies) onto screws twenty centimeters apart on top of a sliding

aluminum rail as depicted in figure 1. The aluminum rail was clearly marked with a ruler

system etched using a milling machine with a digital read-out system and equipped with

glass scales with a resolution of 0.01 mm. We mounted the aluminum rail to a tripod

equipped with a crank mechanism to adjust the height of the apparatus. We recorded video

data with a CMOS Sony HD handy-cam (HDR-XR260V, 8.9 megapixels). A floor grid

system, floor markers, carpenter's square and plumb bob were used to ensure that the slider

and camera were square and positioned perpendicular to one another. We used a carpenter's

level to ensure the cameras and aluminum rail were level.

Procedure

 We carefully levelled and positioned the camera at a right angle to the aluminum

slider at height of 94 centimeters and a distance of 158 centimeters. We also levelled the

aluminum rail. In the first video, we recorded the two balls mounted on the aluminum rail

sliding left through a range of 15 centimeters. The sliding movements were generated by

hand. In a second video, we repeated the sliding test at a height exactly one centimeter above

the original reference test, confirming the one-centimeter vertical displacement of the

aluminum slider using a digital calliper. In a third video, we recorded the hanging

polystyrene ball seen on the right side of figure 1 as it was swung once to the left and right.

Figure 1. Experimental set-up for accuracy and reliability testing. The photo
on the left is the sliding aluminum rail mounted with spherical markers, and
a hanging ball on the right. The photo on the right is the camera, set up
perpendicular to the apparatus.

Measurement

Four measurers (two with prior experience, and two new to the software) used

Dartfish software to track the two Styrofoam balls throughout their horizontal sliding-

movement in the first video, three times each. First, the measurer placed an origin marker in

the video at the visible point marked clearly on the centre of the tripod. Next, they

established a reference distance of 15 centimeters by dragging a distance-measuring tool the

full length of the visible 15-centimeter ruler marks etched on the aluminum. Finally, the

measurers positioned circular tracking markers over the two balls and carefully monitored them as the video played at half speed to ensure that the markers remained precisely positioned over the image of the balls in the video. The data table tool was used to export the *x* and *y* coordinates of the tracked balls for each of the three measuring trials.

We used the same tracking procedure for the second video to track the horizontal ball movements at a height one centimeter higher than reference, but due to limited access to research volunteers, data from only two measurers (one experienced, one inexperienced) completed three tracking trials for this portion of data collection. Similarly, only three measurers tracked the trajectory of the swinging ball in the third video.

Analysis

Reliability. To determine the threshold of measurement error for distance and angle measurements made using our Dartfish tracking procedure, we calculated the mean horizontal distance and standard deviation of the distance between the two balls mounted on the aluminum rail for each of the three tracking trials completed by each measurer. We used the standard deviation across measurers to calculate a measurement error estimate. For our purposes, the measurement error was defined in terms of percentage chance that the measurement would be within a selected error range (calculated using the area under the normal curve). We then trigonometrically analyzed the threshold of measurement error determined from this method to estimate a measurement error for angle measurements made from line segments formed by three tracked points.

Accuracy. To determine how accurately Dartfish tracking represents known distances in the *x*-axis, we subtracted the average difference between the four measurers' tracked measurements of the horizontal distance between the two balls on the rail from the known distance of 20 cm. To determine how accurately Dartfish tracking represents actual

distances in the *y*-axis, we calculated the difference between the height of the ball markers in

the videos taken at reference height and one centimeter above reference height for each of

the three tracking trials of two of the measurers. The average difference of ball height in

videos one and two will be subtracted from the known height difference of one centimeter to

determine how close the tracking measurements came to the actual distance.

RESULTS

Reliability of distance measurements

This section presents results that answer the first research question, which examines

the reliability, or repeatability of measurements taken using our Dartfish tracking procedure.

We calculated the average distance and the standard deviation of the measured horizontal

distance between the two balls for each measurer as presented in table 1.

Table 1
Average marker distance calculated from four different users' tracking data

Measurer 1 (4 months experience)	Average distance (cm)	Standard deviation (cm)
Trial A	19.8	0.02
Trial B	19.7	0.03
Trial C	19.7	0.03
Measurer 2 (3 months experience)	Average distance (cm)	Standard deviation (cm)
Trial A	19.8	0.04
Trial B	19.8	0.06
Trial C	19.8	0.04
Measurer 3 (no previous experience)	Average distance (cm)	Standard deviation (cm)
Trial A	19.8	0.03
Trial B	19.7	0.04
Trial C	19.8	0.02
Measurer 4 (no previous experience)	Average distance (cm)	Standard deviation (cm)
Trial A	19.7	0.04
Trial B	19.6	0.04
Trial C	19.7	0.04
Average overall	19.7	0.04

We confirmed that the distance between the two balls was 20 centimeters using a digital calliper. Since the balls were fixed firmly to the sliding rail this distance remained constant, and therefore the standard deviation of the tracking data of our measurers would be zero if the measuring tool were able to measure this distance identically in every video frame. As can be seen in table 1, the standard deviations were all beneath 0.06 cm, and averaged at 0.04 cm. This indicates that the tracked distance between the two balls was highly consistent from frame to frame for the measurers in our study.

In order to arrive at an estimation of how reliable, (or repeatable), results are for our tracking procedure, we needed to calculate the variability of the distance measurements tracked between the two tracked balls, since each measurement would be identical if the measuring tool was perfect, with the two balls remaining 20 centimeters apart at all times. Assuming the data for the distance measurements is normally distributed, we can make this estimation by finding out what range of measurements are represented on a normal distribution curve based on the average difference between the known distance and the measured distances, and the standard deviation calculated from our data. It is known that 98.8% of data points can be found between -2.5 and 2.5 standard deviations on a normal distribution curve. This means that we can expect almost all of our data points to be found within this range in the normal curve. To find out what range of measurements are represented by -2.5 and +2.5 standard deviations in our data set, we used the following equation:

$$z = \frac{x - \mu}{\sigma}$$

In our calculations, the value of variables in this equation will be as follows:

- z is a standardized score on a normal distribution curve. In our calculations, z will be selected as 2.5 and -2.5, since we want to know which measurements can account for at least 98.8% of our total data points.

- μ is the mean of our data set. Therefore, $\mu = 19.7$ cm.

- σ is the standard deviation of our data. The mean standard deviation of our data was 0.04, and no standard deviation for any measurer exceeded 0.06 cm. We chose to make a safe, conservative estimate that standard deviation would never exceed 0.1 for any measurer. Therefore, we will be using a slightly high estimate of 0.1 cm as the standard deviation for our calculations.

- We will solve for x, which represents the data value represented by 2.5 and -2.5 standard deviations on the normal curve.

$$2.5 = \frac{x - 19.7}{0.1} \qquad -2.5 = \frac{x - 19.7}{0.1}$$

$$x = 20.0 \text{ cm} \qquad x = 19.5 \text{ cm}$$

This means that 98.8% of our data points are likely to fall between 19.5 and 20.0 cm. This is a range of 0.5 centimeters. As such, we will round our measurement error for reliability to 0.5 cm (+/- 0.25 centimeters). Therefore we can expect that Dartfish measurements of a given distance taken frame to frame to vary within a range of about 0.5 cm using our tracking procedure.

Accuracy for distance measurements

This section presents results that answer the second research question asking how accurately Dartfish can track known distances in both the *x* and *y* axes. As can be seen above in table 1, the average horizontal distance between the two tracked balls across all measurers ranged from 19.6 cm to 19.8 cm, and the average distance from across all trials for all measurers came to 19.7 cm. At no point throughout the tracking did the measurement exceed 19.8 cm for any measurer, despite the fact that the balls were mounted exactly twenty centimeters apart. This suggests that some factor in the experimental set-up, (such as the contour of the camera lens or potential rotation of the slider), or in the software operation resulted in a measuring bias that caused distances to be measured slightly smaller than reality. Based on the measurements attained, it could be considered that on average, distance measurements reported in this study may likely be 0.2 to 0.4 cm shorter than reality.

Similar results were found for distances measured in the *y*-axis. As can be seen in table 2, the difference between the average height of the middle ball in the first video at a reference height and the second video when the tripod was raised exactly one centimeter ranged from 0.9 cm to 1.2 cm across the three trials each taken by two different measurers. We only collected data from two measurers for the test at one centimeter higher. The average difference across all of the trials of these two measurers was 1.0 cm, indicating that the vertical displacement between values that change primarily in one plane from session one to session two can be considered accurate within about two millimeters using the equipment and data collection procedures used in this study.

Table 2
Average height of middle ball at reference height, and 1cm higher (cm)

	Reference height	Platform 1 cm higher	Difference
Measurer 1 (experienced)			
A	27.4	28.3	0.9
B	27.3	28.3	1.0
C	27.3	28.3	1.0
Measurer 1 average	27.3	28.3	1.0
Measurer 2 (inexperienced)			
A	27.3	28.4	1.1
B	27.2	28.4	1.2
C	27.4	28.3	0.9
Measurer 2 average	27.3	28.4	1.1
Total average difference:			1.0

Figure 2 presents the time plots of the *y*-axis coordinates of the first and second measurers' tracking sessions of the horizontal ball shifting test at both base level, and one centimeter higher. It illustrates that variability of the *y*-axis coordinates generally stays within a narrow range of about 2 mm for both videos.
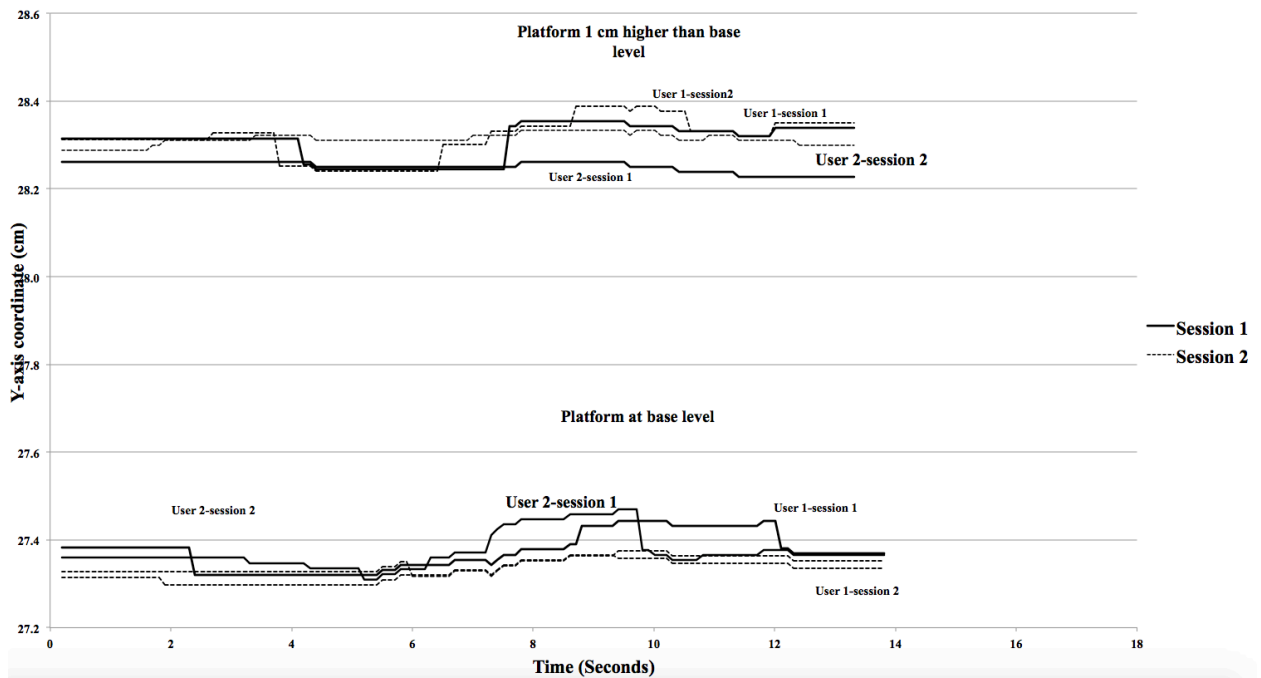
Figure 2. Time-plots of user 1 and user 2's first and second tracking sessions of both the baseline and 1-cm higher horizontal-shift video for the middle ball.

Total analytical error

This section presents results that answer the third research question, which seeks to combine the error found for reliability and the error found for accuracy into one component.

Total analytical error for distance measurements. A common way to estimate total analytical error can be achieved using the following equation (Westgard, J. &Westgard, S., 2013):

$$\text{Total analytical error (TAE)} = \text{bias} + 2SD$$

For our calculations, the terms will be represented as follows:

- "Bias" is calculated as the difference between the target value and the mean. In our study, the greatest difference between target value and mean was found in the horizontal measurements presented in table 1. The target value was 20.0 cm, and the mean was 19.73 cm. Therefore:

$$\text{Bias} = 20.0 \text{ cm } \text{-}19.7 \text{ cm}$$

$$\text{Bias} = 0.3 \text{ cm}$$

- "SD" stands for "standard deviation". The standard deviation across all measurers and trials for our horizontal distance results presented in table 1 was 0.04 cm. However, since SD was as high as 0.06 for one measurer, we conservatively estimated that SD would likely never exceed 0.1 cm. Therefore, we will use 0.1 cm as the SD for our estimation of total analytical error.

$$\text{TAE} = 0.3 \text{ cm} + 2(0.1 \text{ cm})$$

$$\text{TAE} = 0.5 \text{ cm}$$

Therefore, the combined measurement error for our Dartfish tracking procedure can be summarized as 0.5 cm. This means that when comparing measurements of variables across different trials, we will consider differences 0.5 cm and higher as measureable

differences. Any changes observed below 0.5 cm (+/-0.25 cm) will be considered outside the threshold of measurement error, and be attributed to systematic or random error. This estimation of total error aligns well with our hypothesis based on the average 0.5 cm tracking error reported by Eltoukhy and colleagues (2012).

Total error for angle measurements. Some of the measurements we are interested in examining in pianists will involve calculating posture angles using the coordinate points tracked by Dartfish. Therefore, we used the 0.5 cm total error estimated for distances to estimate the degree of measurement error for angle measurements. The following equation estimates the error in degrees for an angle formed between a line segment between two tracked points, 10 cm apart, and a horizontal reference line:

Angle-arctangent (TAE/length of line segment)

Angle =arctangent (0.5/10)

Angle = 2.86 °

Calculating this angle represents the largest possible error, since it represents the scenario in which the tracked point would move the full degree of measurement error (0.5 cm) perpendicularly to the other tracked point. Therefore, the measurement error for an angle formed between a line segment between two tracked points, 10 cm apart, and a horizontal reference line could be estimated to be about 2.86 degrees (+/-1.43 degrees). It is important to note that shorter line segments will result in higher error, so the estimated error for angle measurements should be considered on a case-by-case basis.

Tracking consistency for movement in both axes

This section presents results answering the fourth research question, which asks if measurers can consistently track movements that take place simultaneously in both the *x*- and *y*-axes using Dartfish. Figures 3 and 4 below present time plots from the tracking tests of

three measurers from our third video that involved manually swinging the right-most ball in

figure 1 to the right, then left, and then bringing it back to rest at centre. Three separate

measurers, (one experienced, two newly trained), tracked the ball throughout this movement.

The time plots for the three trackers are almost indistinguishable from one another, indicating

that Dartfish tracking using our procedure can yield reliable, smooth, consistent tracking of

movements taking place simultaneously in both axes, as hypothesized. These time plots give

a highly detailed representation of the position of a point throughout a movement.
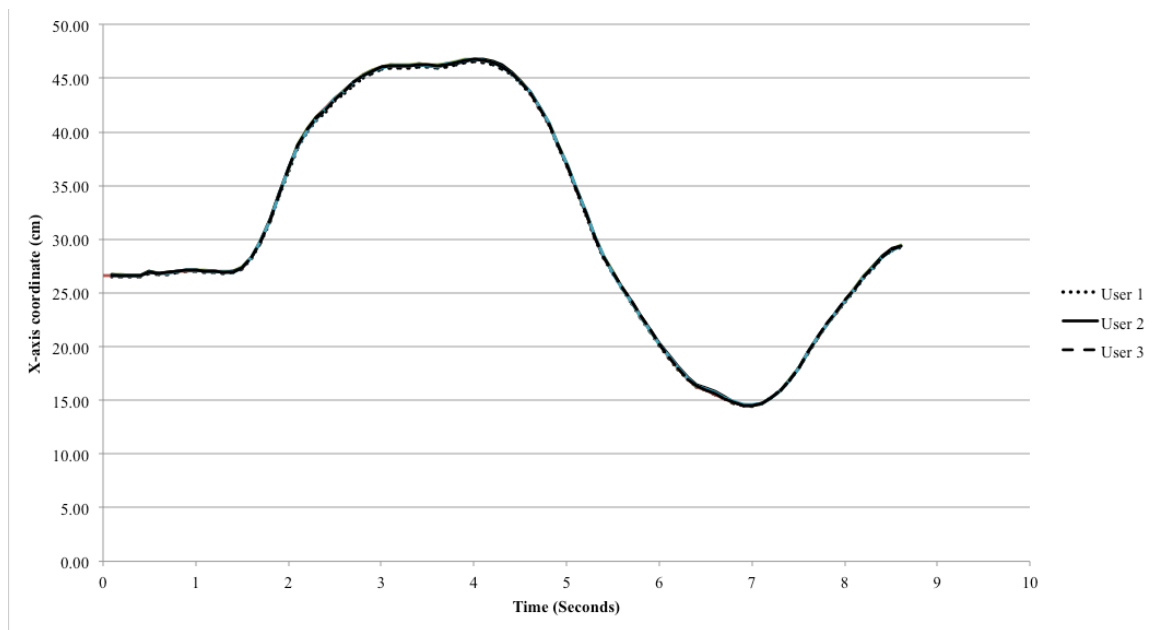
Figure 3. x-axis tracking time-plots of a ball-swinging test generated from Dartfish tracking
data of three different users. The tracking plots of different users are nearly indistinguishable
from one another.
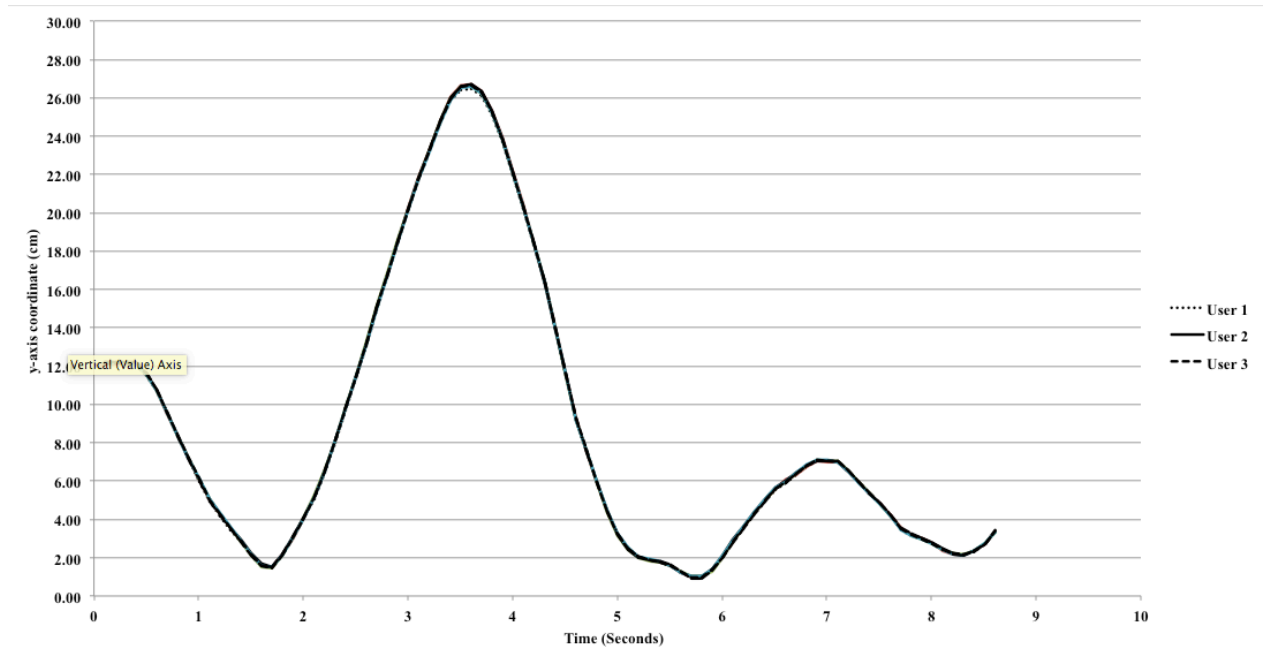
Figure 4. *y*-axis tracking time-plots of a ball-swinging test generated from Dartfish tracking data of three different users

DISCUSSION

The results of our tests reveal that tracking measurements between users are repeatable within 0.5 cm and are accurate to within about 0.4 cm. Both of these results are within the expected range of 0.5 cm hypothesized in response to research questions one and two. Although we hypothesized that the total analytic error would be slightly greater than 0.5 cm, our method of estimation placed it at about 0.5 cm. These results align well with the findings of Eltoukhy and colleagues, who found that on average the Dartfish tracking trajectories varied within 0.5 cm of the simultaneously captured trajectories of the Vicon system (Eltoukhy et al., 2012). The time plots generated from tracking data of the swinging ball in the third video were indistinguishable between different users, suggesting that Dartfish tracking results are consistent for movements taking place in the *x* and *y* axis simultaneously as hypothesized.

The results from our study are exciting because it appears that Dartfish tracking is accurate and reliable even when using standard CMOS video cameras as opposed to Basler video cameras. Future studies should examine accuracy against a known reference distance to see if the bias we found for distance measurements to be projected slightly shorter than reality is found consistently in other measurement situations. As can be viewed in table 1, the average distances and standard deviations of horizontal distance measurements from the new users did not differ significantly from more experienced users, suggesting that the measurement procedure used by the software is easy to learn and that reliable results can be obtained with minimal training. Interestingly, the time plots from the ball-swinging test (figures 3 and 4) are much smoother than the time plots tracking the horizontal movement of the two sliding balls (figure 2), with fewer user corrections of the position of the Dartfish marker over the target in the video. It could be that we encountered the same problem as the researchers as Eltoukhy et al. (2012), which is that the software appears to have more trouble tracking points that remain stationary in respect to the x- or y- axes. Their team suggests that this may be related to the way Dartfish is programed to search surrounding pixels for matching colours to make sure it has not lost the marker. In our study, the sudden, jerky changes in tracking trajectory visible in figure 2 are likely user induced, resulting when a measurer pauses the video to correct the course of a marker that is drifting off of its mark. This example illustrates that it is integral for measurers to carefully watch the video and monitor markers that will frequently drift in order to maintain accuracy of the results. Finally, it is interesting that tracking of the horizontal ball movements in video one and two at both platform heights seems to become less consistent at about 8 seconds, which is approximately when the aluminum slider began shifting in the opposite direction. It could be that perhaps the platform moved slightly during the direction change in the test, or that either

the floor or camera was not perfectly level, with the right side resting slightly higher than the left in comparison to the point of origin set in the video. It could also be that perhaps the aluminum slider was not perfectly perpendicular, resulting in one side being closer to the camera than the other. Future studies should use additional technology, such as laser levelling and squaring technology, to ensure that the testing platform is perfectly level and perpendicular to the camera.

CONCLUSION

Our Dartfish tracking procedure appears to be accurate and reliable to within 0.5 (+/-0.25) cm for distance measurements in the *x* and *y*-axes. Based on these results we recommend that Dartfish tracking can be considered reliably and repeatable quantitatively compare measurements of pianist posture from before and after somatic training interventions. Using Dartfish, researchers will be able to get accurate and reliable quantitative data representing the distance between different tracked points on pianists' bodies. For instance, researchers could measure the height of the eye or a point on the ear above a reference point in order to determine whether or not an individual is sitting up taller after somatic training interventions. Researchers could also place markers to examine other posture variables significant to posture researcher, such as the height and forward position of the shoulders (Szeto, Straker & Raine, 2002; Raine & Twomey, 1997), or the degree to which the head is held forward from the spine (Szeto et al.; 2002; Ruivo, Pezarat-Correia & Carita, 2014). Since digital video cameras can be easily set-up in performance spaces, Dartfish can be used as an effective quantitative measurement tool for examining pianist posture during live performance. An estimated error of 0.5 cm for tracked data is promising, since researchers can track data throughout a performance instead of taking measurements from isolated video frames or from photos that may not adequately represent a pianists'

posture during performance. This will allow researchers to create time plots to examine

details in the dynamic playing movements of pianists as they play.

CHAPTER 4:
RESEARCH PAPER 2

Using Dartfish to measure posture variables of pianists before and after a Feldenkrais

Functional Integration lesson

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Abstract

Dartfish video-based motion tracking software could be used to effectively track pianists'

movements during live performances to compare quantitative posture measurements from

before and after somatic training sessions. This exploratory study seeks to answer three main

research questions to assess the suitability of this software in this application: (1) Can

Dartfish be used as an effective measuring tool for comparing measurements of posture

across different testing sessions; (2) Are trends in posture change noted across a group of

pianists after a single Feldenkrais Functional Integration (FI) lesson?; and (3) Are changes to

posture and movement characteristics evident for any particular participants after a single FI

lesson? We used Dartfish to track anatomical points of interest on 15 advanced pianists

performing a contrary motion scale, a sight-reading test, and the first section of *Für Elise*

immediately before and after receiving a 30-minute FI lesson. Dartfish motion tracking was

found to be an effective but time consuming method of data collection in this context.

Results revealed that posture variables and movement patterns tended to remain consistent

for most participants between the first and second session. No group trends were noted from

pre- to post-test for any posture variables measured in the head, shoulders and spine regions.

However, examination of time-plots of posture variables revealed compelling changes in

movement quality, range of motion, and body integration of the head and torso of two

individuals for specific playing tests. These observations are intriguing, and future

researchers could conduct longer-term studies with control groups to establish if postural

habits can be measurably impacted as a result of somatic training.

Keywords: Dartfish, posture, video-based motion tracking, somatic training,

Feldenkrais,   piano pedagogy

LITERATURE REVIEW

The significance of posture in piano pedagogy

Both historical treatises on keyboard playing (Couperin, 1716; Bach, C.P.E, 1949, originally published 1753, rev. ed. 1787; Hummel, 1827; Brée, 1997, originally published in 1902; Bratók and Rechaufsky, 1950, originally published 1913) and modern beginner piano method books (Bastien, J. & Bastien, J. S., 1985; Barden, Kowalchyk, & Lancaster, 2009; Vogt & Bates, 2001; Curie, 1985; Fletcher, 2012) frequently open with diagrams or descriptions of recommended playing posture. The various posture descriptions tend to emphasize a still, upright position, and seem to place a greater importance on how the position looks externally rather than on how the body is used to play or feels to the performer. Some pedagogues have criticized these posture descriptions for overlooking issues related to balance and movement, and attribute the proclivity of many students to play rigidly or to develop musculoskeletal problems in part to their adherence to the tenets of fixed, erect posture introduced to them from their earliest lessons (Newman, 1984; Prieur, 1994).

Since the 1960s, pianists have become increasingly concerned with incorporating total body awareness into playing technique. This new concern for body awareness stems, in part, from concerns that excess tension in the trunk and limbs, and misaligned posture during playing inhibits expressive control at the instrument (Neuhaus, 1967; Fink, 1992; Taubman, 1995; Wheatley-Brown, Comeau, & Russell, 2014). Perhaps more significantly, prolonged misaligned or rigid postures and excess tension in muscles and joints are frequently cited as factors in the development of playing-related musculoskeletal disorders (PRMDs) in both the medical and performing communities (Cailliet, 1990; Brandfonbrener, 1997; Dommerholt, 2010; Allsop & Ackland, 2010). Recent studies have confirmed high prevalence rates of

PRMDs for professional instrumentalists and students (Zaza, 1998; Brandfonbrener, 2009), and it appears that pianists are in the high-risk group amongst their fellow instrumentalists (Cayea & Manchester, 1998, Dawson, 2002). Research has also shown that PRMDs can not only severely impact affected musicians psychologically (Zaza, Charles, Muszynski, 1998; Bialocerkowski, McMeeken, & Bragge, 2004; Kenny & Ackermann, 2015) but that they can also impact a musician's ability to coordinate their fine motor skills and posture during performance (Fry, Hallett, Mastrioanni, Dang, & Dambrosia, 1998; Daenen, Roussel, Cras, & Nijs, 2010; Steinmetz, 2009; Steinmetz, Seidel, Muche 2010). Alarmingly, research suggests music students do not have a comprehensive knowledge of strategies to address playing-related pain, and professional teachers are often ill equipped to help students when these issues arise, despite desiring to help (Quarrier, 1995; Redmond & Tierman, 2001; Spahn, Richter & Zschocke, 2002; Britsch, 2005). The increasing awareness of the prevalence of PRMDs and their serious impact on musicians has motivated many to seek pedagogical alternatives to the issue of body use in keyboard performance, since traditional approaches to piano pedagogy lack specific strategies to address these issues.

Somatic training methods in piano pedagogy

Somatic training approaches such as the Alexander Technique (Alexander, 1932), Body Mapping (Conable, 2009), and the Feldenkrais Method (Feldenkrais, 1981), seek to help individuals elicit a more refined awareness of the total body helping people replace maladaptive movement habits with ergonomic alternatives, thereby improving quality of life and musculoskeletal health (Spire, 1989; Conable, 1995; Alcantara, 1997; Ginsburg, 1999; Mark, 2003). Depending on the method, practitioners use therapeutic touch, diagrams, verbal directives, exercises, and manipulation of joints to help individuals reconfigure habits of motor-control that mediate posture and movement (Eddy, 2009). Although these methods

each employ their own set of techniques, and embody their own theoretical foundations, they all seek to help individuals move with greater ease by helping them to integrate different parts of the body into habitual movement more effectively.

Interest in somatic training methods increased among musicians in response to the growing concern for body awareness strategies in music pedagogy, and many prestigious music schools and music festivals now incorporate somatic training into their programming. For instance, Tanya Bénard is an Alexander Technique teacher serving on the faculty of the Royal Conservatory of Music in Toronto, where she delivers an Alexander Technique program for musicians she developed in 2006 (The Royal Conservatory of Music, n.d). Similarly, trumpet player Lauren (Lori) Schiff teaches the Alexander Technique to music students at the Juilliard School and the Aspen Music Festival (Schiff, 2014). Somatic training is also at the core of many workshop programs for musicians. For instance, Thomas Mark teaches a six-hour Body Mapping course overviewing the material in his book "What Every Pianist Needs to Know About the Body" in various cities in the United States and Canada (Mark, 2015). A more general Body Mapping course based on the book *What Every Musician Needs to Learn about the Body* is offered by trained Andover Educators all over North America (Andover educators, 2013). Many Feldenkrais practitioners have developed careers specializing in helping instrumentalists. For instance, Aliza Stewart teaches the Feldenkrais method to musicians in seminars and institutes at various music schools, notably the Mannes School of Music and the Julliard School (Stewart, 2015). Similarly, Alan Fraser is a Feldenkrais practitioner, pianist, and author of several piano technique books and instructional DVDs (Fraser, 2003/2010/2011). Fraser regularly offers piano technique workshops in Europe and North America incorporating principles of the Feldenkrais Method into strategies for developing ergonomic piano technique (Fraser, 2012). These examples

illustrate how somatic training methods have been embraced by the music community and are often associated with professional level musical training.

Assessing somatic training outcomes

The following sections review literature from both subjective and objective sources that provide evidence of both physiological and artistic benefits of somatic training for musicians.

Qualitative evidence and testimonials. Musicians tend to speak positively about their somatic training experiences. Practitioner websites are littered with testimonials of people who insist that their playing perceivably improved, or that symptoms of playing-related pain disappeared after participating in somatic training sessions (Goldansky, 2008; Stewart, 2010; Fraser, 2015; Boyd, 2015; Johnson, J., 2015). The earliest academic publications purporting the benefits of somatic training to musicians contained practitioners' accounts of significant improvements in performance quality, or diminishment of playing-related pain symptoms (Rosenthal, 1987; Nelson, 1989; Mayers & Babits, 1989). Although testimonials and practitioner-reported results convey pertinent details about the recovery of individual clients, they do not constitute research-based evidence of somatic training outcomes, and offer little to contextualize the results in terms of expected outcomes in the general population of musicians. Although the theoretical foundations of most somatic methods are based on scientific theories of motor control, neuroplasticity, and motor-learning (Feldenkrais, 1966; Buchanan & Ulrich, 2001; Nichols, 2004; Ginsburg, 2009; Doidge, 2015), the body of scientific research investigating the outcomes of somatic training in both musician and non-musician populations is very small, and ultimately our understanding about the mechanisms behind any positive outcomes from somatic training remains almost exclusively theoretical (Jain, Janssen & DeCelle, 2004).

Scientific research on somatic training outcomes. Most scientific research

conducted on somatic methods to date has focused on assessing the Feldenkrais Method or

the Alexander Technique as therapeutic interventions for musculoskeletal disorders, and

these studies do not seem to point to a strong relationship between somatic training and pain

improvement, although results indicate that participants often feel more empowered to

continue treatment plans that incorporate somatic training compared to more traditional

physiotherapy interventions (Lundblad, Elert & Gerdle, 1999; Kendall, Ekselius, Gerdle,

Sörén & Bengtsson, 2001; Malmgren-Olsson, Armelius, B. & Armelius, K., 2001;

Malmgren-Olsson & Bränholm, 2002; Malmgren-Olsson & Armelius, B. 2003). Studies with

musicians tend to focus on assessing improvements to performance quality, but as of yet, no

conclusive results have been reported. This is due, in part, to methodological challenges of

objectively measuring the quality of a musical performance, and small sample sizes

(Valentine & Williamon, 2003; Schlinger, 2006; Wong 2015). A few individuals have set out

to take an objective look at the impact of somatic training on physical and psychological

experiences of performing musicians. For instance, Mozeiko's (2011) mixed-method study

investigated health and performance outcomes of 51 female violinists assigned to receive

either 12 weeks of Alexander Technique training or no intervention. The researcher used

rating scales and interviews to learn about participants' experiences of pain, body awareness,

executive functioning, and playing experiences before and after the intervention. Results

provided significant evidence for improvement in body awareness for the intervention group,

but no significant improvement in pain symptoms for either group. Another interesting study

used sEMG to detect if differences in the variability of trapezius muscle activation during

violin playing were detectable after participants practiced Body Awareness Therapy, but no

significant results were found (Fjellman-Wiklund, Grip, Andresson, Karlsson, & Sundelin,

2004). More research will be required to gain a better understanding of the physiological,

psychological, and performance outcomes of somatic training for musicians.

Posture as a dependent variable in somatic training research

Few studies have set out to examine the impact of somatic training on externally

visible posture attributes, even though changes to biomechanical functioning and skeletal

organization are primary objectives of somatic training, with somatic practitioners routinely

using visual assessments of posture as an aspect of their teaching (Ginsburg, 2009;

Buchanan, 2001). However, quantitative research on non-musicians has provided some

initial evidence that participation in somatic training can impact postural alignment and

muscle activation. For instance, Kutschke (2010) measured the neck and shoulder postural

alignment, range of motion and muscle activity in healthy people after participating in 20

Alexander Technique sessions over 8 weeks. sEMG measurements from this study indicate

that muscle activity in the neck and shoulder altered after the Alexander training and that

measurements of forward head posture improved significantly for the intervention

participants, especially during sitting and typing. Other studies have found evidence that

patterns in postural muscle recruitment are altered in individuals with Alexander Technique

training (Cacciatore, Horak, & Henry, 2005; Cacciatore, Gurfinkel, Horak, Cordo & Ames,

2011). These studies provide evidence that somatic training could impact motor control

strategies for posture, and further study is warranted.

The two previously mentioned studies on music performance quality of

instrumentalists by Valentine and Williamon (2003) and Wong (2015) both incorporated

rating scales to examine practitioner reported differences in musician posture characteristics

from before and after somatic training interventions. For instance, the study by Valentine and

Williamon (2003) randomly assigned eighteen musician participants (consisting of wind

players, string players, keyboardists, and singers) to receive 30-minute Alexander lessons

once a week for 12 weeks (n=10), or to undergo 10 sessions of neurofeedback training over 6

to 8 weeks (n=8). Music performances were video recorded before and after the training, and

the videos were randomly ordered and assessed by experts external to the college. The

posture of the musicians was rated before and after the interventions using a rating scale

developed by the practitioner conducting the lessons in the study. The scale examined ten

categories of Alexander Technique movement and posture goals, including "head-neck-

back" relationship, and "upper-limb/back." It was found that the Alexander Technique

participants demonstrated improvements in seven out of ten categories of the Alexander

Technique movement and posture goals when compared with the neurofeedback participants.

The clearest improvements in posture were noted in singers. In the study by Wong (2015), 10

pianists were assigned to undergo a fifty-minute Feldenkrais, Body Mapping, or Alexander

Technique lesson. A panel of eight somatic training practitioners rated the body usage of

participants in the video recordings of participant performances of scales, Beethoven's *Für

Elise,* and Schumann's *Wilder Reiter* from before and after the somatic training

interventions. The scale developed by the researcher was a seven-point Likert scale that

required raters to assess the quality of body usage in the head/neck, shoulders, arms, torso,

legs, and feet from "very good usage and coordination" to "severe misusage". Statistically

significant post-somatic improvements were only noted for head and neck usage, although

raters tended to rate body usage as slightly better in post-somatic for the other areas of the

body as well. These studies are important because they are the first examples of scientific

evidence that somatic training can impact playing posture in musicians. However, research

has called into question the validity of visual assessment scales as tools for reliably

measuring posture in scientific research (Fedorak, Ashworth, Marshall, and Paul, 2003;

Aitken, 2008; Silva, Punt, & Johnson, 2010), illustrating a need for more objective measurement tools in posture research. As of yet, no studies with musicians have used objective measurement tools to quantitatively measure visible attributes of posture and movement from before and after somatic training.

Motion tracking tools for measuring posture quantitatively

Feldenkrais himself maintained that it would be useful to measure posture quantitatively to learn about characteristics of upright stanceshould it become technologically feasible to take measurements of body alignment accurately (Feldenkrais, 1966). In general Feldenkrais adhered firmly to the tenet that posture should not be thought of as a static position but a dynamic process by which the brain solves problems of balance and movement as an individual moves through their environment. However, in the twelfth chapter of *Body and Mature Behaviour* (1966) entitled *"Measuring" Posture,* he writes the following in regards to the value of quantitative posture measurement:

> I am quite aware that in practice, these methods are not more than an
>
> indication. It is important, however, that it is possible to obtain some sort
>
> of measurement, even though indirect, of what is usually considered
>
> unfathomable. I have little doubt that with the accumulation of extensive
>
> data…very useful information would be obtained. (p.107)

Developments in motion tracking technology have made these types of objective measurement of body positioning possible, providing researchers with tools that could help them investigate changes to posture and movement of pianists as a result of somatic training. Currently, 3D optical-based systems that require the use of reflective markers fixed to points of interest on participants' bodies are the most reliable tracking method for quantitative analysis of human movement. This type of technology has a high resolution for the capture

of fast, small movement, and has even been used to track the hands, wrists, and fingers of

performing pianists (Sugawara, 1999; Holmquist, 2002; Furuya, Altenmüller, Katayose, &

Kinoshita; Sakai & Shimawaki, 2010; Furuya, Flanders, & Soechting, 2011; Oikawa,

Tsubota, Chikenji, Chin, & Aoki, 2011). Although such systems are precise, data preparation

and analysis is time-consuming. Furthermore, the equipment is not highly portable, and data

collection is usually restricted to laboratories, making it difficult to use in live performance

situations. Ideally performance researchers would require a tool that could offer the accurate

and reliable tracking of 3D optical systems with greater portability and more efficient data

processing procedures.

Video-based tracking software, such as Dartfish (http://www.dartfish.com/), could

offer a simpler alternative to 3D optical based systems that could be used unobtrusively in

performance settings. Dartfish was originally developed as a performance analysis and visual

feedback tool for professional coaches, trainers, and athletes. Advanced versions of this

software include an object-tracking feature that can follow pixels of a selected colour as a

video plays (Beacon, 2015a). Researchers have used this feature to quantitatively measure

posture for a variety of different purposes, including the assessment of sitting posture of

subjects with postural backache (Womersley & May, 2006), the assessment of a sit-and-

reach test for hamstring flexibility (Mier, 2011), the influence of neck pain on neck flexion

during a reaching task (Constand & MacDermid, 2013), the thoracic posture of rugby players

(Bolton, Moss, Sparks, & Venter, 2013), standing posture in asthmatics after diaphragmatic

and aerobic breathing training (Shaw, B., & Shaw, I., 2011), and comparing the impact of

strength and stretch interventions in range of motion in dancers (Wyon, Smith & Koutedakis,

2013). Dartfish has also been used in a few applications with musicians. For instance, the

program's slow motion and multi-video playback features are an important component of

Riley's multi-modal feedback system used to teach students more efficient ways to move their hands (Riley, Coons, Marcarian, 2005; Riley, 2009/2010/2011). The Dartfish semi-automatic tracking function has also been used to track the bow movements of violinists in order to compare the bow trajectories of student and professional violinists (Deutsch, 2011). More pertinently, the Dartfish angle and distance measuring tools have been used to analyze the posture of a singer by measuring variables in still frames taken from videos in order to measure the impact of physiotherapy on posture (Staes, Jansen, Vilette, Coveliers, Daniels & Decoster, 2006). To date, the object tracking function of Dartfish has not yet been used to export coordinates from continuous motion tracking data to analyze posture and movement habits during live music performances. This feature could make Dartfish a simple, performance-friendly alternative to 3D optical based systems that could allow researchers to objectively measure the posture and movement of pianists throughout performances to assess somatic training outcomes. Although Dartfish would only elicit 2D tracking results, posture variables that vary primarily in one plane of motion, such as the angle of inclination of the torso or head, could be measured successfully in two dimensions.

Measuring posture with Dartfish

To track human movement with Dartfish, researchers must clearly mark anatomical points of interest on participants' bodies so that the software can identify the pixel colour of the object to be tracked. Studies have confirmed fair to high inter- and intra-rater reliability for procedures measuring posture from still video frames using Dartfish to track anatomical markers (van Niekerk, Louw, Vaughan, Grimmer-Sommers, & Schreve, 2008; Grimmer-Sommers, Milanese, & Louw, 2008; Perry, Smith, Straker, Coleman, & O'Sullivan, 2008; Ferreira, Duarte, Maldonado, Burke, & Marques, 2010). It has also been demonstrated that postural measurements made from external markers in photographs using video-based

software like Dartfish correlate well with measurements taken from radiographs of the

skeleton (van Niekerk et al., 2008). Eltoukhy and colleagues compared Dartfish tracking

results of a simple squatting movement with data simultaneously acquired with the highly

reliable Vicon 3D tracking system and found that the difference between tracked objects'

trajectories was about +/- 5 mm between the two systems, with magnitudes of differences in

marker position ranging from -10 to +20 mm depending on the anatomical marker and the

axis of movement examined (Eltoukhy, Asfour, Craig, & Thompson, 2012). We conducted

our own pilot test for accuracy and reliability of Dartfish tracking results and found that error

between different measurers was within 5 millimeters, and that distances measured with

Dartfish are accurate to within 4 millimeters using standard, CMOS (complementary metal-

oxide semi-conductor) video cameras (Beacon, 2015a) The total analytic error for distances

measurements taken from Dartfish tracking data is estimated to be 5 millimeters (+/-2.5

millimeters).

Using Dartfish to measure posture during piano performance

       Choosing appropriate posture variables. Researchers desiring to measure the

posture of pianists quantitatively must choose which parts of the body will be measured.

Since somatic practitioners frequently seek to improve posture alignment of points of balance

in the head, shoulders, and spine (Alexander, 1932; Feldenkrais, 1966; Feldenkrais, 1981;

Mayers & Babits, 1987; Monette Corporation, 2015), and since poor postural alignment in

these parts of the body is frequently cited as a factor in the development of PRMDs, (Cailliet,

1980; Dommerholt, 2010), researchers could look to these areas of the body first in initial

investigations on somatic training with pianists. Traditionally, vertical alignment in these

parts of the body have been assessed against plumb lines that can be drawn through points of

balance to check if important structural joints are vertically arranged in such a way that the

body can balance freely. This principle is frequently used in chiropractic, physical therapy, and somatic training assessments, and has been used as a criterion for assessing posture quality in resting positions in research (Krasnow, Chatfield, Barr, Jensen, & Dufek, 1997; Kendall, McCreary, Provance, Rodgers & Romani, 2005). However, the usefulness of straight plumb lines as a diagnostic criteria for posture has been questioned, and evidence shows that the points of balance at the ear, shoulder, hip, knee, and ankle are not generally arranged in a straight vertical line in standing positions (Woodhull, Maltrud, & Mello, 1985; Woodhall-McNeal, Clarkson, James, Watkins, & Barrett, 1990). Postural symmetry in the right and left sides of the body in the anterior and posterior views has also been used as a standard representing postural health for diagnostic purposes, however research has demonstrated that asymmetry in the resting positions of the pelvis, shoulder and trunk is normally observed in healthy individuals, which raises questions about the use of symmetry as a baseline criterion for good posture in research applications (Ferreira et al., 2011). Researchers should therefore interpret posture data comparing variables to straight plumb lines, or lines of symmetry with care, and consider alternative forms of posture measurement and assessment.

      Strategies for measuring head, shoulder, and spine position. Researchers have devised different approaches to measure head, shoulder, and spine positioning. For example, forward head position is frequently measured as the angle formed between a line passing from the C7 vertebra through the ear tragus, and a horizontal line passing through C7 in the sagittal plane, while an individual is sitting or standing. Similarly, the angle formed between a horizontal line passing through the ear tragus, and the line connecting the ear tragus and the outer canthus of the eye has been used to assess the angle of the head at the atlas occipital joint. Shoulder position is occasionally determined by measuring the horizontal and vertical

displacement of a point on the shoulder in relation to the C7 joint to measure whether the shoulders are elevated or rest substantially forward from the body (Szeto, Straker & Raine, 2002). Other researchers have measured the angle between the line connecting a point on the shoulder and the C7 vertebra, and a horizontal line extending forward from the shoulder in the sagittal plane to represent the degree of forward shoulder posture (Raine & Twomey, 1997). Methods for measuring spine curvature vary widely from study to study, with different studies using different vertebrae as landmarks (Bernhardt & Bridwell, 1989; Harrison, Janik, Troyanovich & Holland, 1996). Also, some studies repor results based on measurements from internal radiographic images while others report results from measurements taken from photographs of externally placed landmarks (Leroux, Zabjek, Simard, Badeaux, Coillard & Rivard, 2000). These examples demonstrate that measurement procedures for posture of the head, shoulders, and spine have not been standardized, making it difficult to compare results across different studies examining similar postures.

Since the definition of posture variables and their corresponding measurement protocol have not been standardized, researchers interested in measuring the impact of somatic training on pianists' posture must design their own posture measurement protocols according to their own needs and expertise. The posture measurements of forward head positions, shoulder position, and the C7, T4, T8, T12, and L5 vertebrae showed good consistency over a week of measurements in standing and sitting of eleven men in the study of Pownall, Moran & Stewart, (2008). Their choice of anatomical marker placement and measurement protocol is comprehensive, and may prove adequate to examine similar variables in pianists' posture using Dartfish tracking. Their protocol involves placing anatomical markers next to the eye (eye canthus), on the ear (ear tragus) and the C7 vertebra at the top of the spine, allowing researchers to measure the position of the head and shoulders

in relation to the C7 vertebra, which is clearly visible on the body, and easy to mark. Choosing to track the C7, T4, T8, T12, and L5 vertebrae as they did in this study allows for points in the cervical, thoracic, and lumbar spine to be tracked, giving researchers a good overview of the spine (Pownall et al., 2008). Quantification of these points would allow for spine angles to be calculated between the points or for the vertical distance of the vertebrae to be compared in pre and post-intervention videos for evidence of change in spinal position.

Research questions

In this study we use a marker-based procedure similar to that of Pownall and colleagues (2008) to measure pianist posture using Dartfish automatic tracking. We are interested in evaluating the Dartfish Pro Suite 2D motion tracking software's suitability as a tool to address the need for more objective measurement approaches in somatic training research with musicians and discovering if a single Feldenkrais Functional Integration (FI) lesson will measurably impact posture and movement habits of performing pianists. In this exploratory study we seek to answer the following questions:

1. Will our experimental set-up allow for posture measurements to be taken accurately and reliably across testing sessions with live pianists using Dartfish tracking?

2. Are trends in posture change noted across the group of participants after a single FI lesson?

3. Are significant posture changes evident for any particular participants after a single FI lesson?

Based on existing research, we present the following hypotheses:

1. Research has demonstrated that Dartfish is a convenient method for 2D posture measurement when measured manually from individual video frames (Staes, et al., 2006; van Niekerk et al., 2008; Pownell et al., 2008), and our reliability testing

(Beacon, 2015a) indicated that Dartfish tracking results are repeatable and accurate using our data collection protocol for tracking balls on a fixed rail. We hypothesize that the usability and accuracy found will extend to situations with live pianists.

2. We hypothesize that no trends to posture change will be noted in the group after one Feldenkrais FI lesson due to the variability of posture between different individuals, and the natural variability of an individual's posture from day to day (Dunk, Chung, Compton & Callaghan, 2004; Dunk, Lalonde & Callaghan, 2005; Grimmer-Sommers et al., 2008).

3. We hypothesize that specific change to some posture variables might be noted for some individuals, since somatic practitioners and their students often report differences in alignment or movement quality after minimal exposure to the method (Fox & Korentayer, 1980; Mayers & Babits, 1989; Stewart, 2010 b; Stewart, 2010; Vardi, 2015; Boyd, 2015).

METHODOLOGY

Design

This repeated measures study aims to investigate the suitability of Dartfish software as a quantitative measuring tool for examining the posture of pianists from before and after somatic training interventions. Dartfish motion tracking software is used to measure posture variables of the head, shoulders, and spine in videos of piano performances recorded before and after the pianists received a 30-minute Feldenkrais Functional Integration (FI) lesson.

Participants

Pianists. Sixteen pianists (12 female, 4 male) responded to advertisements administered through the Ontario Registered Music Teachers' Association (see appendix A). The age of participants varied between 14 and 55 years, with a mean age of 27. All had

achieved a minimum playing level of Grade 10 in the Royal Conservatory of Music. None of

the participants had previous experience with the Feldenkrais method, but four had minimal

past exposure to Alexander Technique. We informed participants were informed that the

study sought to investigate the influence of Feldenkrais FI lessons on pianists without

specifically mentioning that we were interested in movement or posture.

   Playing requirements. As discussed in the literature review, research has shown that

posture recruitment strategies can be influenced by the cognitive demands of competing tasks

(Lajoie, Teasdale, Bard & Fleury, 1993; Andersson, Hagman, Talianzadeh, Svedberg &

Larsen, 2001; Pellecchia, 2003). Since different playing activities involve different types of

cognitive processing, we were interested in measuring posture in different playing

conditions. We asked participants to perform the following three playing tests in the given

order:

a. C major contrary-motion scale in sixteenth notes (quarter note=80 bpm), beginning

  on middle C and extending the full range of the piano, repeated 4 times

b. The 'A' section of *Für Elise* by Beethoven (measures 1-22), with repeats, from

  memory

c. An eight-bar sight-reading piece of approximately a grade 2 RCM level in the style of

  a Gavotte.

We informed participants of the playing tasks a minimum of two weeks in advance, and we

asked them to rehearse the C major scale at the required tempo and to prepare *Für Elise* from

memory. We permitted the participants to examine the sightreading pieces without playing

for up to a minute before performance. The score we used for *Für Elise* is available from

IMSLP Petrucci Public Domain Music Library (Faiman, 2003). We chose the first and

second sight-reading examples from page four and eight respectively of the grade four sight-

reading preparation material from the syllabus of the Associated Board of the Royal Schools of Music (Johnson, T., 2001).

Set-up

        Anatomical markers. We placed anatomical markers onto participants' bodies according to the protocol of Pownall et. al (2008) as illustrated below in figure 1. The markers were large green circles with a smaller red circle inside to maximize visibility of the marker on the skin. We provided participants with sleeveless black sports tops to ensure markers did not become occluded by loose clothing. We cut round stickers approximately two-centimeters in diameter from reflective kinesiology tape to create the markers for the arms and face. We fixed strong, flat magnets of a five-millimeter diameter to the C7, T4, T8, and T12 vertebrae of each participant using medical tape. We mounted white, polystyrene balls to magnetic bases of one-centimeter long, allowing them to be attached over top of the clothing and remain securely positioned over the appropriate vertebrae. This magnet system allowed us to remove the spinal markers for the FI lessons of participants, and subsequently reposition the markers in identical anatomical positions for the second session of testing. A medical student positioned all anatomical markers to ensure they were placed accurately and consistently.
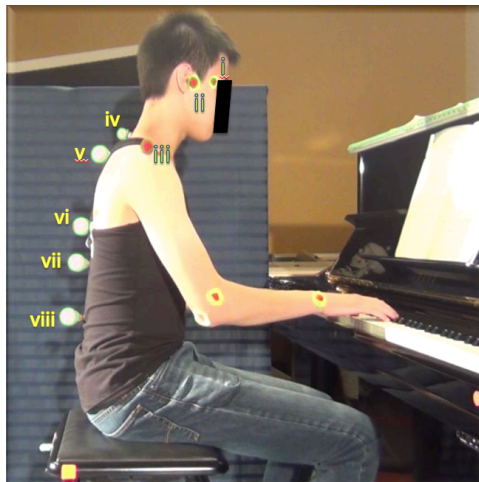
Figure 1. Placement of anatomical markers for Dartfish tracking (i) canthus (outer corner) of the right eye; (ii) ear tragus; (iii) anterior acromioclavicular joint (shoulder); (iv) C7 spinous process;(v, vi, vii, viii)- T4, T8, T12, and L5 spinous processes.

Experimental set-up. We recorded video data with two Sony HD HandyCams, (HDR-XR260V, 8.9 megapixels) set to record at a frame rate of 60i, (capturing 30 frames per second). We mounted them on Manfrotto tripods and positioned the lens perpendiculary to the participant's right shoulder for the sagittal view, and perpendicularly to the participant's back for the posterior view. We mounted a dark coloured curtain behind the performers to maximize contrast with the white-spherical markers placed on the spine and positioned1000-watt spotlights perpendicular to participants approximately four meters away to ensure marker visibility. We adjusted the heights of the video cameras on the tripods individually for each participant and recorded and retained the height of the cameras and their distance from the piano for each participant. We also recorded the participants' preferred piano-bench height and the distance of the piano bench so that the positions could be retained for each testing session. Pianists performed the playing tests on a Yamaha upright piano.

4.3 Procedure

We obtained ethics approval from the University of Ottawa prior to data collection, and all participants signed consent forms (see appendix B). We completed testing at the University of Ottawa Piano Pedagogy Research Laboratory. Once all anatomical markers were positioned and the heights of the cameras and piano bench had been recorded, we asked participants to perform the three playing tests while being video recorded in the sagittal and anterior views. Following the pre-test performance, we removed the spherical magnetic markers from the spine while the flat magnets beneath the clothing and the Kino-tape markers remained in their original positions. We then escorted participants to an adjoining room where they immediately received a 30-minute FI lesson from Alan Fraser, which was video recorded for reference. Mr. Fraser is the author of *The Craft of Piano Playing* (2003, 2nd Edition 2011, also in DVD), *Honing the Pianistic Self-Image* (2010) and *All Thumbs: Well-Coordinated Piano Technique* (2012). He is also a professor of piano at The University of Novi Sad, Serbia and a certified Feldenkrais practitioner who has been teaching for 24 years. Although each FI lesson was unique based on the participant's specific needs, each involved similar body movements focusing on the neck and upper back conducted while participants lay on their sides and backs. We repositioned the spinal markers over the magnets after the FI lesson and rerecorded the playing tests in the same manner as the previous session.

Measurement

Dartfish tracking procedure. We cropped the videos of playing test performances so that each video clip began with the first note of the performance and ended when the performers placed their hands back on their lap. We then imported the shortened video clips into the Dartfish software. Trained software users generated 2D coordinate positions of the

anatomical markers in the videos were using the object tracking and data extraction features of the Dartfish TeamPro software, version 7.0. They tracked all markers at a "medium speed" setting, which searches 10% of the video for identically coloured pixels. The measurers in this study ensured that the markers remained centered over the objects in the video by using the scrolling, zoom, and slow-motion playback functions to prevent the marker from slipping or jumping from its target.

The measurers set a reference distance and a point of origin on the video frame to allow the system to generate the coordinates for the tracked markers. For sagittal view videos, they recorded the width of the bench next to the person's right leg as a reference distance. For anterior view videos, they marked the length of the bench as a reference distance. They marked the origin as the apex of the green tab on the back of the piano bench for all sagittal view videos and the centre of the buttocks at the point where it meets the seat for anterior view videos. Measurers exported x and y coordinates of tracked markers by linking the tracked objects to columns in the data table tool and exporting the automatically generated coordinates to Excel.

Posture variables. We chose to measure the variables in table 1 to examine if spine, shoulder, and head positioned altered measurably from pre-test to post test sessions.

Table 1
Description of measurement of posture variables for Dartfish tracking

Variable	Description of measurement	Justification for measurement
Head region		
(i) forward head angle (°)	Angle formed between a horizontal line passing through the C7 spinous process and a line connecting the C7 process to the ear tragus	Found to be a good indicator of forward head position (Raine &Twomey, 1997; Pownall et al., 2008; Ruivo, et al., 2014). A smaller cervical angle has been associated with increased forward head position and neck pain in computer users (Szeto et al., 2002).
(ii) head height (cm)	Height of the ear-tragus marker above the origin of the Cartesian coordinate system	Not previously found in literature. A simple way to determine if a person is sitting more or less erectly overall between testing sessions.
Shoulder region		
(iii) shoulder protraction angle (°)	Angle formed between a line connecting a point on the shoulder and the C7 vertebra and a horizontal line extending forward from the shoulder in the sagittal plane	Gives information about the degree of protraction (forward rounding) in the shoulders (Raine & Twomey, 1997). Measured here according to the procedure of van Niekerk et al. (2008).
(iv) vertical and horizontal shoulder displacement (cm)	Difference between the *y*-axis value of C7 and the right shoulder	A mode of measurement used by Szeto et al., (2002) to investigate shoulder elevation and shoulder protraction separately.
Spine region		
(v) origin-C7 angle (°)	Angle formed between the *x*-axis and a line joining C7 to the origin of the coordinate system at the back of the piano bench	Not previously found in literature. Used here to represent the angle of forward inclination of participants as they play.
(vi) T4 angle (°)	Angle formed between the C7, T4, and T8 vertebral markers	Used in Pownall et al., 2008. Gives an indication of curvature in the upper thoracic region of the spine.
(vii) T8 angle (°)	Angle formed between the T4, T8, and T12 vertebral markers	Used in Pownall et al., 2008. Gives an indication of curvature in the lower thoracic region of the spine.
(viii) T12 angle (°)	Angle formed between the T8, T12, and L5 vertebral markers	Used in Pownall et al., 2008.Gives an indication of the curvature in the lower thoracic/upper lumbar regions of the spine.
(ix) height of vertebral markers (cm)	Height of spine markers (C7, T4, T8, T12, L5) above the origin of the Cartesian coordinate system	Not previously found in literature. Used here to give information about changes in vertical positioning in certain regions of the spine.

Analysis

Comparing posture variables. We calculated the mean value of each posture

variable from tracking data collected every three video frames for each playing test. We

subtracted average values from the pre-test from those in the post-test in order to determine if

there were any differences in the average values between the pre- and post-somatic recording

sessions.

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Examination of time-plots. We plotted the posture variables measurements against time in Microsoft Excel to get a visual representation of how the movement of various parts of the body progressed or varied across a performance. We qualitatively compared pre and post-test time plots individually in order to assess if any significant differences in movement patterns were visible for any posture variables. We looked for significant differences in range, pattern, or smoothness of movement, and made note of time plots that had very different characteristics in pre and post-test tracking sessions for a given body position. This type of data analysis was used in a previous study that plotted coordinates of violin bow positions generated from Dartfish to gain information about the characteristics of bowing patterns in professional and amateur violinists (Deutsch, 2011).

RESULTS

Suitability of Dartfish for measuring posture variables of pianists over multiple sessions

This section addresses the first research question, which investigates if our marker-based experimental set-up allows for posture measurements to be taken accurately and reliably across testing sessions with live pianists using Dartfish tracking. Our previous research study demonstrated that Dartfish tracking is accurate and reliable to about +/-0.25 cm and that the tracking procedure is easily learned by novice software users (Beacon, 2015a). However, these results were conducted using balls mounted on a sliding rail, and we were interested to comment on the functionality of the experimental set-up required for use with live pianists wearing anatomical markers. As hypothesized, our experimental set-up was found to be highly functional for taking posture measurements over multiple sessions using Dartfish tracking. The round Kinotape markers and spine magnets stayed securely in place during the FI lessons, ensuring that the markers were positioned identically in the pre and post-test recording sessions. Marking and retaining the bench height, bench position, and

camera heights allowed us to retain the positioning of the pianists in respect to the camera

between sessions. As long as care is taken to maintain camera and bench positions between

recordings, posture measurements can be confidently compared across testing sessions. The

marker size and colour were highly visible in the videos, allowing the software users to

clearly position Dartfish tracking markers in the videos. The measurers in this study ensured

that the markers remained centered over the objects in the video throughout tracking by using

the frame-by-frame scrolling, zoom, and slow-motion playback functions to keep the marker

precisely in position. Dartfish appears to be an effective tool that can be operated

straightforwardly by researchers to quantitatively measure the body positioning of pianists

during live performances.

Comparing group averages of posture variables

This section presents results that answer the second research question investigating

group trends in posture change after a single FI session. Table 1 and 2 present the cross-

participant average measurements of the distance and angular posture variables from before

and after the FI intervention in all three playing conditions.

Table 2
Cross-participant average measurements of angular posture variables from before and after FI intervention three playing conditions (°)

Variable	Playing condition	Pre-test	Post-test	Difference
Forward head angle (°)	Scale	31.3	31.7	0.4
	Für Elise	29.9	30.6	0.7
	Sight-reading	32.2	32.4	0.2
Shoulder protraction angle (°)	Scale	43.5	43.6	0.1
	Für Elise	49.6	49.4	-0.2
	Sight-reading	38.8	33.7	-5.1
T4 angle (°)	Scale	150.7	151.2	0.5
	Für Elise	150.8	151.2	0.4
	Sight-reading	150.8	150.9	0.1
T8 angle (°)	Scale	166.1	166.2	0.1
	Für Elise	166.0	166.4	0.4
	Sight-reading	166.0	166.2	0.2
T12 angle (°)	Scale	182.2	181.9	-0.3
	Für Elise	181.7	180.9	-0.8
	Sight-reading	182.7	180.7	-2.0

Notes. An increase in forward head angle means the head has moved backward into a more erect position. A decrease in shoulder protraction angle means the shoulders are moving forward, becoming more rounded.

Table 3

Cross-participant average measurements of distance posture variables from before and after FI intervention three playing conditions (cm)

Variable	Playing condition	Pre-test	Post-test	Difference
Head height (cm)	Scale	73.9	74.2	0.3
	Für Elise	74.1	74.5	0.4
	Sight-reading	73.9	73.5	-0.4
C7 height (cm)	Scale	65.4	65.7	0.3
	Für Elise	65.6	65.8	0.2
	Sight-reading	65.4	65.0	-0.4
T4 height (cm)	Scale	59.6	59.9	0.3
	Für Elise	59.7	59.9	0.2
	Sight-reading	59.3	59.2	-0.1
T8 height (cm)	Scale	47.3	47.6	0.3
	Für Elise	47.3	47.6	0.3
	Sight-reading	47.0	47.2	0.2
T12 height (cm)	Scale	37.0	37.4	0.4
	Für Elise	37.0	37.2	0.2
	Sight-reading	36.7	37.0	0.3
L5 height (cm)	Scale	26.9	27.5	0.6
	Für Elise	26.9	27.0	0.1
	Sight-reading	26.9	26.8	-0.1
Horizontal shoulder displacement (cm)	Scale	5.2	5.1	-0.1
	Für Elise	4.9	5.0	0.1
	Sight-reading	5.8	6.1	0.6
Vertical shoulder displacement (cm)	Scale	4.2	4.0	-0.2
	Für Elise	4.0	3.9	-0.1
	Sight-reading	3.6	3.4	-0.2

Cross-participant averages remain stable between pre and post-test sessions for almost all variables, suggesting there were no group trends as a result of the FI intervention, as hypothesized in response to our second research question. The group averages for spine angles were particularly stable between sessions and across playing conditions, with average differences of less than one degree for all variables except for the shoulder protraction and T12 angle in the scale condition. The average forward head angle increased slightly across all three playing conditions, which could suggest a tendency for slightly more erect head position in post-test sessions. However, angle measurements of less than two degrees are considered below the threshold of measurement error according to our reliability testing (Beacon, 2015a), and since baseline measurements of spine angles have been found to vary significantly for individuals when taken over different days, (Dunk et al., 2004), it is possible

that most of the differences in spine angles observed in this study could be attributed to natural posture variability. Therefore, changes of the magnitude observed in our study cannot be attributed to FI with any certainty. There was no average overall change in a distance posture variable of greater magnitude than +/-0.4 cm, except for the horizontal shoulder displacement in the sight-reading condition and the height of the L5 marker in the scale condition, which both increased by an average 0.6 cm in session two. A possible explanation for the greater degree of shoulder protraction in the sight-reading post-test is that participants may have had to extend their arm further forward to reach the shorter black keys in the post-test sight-reading piece that was in D major compared to the pre-test sight-reading piece in C major, (which required no black keys to be played). The group average height of all spine markers increased marginally from session one to session two for both *Für Elise* and scales, suggesting a trend toward slightly elevated spine posture in session two for these two playing conditions. In contrast, the group average for the height of the head, C7, T4, and L5 marker decreased slightly for the sight-reading condition, raising questions about tendencies for pianists to adopt different postural strategies depending on playing condition. However, since changes smaller than 0.4 cm are considered below the threshold of measurement error based on our reliability testing (Beacon, 2015a), the significance of this observation is questionable, and further testing would be required to search for trends in elevated or lowered spine conditions in various playing conditions.

Table 4 presents the average group change for the height of the spine and head markers in magnitude only, irrespective of the direction of change. It illustrates that the average vertical position of most of the tracked markers was at least 0.5 cm different for all variables, whether that change reflected a higher or lower post-test position. Therefore, when

the results are examined for magnitude of change only, an average degree of change in a

measurable range is observed over the group.

Table 4
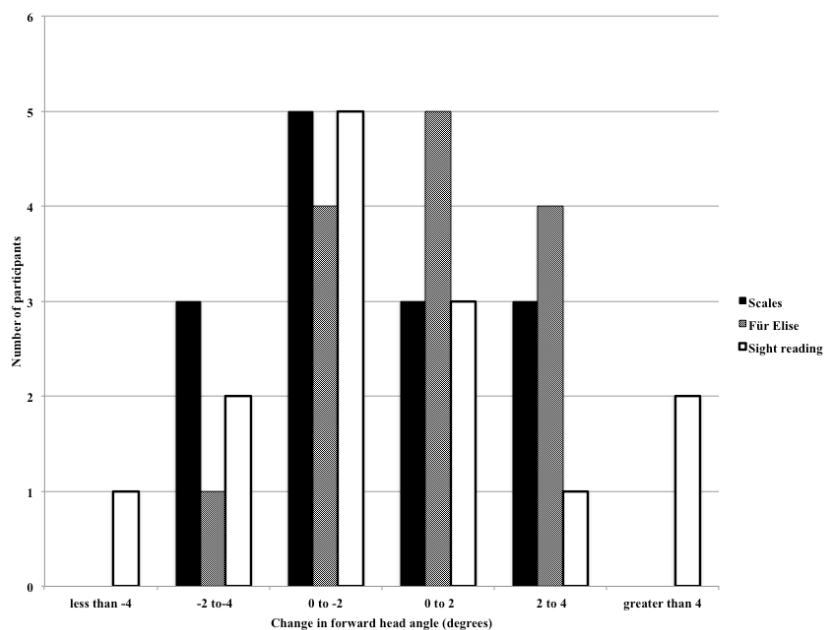*Average magnitude of change for spine and head height variables*

Playing condition	Change in marker height (cm)					
	Ear-tragus	C7	T4	T8	T12	L5
Für Elise	0.6	0.4	0.6	0.9	0.5	1.0
Scales	0.5	0.5	0.7	0.6	0.6	1.0
Sight reading	0.8	0.6	0.6	0.7	0.4	0.9

Note. All height data is in relation to the point of origin of the coordinate system, which was set to a point marked clearly on the back of the piano bench.

However, it is likely that these changes could be attributed to the natural variability in

participant posture, since particular variables were not found to increase or decrease either

across the group, or for a given participant. For example, figure 1 displays the distribution of

changes in the degree of forward head angle across the various playing conditions. It shows

that the degree of change was within the range of +/- 2 degrees for most people, which is

below the threshold for measurement error for angles using our Dartfish procedure. Out of a

total of 42 tests, 10 resulted in an increase of the forward head angle by greater than 2

degrees, while seven resulted in a decrease in forward head angle of greater than 2 degrees.

The similar distribution of measurable positive and negative post-test differences cancel each

other out in group averages, and it is difficult for researchers to make conclusions about

whether or not desirable changes have taken place, since it is often not possible to define

whether or not an increase or decrease in a particular variable should be considered

beneficial for an individual, or for a group.

Figure 1. Distribution of change in average angle of forward head position across three playing conditions.

Also, the direction and magnitude of change for a given variable are often different depending on the testing conditions for a given participant. For instance, figure 2 clearly shows that most participants did not exhibit a similar direction or magnitude of change in shoulder protraction angle over all three playing tests. We do not currently have criteria for defining whether or not their position was desirable to start with, and therefore cannot comment as to whether or not any potential changes viewed in the post-test should be considered improvements.
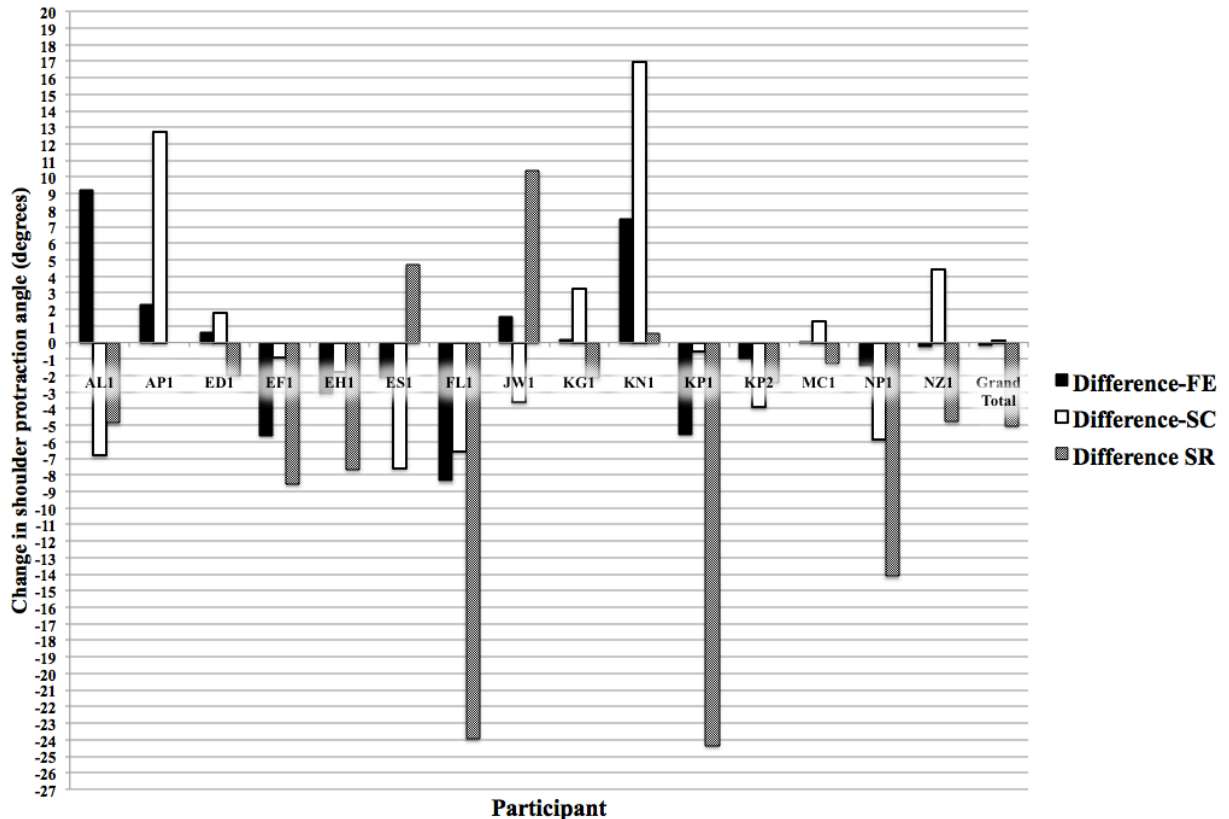
Figure 2. Change in shoulder protraction angle for individual participants in various playing conditions from pre-test to post-test. There is no data for the SR test for participant AP1 because the shoulder marker obscured the C7 marker in the session 2 recording.

Results of individual participants

This section presents results which answer the third research question, which asks if significant changes in posture variables or movement patterns were noted for any individual participants. To answer this question we examined time-plots of posture variables of individual participants throughout the duration of their first and second sessions performing each playing test. Most often, time-plots from both the pre and post-test recordings display similar movement patterns for a given participant, often containing even small details of torso movement at the exact same musical points in the phrases. For example, the pre and post-test time plots of participant EF1's performance of *Für Elise* in figure 3 are very similar.
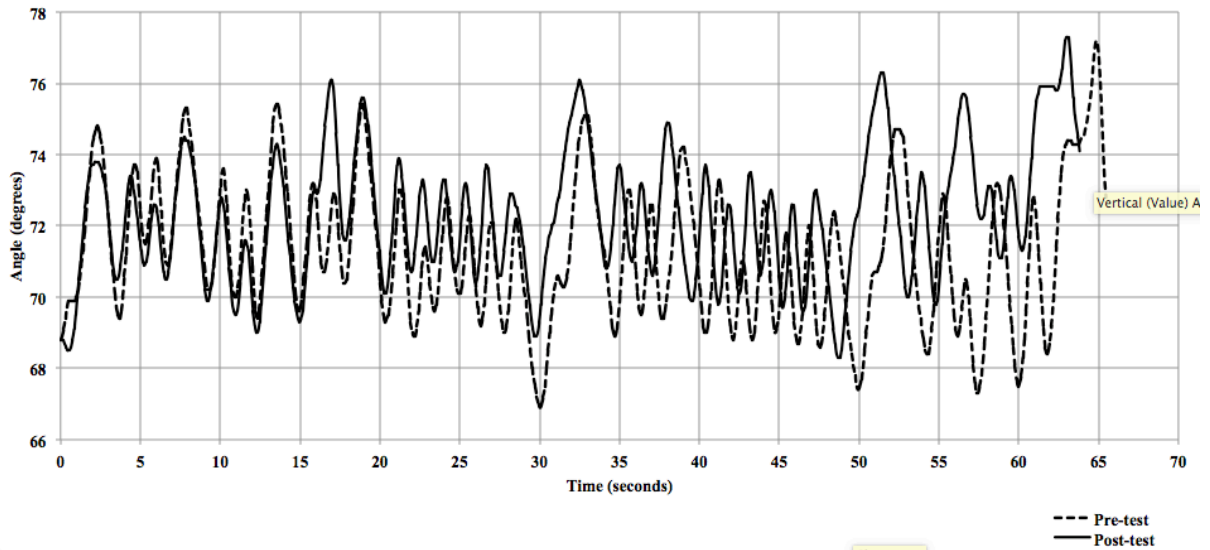
Figure 3. Pre- and post-test time plots of the angle between a line connecting the C7 marker and the point of origin on the bench, and the *x*-axis for participant EF1.

However, analysis revealed that the time-plots for some individuals showed different movement patterns in pre and post-test recording sessions. For example, figure 4 illustrates that in the pre-test, participant KP2 kept her head almost perfectly still. Her pre-test head movement appears jerky, with a limited range of only about 3 degrees. In the post-test, the participant's head appears to have moved in a smoother, wavelike pattern compared to the pre-test, and the range of motion increased to about 10 degrees. It is interesting to note that this difference in pre and post-test head movement patterns was observed in both the scale and *Für Elise* performances, but not the sight-reading condition.
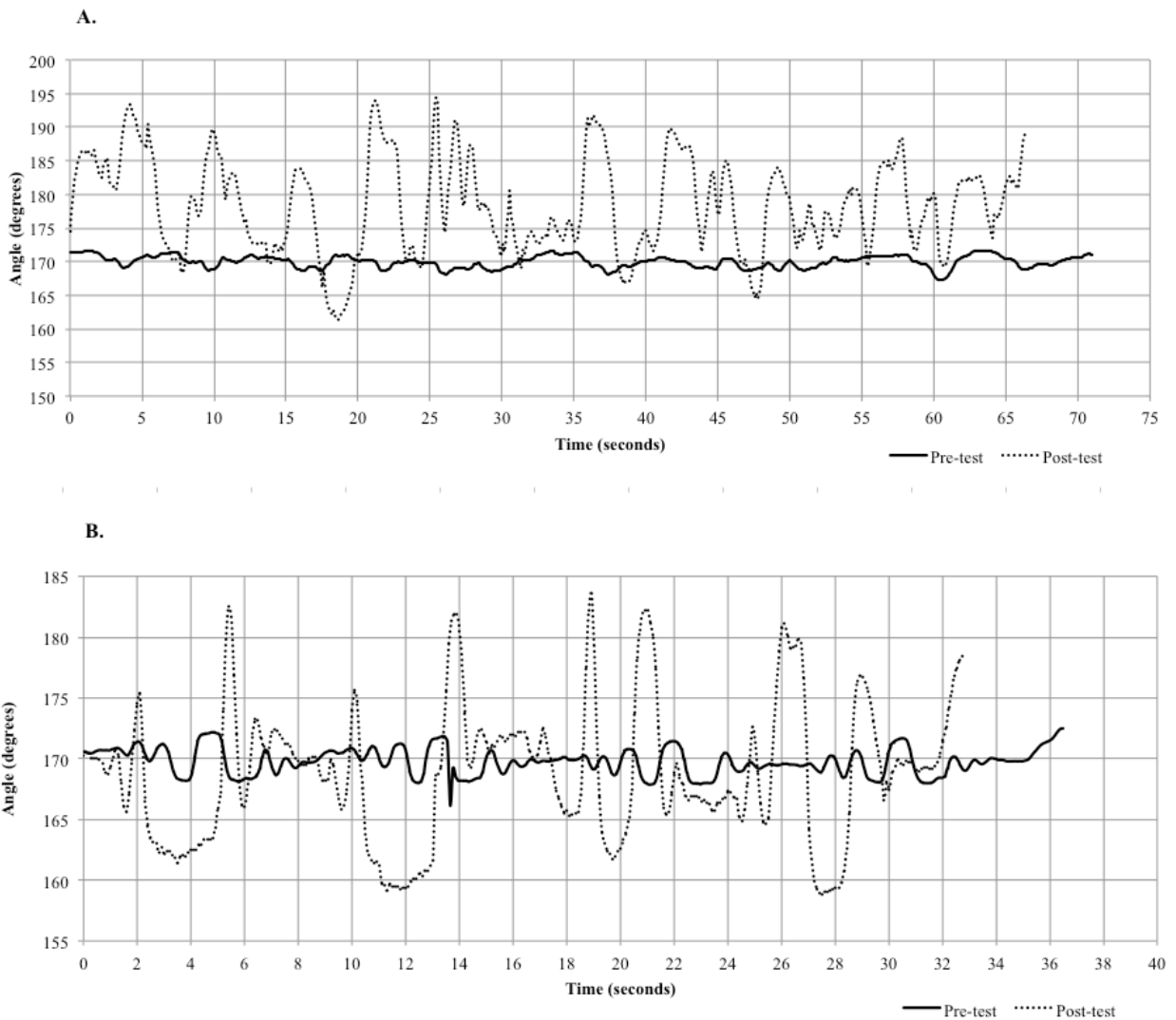
Figure 4. Pre and post-test time-plots of the angle formed between the horizontal plane and a line connecting the C7 vertebral marker and the eye-tragus marker for participant KP2 during (A) *Für Elise* and (B) scale performances.

Another example is presented in figure 5, which illustrates a increased range and apparent smoothness of movement of the torso of participant AL1 in the post-test compared to the pre-test performance of scales. This example is interesting because it clearly illustrates a consistent movement pattern throughout the three scale repetitions that integrates corresponding movements in the head, neck, and lower back. The post-test movement only appeared more integrated throughout the torso for the scale condition.
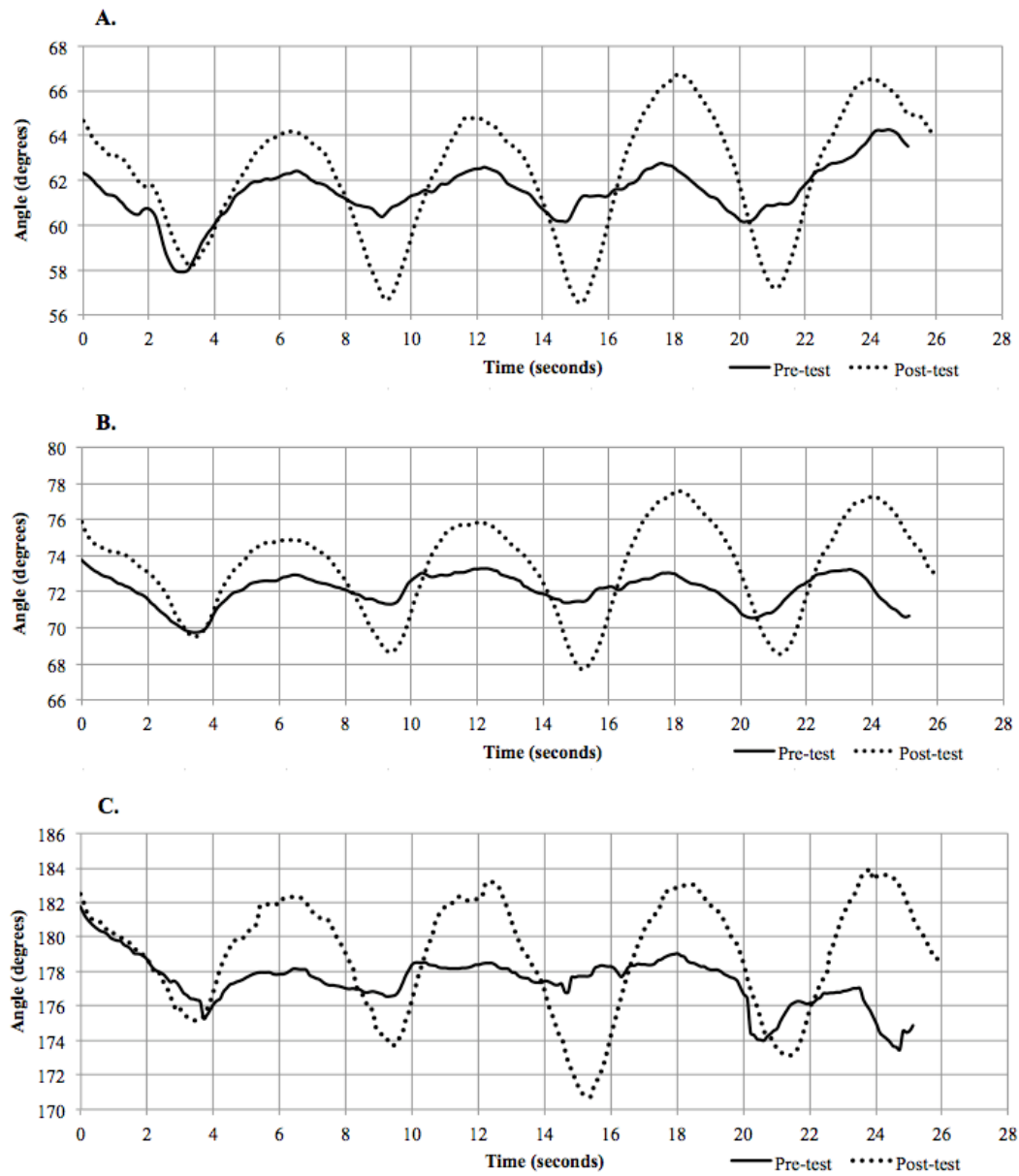
Figure 5. Pre and post-test time plots of (A) eye-tragus, C7, horizontal angle, (B) C7 marker, horizontal angle, and (C) T12, L5, vertical angle for participant AL1's performance of scales.

DISCUSSION

Research question 1: Suitability of marker-based system for comparing posture measurements of pianists across different testing sessions

The results of our study demonstrate that an anatomical marker-based system can be used to successfully measure pianists' posture during live performances, and that these measurements can be meaningfully compared across testing sessions. Although the markers were successfully tracked using our experimental set-up and tracking procedure, researchers should consider some important points when planning methodologies that use Dartfish to track human movement for measurement purposes. For instance, although the software generally tracks anatomical markers continuously, the tracking marker occasionally slips or jumps and must be repositioned manually by the measurer. Since the Dartifish motion tracking process requires a high degree of monitoring and repositioning on the part of the measurer, the process can only be characterized as semi-automatic. To ensure accuracy and reliability, the individual must be trained to use it properly and proceed slowly throughout the videos. This makes quantitative measurement using the Dartfish tracking tool a time consuming but reliable process of measurement. Measurers typically conducted fifteen minutes of video analysis for every minute of video data recorded. Researchers intending to conduct medium to large-scale studies would have to carefully consider these time requirements, and would likely require a few copies of the software and many trained measurers for efficient data collection.

Since tracking is optimized when the markers being tracked have a clear colour contrast, the outer boundary of the marker can often be lost if the marker is similar in colour to the hue of a participant's skin. Our solution of mounting a small red circle on a larger green circle of Kinotape seemed to address this problem well. In any case, the utmost care

must be taken to ensure highly contrasted and visible markers for tracking, since it can greatly impact tracking efficiency. Reflective properties in materials used to make anatomical markers can actually make tracking less reliable, since light reflected back into the camera appears as white flashes in the video, which can cause the software to lose track of the object. It is therefore best to use a brightly coloured and opaque material to create anatomical markers. It is also essential that the video cameras are level and squared with participants to avoid distortion of measurements. If these aspects of the experimental set-up are carefully controlled, it is possible to accurately and reliably measure posture variables of pianists quantitatively using Dartfish.

Research questions 2 and 3: Impact of a single Feldenkrais lesson on posture variables of pianists

As hypothesized, we noted no significant group differences when comparing posture variable measurements from before and after the Feldenkrais FI lesson. Most changes measured in our study were below the threshold of 0.5 cm measurement for the Dartfish tracking procedure established in the first research paper (Beacon, 2015a). Although some changes of a greater magnitude were noted for some participants, it is not possible to determine which, if any were a result of motor-learning changes due to FI intervention with our current methodology. The significant inter and intra-participant variability of posture measurements in this study illustrate that while it is possible to measure the average magnitude and direction of changes in posture variables, their usefulness in assessing the outcomes of short-term FI intervention is limited. One session is not enough to begin to determine whether or not changes in average position of posture variables take place over time as a result of FI. Researchers should be aware that investigating only one or two posture variables may not be the best way to gain insight into how somatic training may influence

posture or movement habits of an individual. Average measurements of a position from a particular piano performance would likely only be useful in studies that tracked the changes in posture variables over long-term intervention. This study offers an opportunity to discuss many issues researchers should consider when using posture variable measurements as the dependent variable in repeated measures studies assessing somatic training outcomes. Although it might seem simple, the following sections explain why conducting repeated measures study on posture outcomes from somatic interventions is much more complicated than simply finding a way to determine if individuals are sitting up taller or straighter post-intervention.

Choosing posture variables. It is very difficult to choose which posture variables will be best to measure for a study investigating many participants, since it is hard to predict which parts of the body might be affected by somatic training. Since participants all have unique anthropomorphic measurements, motor control habits, and personal histories of injury or trauma, they will come to somatic training with different needs. Attentive practitioners will respond to each participant individually, and similar responses to training may not be observable across participants. Researchers must also consider that the body is a complex, interconnected system of interlocking governed by a nervous system that uses various strategies for mediating posture and motor control. Small changes in one region could have large impacts on distant regions, and it is not always easy to predict how a change in one area might impact another. Furthermore, the type of learning that takes place during FI depends on the state of the body and nervous system at the time that the intervention takes place. Therefore, it is possible that certain individuals are naturally more responsive to somatic interventions than others. For instance, the Feldenkrais practitioner in this study commented that some participants seemed naturally more receptive to the FI work that he was doing, and

that he felt he could communicate more easily through touch with some participants. Future studies could try and rate the responsiveness of participants based on the practitioners' perception of how well a student's body appeared to integrate movement changes during somatic sessions. Researchers could consider looking for correlations between practitioner-rated responsiveness and degree of postural change. Whatever the approach to measurement, researchers should recognize that they are taking a necessarily restricted look at part of a complex system when choosing to look only at isolated posture variables. In choosing to focus on only one or two areas of the body, such as the head and shoulders, researchers might miss important changes are taking place in areas not being measured.

  Variability in baseline posture measurements. Since we do not know how naturally variable baseline posture measurements are for the participants in the study, we are unable to comment on whether or not change to observed changes to posture variables for individuals could be associated with receiving the FI lesson. Evidence from research shows that posture is mediated by complex and highly adaptable motor control strategies in the central nervous system that can easily be influenced by factors intrinsic to the participant or their environment and potentially lead to variability in baseline measurements (Shumway-Cook & Woollacott, 2000; Pellecchia, 2003; Krasnow, Monasterio and Chatfield, 2004; Lacour, Bernard-Demanze & Dumitrescu, 2008). Postural sway and the natural variability of positioning of the spine and head in individuals throughout their daily lives present a serious obstacle for researchers attempting to use photographic methods to track changes to posture in repeated measures studies (Grimmer-Sommers et al., 2008). For instance, Dunk and colleagues found poor repeatability of posture measurement of thoracic, cervical, and lumbar curves when measured across three sessions, with the first session conducted in the morning, and the second and third session taken a week later in the morning and afternoon (Dunk, et

al., 2004; Dunk et al., 2005). Researchers have also found that it is difficult to predict positions of spine segments in relation to one another, and that there is a high degree of variability in spinal geometry across different people (Grimmer-Sommers et al., 2008). Contrastingly, Pownall and colleagues found that the posture variables of eleven healthy men remained stable during measurements taken over the course of one week, but posture variables in the sagittal plane, including spine variables, were more inconsistent compared to variables measured in the posterior or anterior view (Pownall et al., 2008). The natural variability of spine posture makes it impractical to use angles of spine curvature measured from pictures or radiographs to assess changes in spine posture due to interventions. This research suggests that baseline posture measurements might vary significantly during pre-intervention recording sessions. Future research should take more comprehensive baseline measurements over a number of days.

Assessing posture quality. Our study examined only whether or not there were measurable differences in the average posture variable measurements in pre and post somatic training sessions. Currently it is not possible to comment on whether or not any changes observed between pre and post-test sessions should be considered as improvements in posture for a given individual. This is because there is not presently an established criterion for judging the quality of posture variables. Researchers have struggled to determine how extreme a measurement must be to count as pathological, and many cases have been unable to find clear correlations between certain posture characteristics and musculoskeletal pain. For instance, some evidence indicates that rounded shoulders are associated with higher incidences of musculoskeletal pain (Greenfield et al., 1995; Pascarelli & Hsu, 2001), but questionable inter- and inter-rater reliability and varying shoulder measurement protocols make it difficult to draw conclusions from available research (Peterson et al., 1997).

Correlations of specific spine positions with musculoskeletal pain are particularly ambiguous. Although research that shows that variations in spinal curvature can alter how trunk muscles are activated to support the body (O'Sullivan et al., 2006; Claus, Hides, Moseley & Hodges, 2009), the details about how certain characteristics of spinal curvature influence musculoskeletal health are not well understood, and diverging theories create confusion about the definition of healthy spine posture (Pynt, Higgs & Mackey, 2001; Scannell & McGill, 2003; Grob, Fraunfelder & Mannion, 2007; Claus, Moseley & Hodges, 2009; O'Sullivan et al., 2010). For instance, researchers still disagree about whether a naturally kyphosed or lordosed curvature in the lumbar spine is healthier for seated posture, and how proper posture should be taught for the prevention of lower back pain (Pynt, Higgs & Mackey, 2001; Scannell & McGill, 2003; O'Sullivan et al., 2010). Evidence also shows that structural abnormalities in cervical spine curvature are not correlated with higher incidences of neck pain, even though they are often considered to be the cause of pain in clinical settings (Grob, Fraunfelder & Mannion, 2007). The case against forward head position is much clearer, with more substantial evidence that smaller angles of forward head position (occurring when the head is held further away from the body) correlate with higher incidences of musculoskeletal pain in the neck and shoulders (Greenfield et al., 1995; Szeto et al., 2002; Yip, Chiu & Poon, 2008; Lau, Chiu & Lam, 2009; Silva et al., 2010; Ruivo, Pezarat-Correia & Carita, 2014). However, some researchers have cautioned against drawing conclusions too quickly, since classifications of forward head position have varied across different studies (Grimmer-Sommers et al., 2008). The many varying approaches to postural variable measurement make it difficult to compare results across studies (Gadotti, Vieira & Magee, 2006). Conflicting results and theories about the influence of posture on musculoskeletal health hinders researchers' ability to interpret results in repeated measures

studies on posture. Even if changes in posture are measured post intervention, it is not

possible to comment on whether or not the changes should be considered improvements.

Additional observations: Evidence for task dependency of posture

   This section presents some important additional observations made during data

analysis that seem to present evidence that some aspects of posture vary predictably within

participants depending on the playing task they are being asked to play. For instance, figure 6

presents the average angle of forward head position for *Für Elise*, scales, and sight-reading

for each participant with a complete data set. It can be seen that the relative size of forward

head angle between tests generally stays the same for a given participant. For instance,

although the angle of forward head position increased slightly overall from the pre- to the

post-test for participant NZ1, the angle remained highest for the scale condition by about five

degrees in both sessions. This is the case for all participants except NP1, who had the

smallest angle of forward head position for scales in the pre-test, and the largest angle of

forward head position for scales in the post-test. The consistency of the relative size of the

forward head position angles for the different playing conditions across sessions suggests

that an individual adopts a different average position of the head depending on the task, and

that these individual tendencies seem to remain consistent despite the FI intervention.
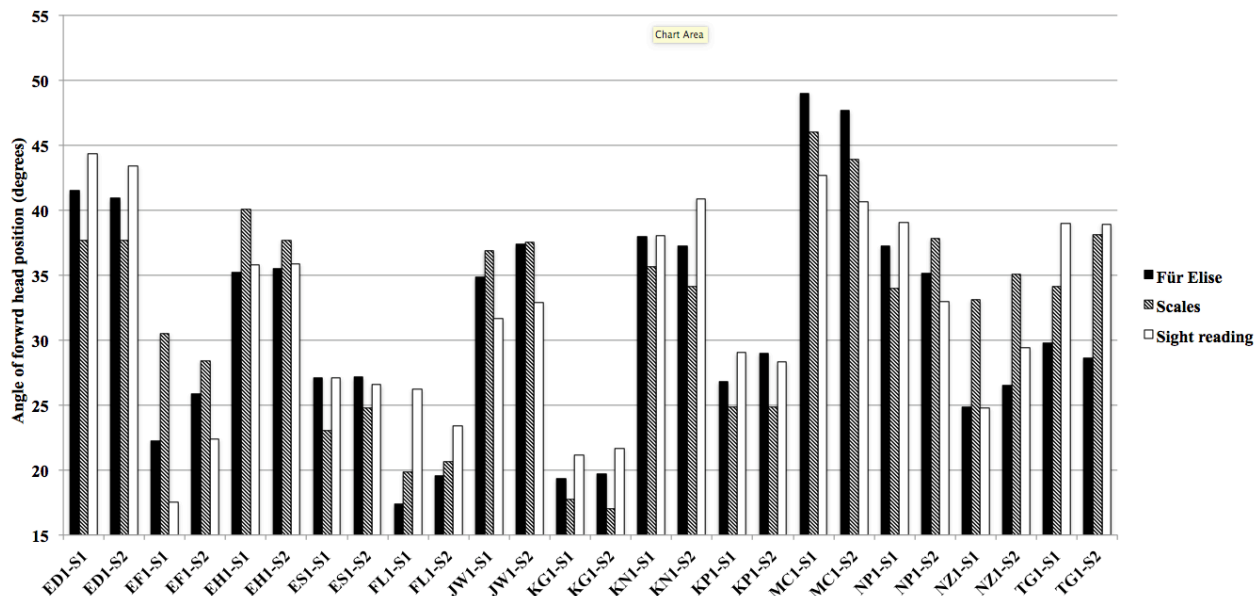
Figure 6. Average angle of forward head position for individual participant in each playing condition. *S1* is for session 1 and *S2* is for session 2.

A second example of task-dependent posture was that was observed in all participants is illustrated in figure 7 which presents the angle of elbow extension on the right and left side from the back-view camera during pre- and post-test sessions of scale performances. It can be seen that each player displays a greater average angle of elbow extension on the right side compared to the left side in both the pre- and post-tests. This is interesting because C-major contrary motion scales involve identical biomechanical demands on the right and left side of the body; the movements are perfectly mirrored, the same fingers play at the same time in both hands, and the distance the individual's arm must travel on the keyboard is also the same. Since most individuals sat at the keyboard with middle-C very near to the centre of their bodies, one might expect biomechanical symmetry in the movements of the right and left arm to match the symmetry of the task demands. However, it appears that all participants have learned a right-side dominant strategy to perform the contrary motion scale, regardless of handedness (there were three left-handed individuals in the study). This gives a clear example of how it is possible for the brain to use different movement strategies for the right

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and left side of the body even when they are completing the same task. In this case, this type

of asymmetrical movement strategy seems to be common for the performance of this

particular scale, and did not seem to be impacted by the Feldenkrais FI lesson.
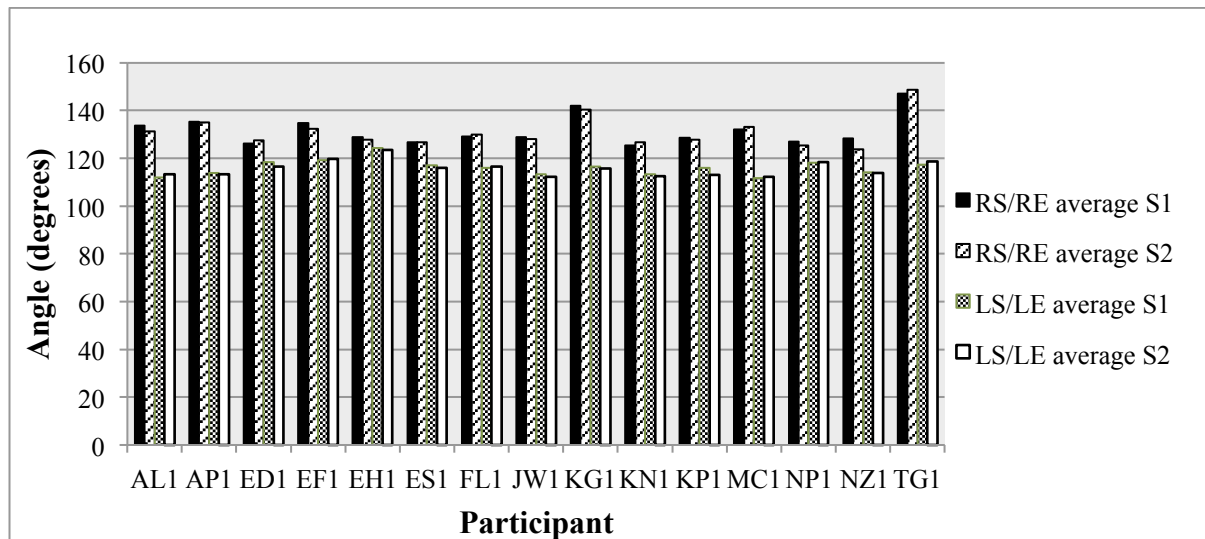
Figure 7. Average angle between a line connecting the elbow and shoulder, and a vertical line down from the shoulder on the right and left sides in performances of contrary motion scales before and after an FI intervention.

These observations could perhaps be attributed to different cognitive demands of

various playing tasks, since research has demonstrated that conscious processes are important

in the regulation of posture and balance in sitting, standing, and walking. For instance,

research shows that maintaining balance during walking, standing, and sitting requires

cognitive resources (Lajoie et al., 1993; Andersson et al., 2001), and that postural sway

increases in healthy individuals when they are completing complex cognitive tasks

(Pellecchia, 2003). Therefore, researchers investigating posture of pianists must consider that

the varying cognitive demands of different types of performing tasks could significantly

impact posture control strategies during performance, and researchers should carefully

control for the type of activity the pianist is doing in repeated measures tests. Future research

will be required to better understand task-dependency on posture when constructing

methodologies to investigate somatic training outcomes with pianists.

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this study indicate that Dartfish can be used to effectively track

anatomical markers on pianists during live performance to quantitatively measure posture

variables before and after somatic training interventions. Results show that while no group

trends were noted after a single FI lesson, the quality of movement changed for some aspects

of movement for some individuals. We have also learned that the type of playing task

performed by the pianist can influence posture strategies, making it important for researchers

to control for the type of playing task in future experimental studies. The present

experimental set-up does not allow us to comment on the degree to which any of the changes

noted in the study can be attributed to the influence of Feldenkrais training, or if they are

merely illustrations of natural variability in posture. The following sections outline

recommendations for future studies that could use Dartfish to more effectively investigate the

impact of Feldenkrais training on the posture of pianists.

Mixed-method case studies

The high degree of variability of posture between and within individuals makes it

difficult to look for trends in changes to posture variables as a result of somatic training since

posture is highly variable within and between different participants. Instead of comparing

results across participants, Dartfish could be used as an important quantitative measuring

component in mixed-method case studies that explore individuals' experiences with somatic

training in detail. Most of the case studies currently presented in research are of limited

usefulness because they do not incorporate objective data about somatic training outcomes.

Dartfish could be used in long-term case studies of pianists undergoing somatic training

interventions as a source of data that could be analysed alongside practitioner reports and participant impressions of the outcomes of somatic training on body positioning, movement, and playing quality. This type of study has been conducted with a singer undergoing a physiotherapy intervention (Staes et al., 2006). The basic methodology of this study could be modified to use the motion- tracking feature of Dartfish instead of still-frame posture variable measurement.

Measuring posture using Dartfish in large-scale, long-term studies of pianists receiving somatic training

Dartfish could be used in future large-scale research studies as a measurement tool to examine the impact of somatic training on body use and movement of pianists. Future repeated measures studies should consider collecting data at multiple sessions throughout the duration of long-term participation in somatic training, since any impact from a single lesson is likely only to be small or temporary, and offer little insight into the type of changes that might be seen through committed practice. Such studies should conduct comprehensive baseline measurements to better understand the range of normal values for each individual participant. More comprehensive measurement of baseline values of posture variables prior to the intervention will help researchers more confidently ascertain whether or not posture changes should be considered outcomes of somatic training, or merely natural variability. Finally, these studies should include a control group, ideally with participants matched in age and gender to those in the intervention group. Extending the basic methodology presented in this paper into a long-term study with many participants and a control group would offer more insight into the true impact of somatic training on the posture and movement of pianists.

Alternatives to measuring average posture variables

Even though our methodology has presented a way to use Dartfish to measure posture variables reliably in the context of piano playing, these variables only tell us information about average positioning, and do not offer researchers insight into *how* pianists are moving. Since Feldenkrais practitioners seek to help individuals integrate movement across various parts of the body, diversifying movement possibilities and increasing ease of motion, future researchers could consider exploring analytical approaches that comment quality, movement patterns, and integration of movement across different parts of the body, instead of looking at average positioning. For example, the time plots for participants AP1 and KP2 illustrate very different qualities of movement between the pre and post-test recording sessions for a given test, raising the important question of whether or not the differences in movement quality are related to the FI lesson. Researchers could devise statistical, mathematical, or graphical ways to analyze tracking data to discuss various factors relating to movement quality, such as smoothness, jerkiness, integration of movement in different parts of the body, speed, acceleration, or frequency of oscillations. This would allow results to be discussed in terms of movement quality, instead of strictly in terms of static positions.

Limitations of this study

The most significant limitations of this study are the absence of a control group and inadequate procedures for conducting comprehensive baseline measurements. Additionally, despite implementing performance criteria, and requiring a minimum level of performance ability of Grade 10 RCM, performance quality varied significantly among performers, with four requiring the sheet music to perform *Für Elise,* and two performing scale and sight reading tests at very slow tempos. Future studies could consider conducting a pre-test with participants ahead of time to ensure that they are prepared to perform the playing tests

adequately prior to data collection. Finally, our participants varied significantly in age, and

since research has illustrated that age can influence the cognitive demands involved in

balance and posture control, future studies should not compare older adults with adolescents

(Raine & Twomey, 1997).

CHAPTER 5:
RESEARCH PAPER 3

Using Kinect to measure posture variables and track movement of pianists before and after a

weeklong Feldenkrais-focused piano technique workshop

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Abstract

The Microsoft Kinect depth sensor could offer a convenient, markerless solution for quantification of head and torso movements of pianists in order to examine the impact of somatic training methods on playing postures. To assess the suitability of the Kinect for this application we tracked four professional piano teachers as they performed scales immediately before and after a weeklong piano technique institute involving daily Feldenkrais Awareness through Movement lessons (ATMs). We compared Kinect skeletal tracking data with 2D tracking data obtained simultaneously using Dartfish video-analysis software, which has been demonstrated to be an accurate and reliable tool for tracking movement of pianists' head and torso (Beacon, 2015a, 2015b). Our comparison of the Kinect and Dartfish time plots of posture variables revealed frequent tracking errors in the Kinect data. Differences in pre-and post somatic measurements of forward head position, head height, C7 height, and shoulder displacement did not correspond between the two tracking technologies. Our results suggest that Kinect skeletal tracking does not currently have a high enough resolution to measure quantitative differences in average posture variables for the purposes of ergonomic assessment in somatic training interventions like Feldenkrais ATM lessons using our present software. However, it could be suitable for analyzing more generalized movement patterns of pianists' head and torso. Changes to the pose estimation algorithm that could restrict range of motion for joints and allow for the customization of bone-lengths could help address tracking problems.

Keywords: Kinect, Dartfish, posture, motion tracking, somatic training, Feldenkrais, piano pedagogy

LITERATURE REVIEW

Somatic training in piano pedagogy

Piano pedagogues and movement specialists hypothesize that the quality of postural alignment while seated at the piano can significantly influence a pianist's fluency and control, and pedagogical theories about the etiology of playing-related musculoskeletal disorders (PRMDs) often include posture as a risk factor (Brandfonbrener, 1997; Allsop & Ackland, 2010). Due to the association of postural alignment with reliable and sustainable playing technique, many musicians have turned to somatic training methods, such as the Alexander Technique (Alexander, 1932), the Feldenkrais method, (Feldenkrais, 1981), or Body Mapping, (Conable, 2009), as means to improve technical and expressive control and ease of motion. Practitioners of these methods seek to heighten individuals' kinesthetic awareness to help them replace potentially harmful movement patterns with more healthful alternatives based on biomechanical principles of balance and alignment (Spire, 1989; Conable, 1995; Ginsburg, 1999) These methods have also come to play a prominent role in some approaches to injury-preventative and rehabilitative piano technique taught by pedagogues who have gained notoriety for their work with injured musicians (Taubman, 1995; Mark, 2003; Fraser, 2011; Baniel, 2012; Stewart, 2015). However, much of the evidence purporting benefits of somatic training comes from subjective sources, such as practitioner reported results (Rosenthal, 1987; Mayers & Babits, 1989; Nelson, 1989) or student testimonials (Goldansky, 2008; Stewart, 2010; Fraser, 2015; Boyd, 2015; Johnson, J., 2015). The use of motion tracking technology could allow researchers to track the movement of musicians during performance in order to objectively determine if somatic training leads to measurable changes in posture and movement.

Human motion tracking with Kinect

The Microsoft Kinect could offer a promising solution to the problem of accessible, reliable, and unobtrusive motion tracking for the purposes of assessing the impact of somatic training on posture in the context of piano playing. It was initially developed to allow people to control video games using gestures, circumventing the need for hand-held controllers, and allowing for a more immersive gaming experience. The Kinect apparatus contains a regular RGB video camera and a depth-sensing camera that projects a dense array of structured infrared light points into the room in order to create a depth image of objects in front of the sensor. The device is equipped with on-board software that identifies body-parts by shape, and tracks their location in three dimensions. Detailed descriptions of the tracking process and the software operation can be found in the overviews of Duffy (2010) and Hadjakos (2012). The main difference between Kinect motion tracking and marker-based optical systems, (such as Vicon), is that the Kinect software predicts the likeliest position of the skeletal points it is searching for based on shapes detected by the infrared sensor instead of measuring the precise location of markers placed on the bodies of participants. These predictions are made continuously while the sensor records at a rate of thirty times a second.

Kinect in rehabilitative and music research. Soon after its release in 2010, researchers recognized the potential for the motion tracking and gesture identification capabilities of Kinect to be applied in rehabilitative research. For example, games have been developed to help physicians monitor progress in rehabilitative exercise regimens prescribed for individuals with injuries or motor disabilities (Chang, Chen, and Huang, 2011; Lange, Chang, Suma, Newman, Rizzo and Bolas, 2011; Roy, Soni & Dubey, 2013; Neri, Adorante, Brighetti & Franciosi, 2013; Sun, Liu, Wu & Wang, 2014; Tseng, Lai, Erdenetsogt & Chen, 2014; Zhao, Espy, Reinthal & Feng, 2014; Zhao, Feng, Lun, Espy & Reinthal, 2014).

Researchers in music have also explored many promising applications for the Kinect or similar depth cameras. For instance, pedagogical software has been developed for the Kinect that allows musicians to improvise musical sounds and harmonic progressions using gestures in order to help train auditory skills (Sentürk, Lee, Sastry, Daruwalla, & Weinberg, 2012). Performing software has been developed that enables pianists to control sound parameters of a live performance simply with hand gestures in front of the motion sensor, which feels natural to the performer and appears aesthetically pleasing to an audience (Brent, 2012; Yang & Essl, 2012). Kinect sensors have also been used to unobtrusively track the head and bow movements of string ensemble performers in order to gain information about patterns of expressive gesture and cuing between ensemble members (Hadjakos, Großhauser, & Goebl, 2013). Finally, research has demonstrated that Kinect sensors can be used to accurately track the position of a pianist's head, shoulders, and arms from a perspective above the keyboard during virtuosic performance (Hadjakos, 2011/2012). These studies illustrate the diversity of research applications for the Kinect that quickly evolved across various fields of study as researchers recognized the potential for markerless motion tracking to revolutionize research on human motion in a variety of disciplines.

Benefits of markerless technology. Recently, researchers have become interested in assessing whether or not the Kinect could be used to obtain quantitative measurements of human movement to track changes as a result of various training or rehabilitative interventions, or to compare movement characteristics in different populations. Currently, 3D optical-based systems that require the use of reflective markers fixed to points of interest on participants' bodies are the most reliable tracking method for quantitative analysis of human movement. Although such systems are precise, they often require a time-consuming process of data preparation and analysis. The equipment is not highly portable, and data collection is

usually restricted to laboratory situations. Furthermore, the necessity of fixing spherical or reflective markers to the body can significantly interfere with the participants' natural movement habits, and can easily become detached during data collection. Kinect could offer an affordable, markerless solution to these problems for researchers interested in using motion tracking technology to assess the impact of somatic training on the posture and movement of pianists. Since Kinect sensors do not require the use of anatomical markers, pianist subjects may wear comfortable clothing during testing and do not have to perform with cumbersome markers attached to their bodies, allowing for more natural performance conditions. Using Kinect sensors, neither the practitioner nor pianist needs to worry about altering the position of markers during testing, which can introduce a significant source of error when measurements are taken for comparison at separate recording sessions.

Kinect accuracy. Many studies have compared Kinect tracking data with data simultaneously captured using 3D optical based systems, such as Optitrack (Webster and Celik, 2014), Optotrak (Tao, Archambault and Levin, 2013), MediaLab (Fernández-Baena, Susíin, and Lligadas, 2012), Codmotion (Alnowami, Alnwaimi, Tahavori, Copland, and Wells, 2012), and Vicon (Clark, Pua, Fortin, Ritchie, Webster, Denehy, and Bryant, 2012) to assess the accuracy of Kinect tracking. Although it is difficult to make a precise estimate of the Kinect accuracy due to the diversity of data collection and analytical procedures across different studies, in summarizing the literature Obdržálek estimates that the Kinect could be considered to have a joint localization accuracy in the range of 1 to 4 centimeters at a distance of 1 to 4 meters (Obdržálek, Kurillo, Ofli, Bajcsy, Seto, Jimison, & Pavel, 2012). Accuracy for angles generated is harder to generalize, but might be conservatively estimated to be within 5 and 13 degrees when major tracking errors are filtered out (Fernández-Baena et al., 2012). Even though the measurement errors in this range are much greater than the

error of marker based systems, the Kinect may be suitable for quantitative measurement in some applications, depending on the data collection strategy used, the variables being measured, and the quality of the software. For instance, Scano and colleagues compared joint position data of reaching movements tracked in the sagittal plane from the Kinect and a passive motion capture system (Scano, Caimmi, Malosio and Tosatti, 2014). Measurement error was found to be within an acceptable range for the assessment of upper limb movement quality and results were precise enough to determine Parkinson's patients from the healthy subjects in the testing group in this study. Similarly, Webster and Celik (2014) found that the Kinect has a high enough resolution to quantitatively measure exercises and diagnostic arm movements prescribed for stroke victims, since the movements were large, slow and simple. Kusaka and colleagues were able to devise a detailed anthropomorphic algorithm for more precisely estimating pose and measuring joint angles that kept error under 10 degrees at all times which allowed them to more successfully quantify arm movements of elderly people to determine if a therapeutic intervention helped with arm mobility (Kusaka, Obo, Botsheim, and Kubota, 2014). Their software solution allowed them to detect differences in the size of shoulder and arm angles in a person with hemiplegia before and after a therapeutic intervention. These researchers extended their study to track arm and shoulder angles in seven elderly people for five days, but no significant change in any maximal arm extension angle was found amongst participants. Thus far, research has shown that the suitability of the Kinect as a quantitative measuring tool for human movement depends on the type of movement being investigated, the software solutions developed for data collection, and data collection procedures. Researchers interested in using the Kinect for human movement quantification should carefully consider their measurement needs, and conduct pilot testing to determine if the Kinect could be a suitable measuring tool.

Pilot testing the Kinect with pianists

Our research team conducted a pilot test to investigate the suitability of the Kinect as a quantitative measurement tool for assessing the impact of somatic training on the posture of pianists using a software solution developed by engineers at the University of Ottawa. The researchers modified the existing skeletal tracking model to track the pianists sitting in the sagittal plane so that we could measure posture variables of the head, shoulders, spine, and hips. Results of our pilot test (Payeur, Beacon, Cretu, Nascimento, Comeau, et al., 2014) demonstrated that the average x, y and z coordinates of the head, shoulder centre, right shoulder, and lower spine position tacked by the Kinect reflect expected differences in position when comparing the tracking data of exaggerated slouched or sway-backed postures with neutral postures during piano performances of scales and short musical phrases. However, since this study did not compare the Kinect tracking results to a baseline measurement from a source known to be reliable, it is unclear how closely the Kinect tracking reflected the actual movements of the pianist, and therefore whether or not the reported average differences reflect the detection of postural change, or artefacts of the tracking process. Furthermore, it is likely that the measured differences in body positions between the neutral and exaggerated postures modeled by our participant are much more pronounced than any expected differences resulting from somatic training interventions in realistic situations, and it is not clear from our pilot research if the resolution of the Kinect allows for the detection of very small differences in postures of the head and shoulders. In an earlier study we found that Dartfish video-based motion analysis is a very accurate and reliable 2D motion tracking software, with a measurement error of +/- 0.25 centimeters for distances, making it an acceptable tool to take baseline measurement for comparison with Kinect tracking results (Beacon, 2015a). Since Dartfish is a 2D tracking tool and the Kinect

tracks in 3D, we will only measure posture variables that use coordinates in one plane and will ask the pianists to perform a playing task that does not involve movement toward and away from the camera. Our previous research has also demonstrated that Dartfish is an effective tracking tool in the context of live piano performance, and can be used to compare posture measurements of pianists across different testing sessions (Beacon, 2015b). By comparing tracking results from Dartfish and Kinect it will be possible to determine if the Kinect has a high enough resolution to track body positions during live performance in order to meaningfully compare posture variables of pianists from before and after somatic training workshops.

5.4 Research question

The aim of this study is to assess the suitability of the Kinect as a quantitative measurement tool for assessing the impact of somatic training on the posture of pianists using the current software solution developed by engineers at the University of Ottawa. We will assess the quality of Kinect tracking by comparing Kinect tracking results to 2D baseline measurements taken with Dartfish. Our research seeks to answer two main questions:

1. How well do time plots of *x* and *y-axis* coordinate data tracked by the Kinect match baseline plots obtained using Dartfish when tracking live pianists?

2. Do Dartfish tracking results reveal differences in single-plane posture variables of pianists from before and after a weeklong Feldenkrais training workshop, and if so, do Kinect tracking results reflect the same differences?

In response to these questions, we present the following hypotheses:

1. We hypothesize that the time plots of coordinate data from the Kinect will contain frequent tracking errors in comparison with Dartfish, since Dartfish was found to reliably track body positioning of pianists in two of our previous

studies (Beacon, 2015a/2015b) and since the time plots in our initial pilot study with the Kinect displayed evidence of many tracking errors (Payeur et al., 2014).

2. We hypothesize that differences in posture variables will likely be measurable for some individuals, since a weeklong exposure to somatic training is likely to have a more profound impact on posture and movement habits compared to a single intervention (Beacon, 2015b). However, it is likely that if any significant changes to posture occur, they might only be reflected in the Dartfish results, since the possibility of frequent tracking errors in the Kinect could impact average posture value calculations, resulting in discrepancies in measurements between the two systems.

METHODOLOGY

Design

The following methodology examines the suitability of the Kinect motion sensor as a tool for quantitatively tracking the body positioning of pianists in order to compare posture variables from before and after somatic training. We used the Kinect to track four pianists' body movements during the performance of scales before and after participating in Alan Fraser's weeklong Feldenkrais and piano technique workshop. We compared single-plane variables taken from the 3D Kinect tracking data benchmark 2D coordinate data obtained using Dartfish video-based motion tracking software.

Participants

Participant attributes. Participants attended Alan Fraser's piano technique and Feldenkrais workshop taking place at the University of Ottawa, July 14-19, 2014. We recruited four professional piano teachers (three female, one male; ages = 24, 29, 50, and 51)

from among the workshop participants. All participants had achieved a minimum of a bachelor degree in music, studying piano. Two had attended prior institutes of Professor Fraser, and two were new to the Feldenkrais method altogether.

Playing requirements. We asked participants to perform three repetitions of a C major contrary-motion scale, starting on C4 and extending to the lowest and highest octave of the piano in sixteenth notes, at approximately eighty beats per minute. We chose this test because it is symmetrical. It requires similar movements on both sides of the body simultaneously and does not require any torso rotation. Furthermore, pianists move primarily by leaning toward and away from the piano bench in the x and y axis during this type of scale. Their bodies remain almost stationary in respect to the camera (the z axis). Since the pianists' torso moves primarily in one plane, we can compare 2D data from Dartfish with the 3D data from the Kinect for single-plane posture variables.

Set-up

Anatomical markers. We fitted participants with red Kinotape markers on their right ear-tragus, right acromion process (top of shoulder), right olecranon process (elbow), and right ulnar styloid process (wrist) prior to each recording session to permit accurate tracking with Dartfish. We marked the C7 vertebral process with a round, Styrofoam ball attached to a strong magnet taped to the skin with medical tape. We provided participants with a tight-fitting sports top to ensure loose clothing did not occlude markers. A medical student placed all markers to ensure accurate and consistent placement.

Apparatus. We recorded video data with a Sony HD HandyCam, (HDR-XR260V, 8.9 megapixels) set to record at a frame rate of 60i, (capturing 30 frames per second). We mounted it on a Manfrotto tripod at an appropriate height for each participant, which was retained for both pre and post-test tracking sessions. We used a Kinect for XBox 360,

equipped with an infrared depth-camera (640×480 pixels, 30 images per second) and an RGB camera (1280×1024 pixels, 10 images per second) to track the pianists' movement. Software developers in the University of Ottawa department of computer engineering modified the original motion-capture software platform of the to track pianists from the sagittal view (Payeur et al., 2014).

      Experimental set-up. We positioned the video camera perpendicular to the right shoulder of the pianist and levelled it. We adjusted the distance and height of the camera for each pianist and maintained the camera positions for both recording sessions. We placed the Kinect at approximately a 45-degree angle to the front and right of participants, but the position of the Kinect had to be adjusted frequently, as it was often unable to initiate tracking of the individual. Due to the inconsistency of the tracking quality, we were unable to keep the Kinect at a consistent height or position for all recording sessions.

Procedure

      All data collection took place at the University of Ottawa Piano Pedagogy Research Laboratory, and we obtained consent from all participations prior to data collection (see consent form in appendix B). We fitted all participants with anatomical markers according to the previously described criteria (Beacon, 2015b). We used the video camera and the Kinect to simultaneously record participants playing the scale test on the first morning of the institute, before activities began. A research assistant initiated Kinect recording as the pianist began playing the exercise, and stopped Kinect recording as they finished playing the last note. Subsequently, each participant attended a one hour-long piano lesson and a one hour-long Feldenkrais ATM session each of the six institute days in addition to attending lectures on piano technique and observing other students' piano lessons. The piano lessons and lectures explored how the Feldenkrais method could be applied to piano technique. At the

end of the institute, we reapplied the anatomical markers and recorded the same four

participants playing a second scale test after they completed the final ATM lesson on the last

day of the institute.

Measurement

       Kinect tracking procedure. The Kinect automatically generated *x*, *y*, and *z*

coordinates of the head, shoulder-centre, right shoulder, right elbow, and right wrist and

exported them into Excel files for analysis. The direction of the axes of the coordinate system

and an example of how the Kinect skeleton points would correspond to a participant's body

is depicted in figure 1.

       Dartfish tracking procedure. Two experienced users tracked all anatomical markers

in the videos using Dartfish TeamPro software, version 7.0, according to the previously

described procedure (Beacon, 2015a). They set the reference distance to the diameter of the

lowest ball marker on the spine (3.7 cm), and they marked the origin of the coordinate

system at a stationary point visibly marked on the piano bench behind the participants.
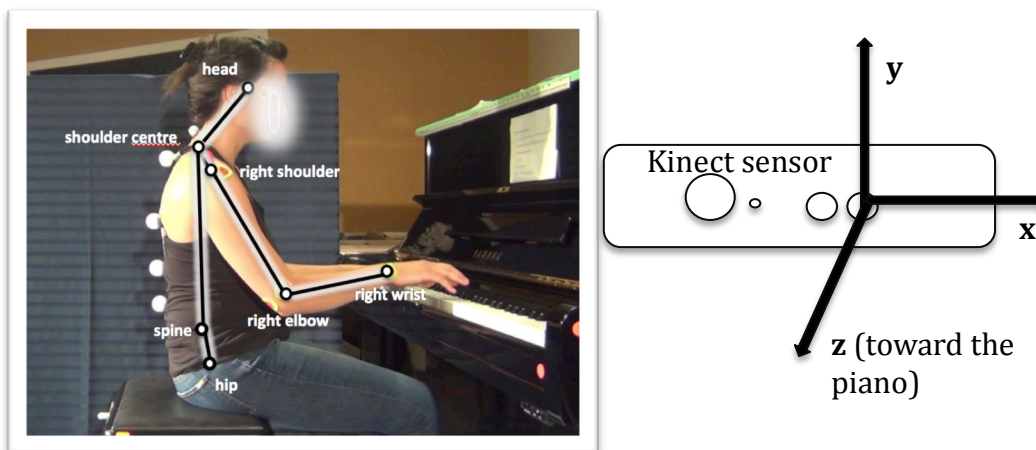
Figure 1. Left: Kinect skeletal tracking points overlaid on a performing participant. Right: Directions of axes
for coordinate system. The origin of the coordinate system is the Kinect sensor, with the *z*-axis increasing away
from the sensor, the *x*-axis increasing to the left of the sensor, and the *y*-axis increasing upward (Microsoft,
2015b).

Posture variables. We chose to measure the variables listed in table 3 to examine if spine, shoulder, and head positioned altered measurably from pre-test to post test sessions. These particular variables all involve coordinates in a single plane, allowing for measurements to be compared between the 2D and 3D measurement data. We measured forward head angle as depicted in figure 2 for Dartfish data. We took the same forward head measurement with the Kinect data, but the used the shoulder centre skeletal position tracked by the Kinect algorithm in place of the C7 vertebra. Since the Kinect predicts specific skeletal points using algorithms containing anthropomorphic information about the size and orientation of skeletal elements based on the depth-map image it produces, the Kinect body positions and markers positioned for Dartfish cannot be considered to be in precisely the same positions. For instance, the shoulder centre projected by the Kinect is a few centimeters lower than the C7 vertebra used in standard calculations of forward head position, and therefore the average angles are expected to be larger for Kinect. However, assuming that the Kinect head coordinate reflects the true centre of the participant's head, any significant difference in average forward head posture apparent in the forward head angles of Dartfish should also be reflected in the head angles calculated from the Kinect coordinates. The shape of the time plots should also yield very similar patterns between the two measuring methods if tracking takes place accurately.

Table 1
Corresponding body positions for comparison between Kinect and Dartfish tracking methods

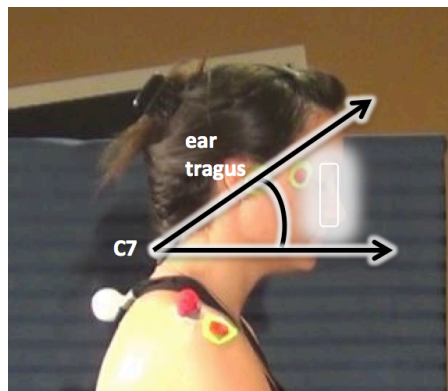| Kinect	Dartfish
Head	Ear-tragus
Shoulder centre	C7 vertebral process
Right shoulder	Right acromion process
Right elbow	Right elbow
Right wrist	Right wrist
Hip	Point on the back of piano bench

Notes: See corresponding illustration in figure 1.

Figure 2. Forward head angle.

Table 2

List of single-plane posture variabless for comparing Dartfish and Kinect Tracking

Posture variable	Description of Dartfish measurement	Description of Kinect measurement.
(i) forwad head angle	Angle formed between a horizontal line passing through the C7 spinous process and a line connecting the C7 process to the ear tragus	Angle formed between a horizontal line passing through shoulder centre skeletal tracking point and a line connecting the shoulder centre to the head skeletal tracking point
(ii) vertical displacement of head and the shoulder centre	Difference between the y-axis value of the ear-tragus and the y-axis value of the C7 vertebrae	Difference between the y-axis value of the head and the y-axis value of the shoulder centre
(iii) horizontal displacement of head-shoulder centre	Difference between the x-axis value of the ear-tragus and the x-axis value of the C7 vertebrae	Difference between the x-axis value of the head and the x-axis value of the shoulder centre
(iv) height of head above hips	Difference between the y-axis value of the ear-tragus and the origin of the coordinate system at the hip	Difference between the y-axis value of the head and the y-axis value of the hip centre
(v) height of C7 above hips	Difference between the y-axis value of the C7 vertebrae and the origin of the coordinate system at the back of the piano bench	Difference between the y-axis value of the shoulder centre and the y-axis value of the hip centre
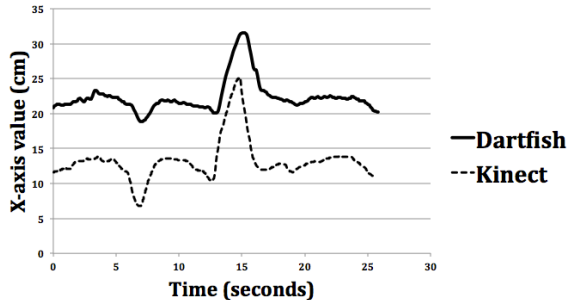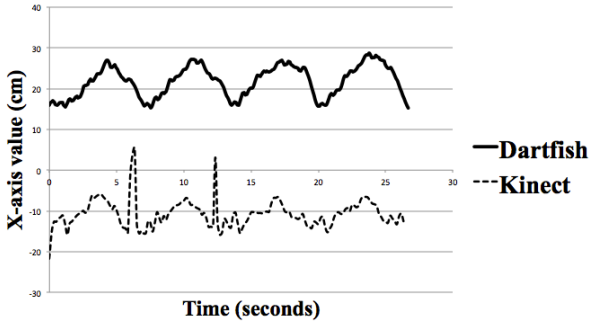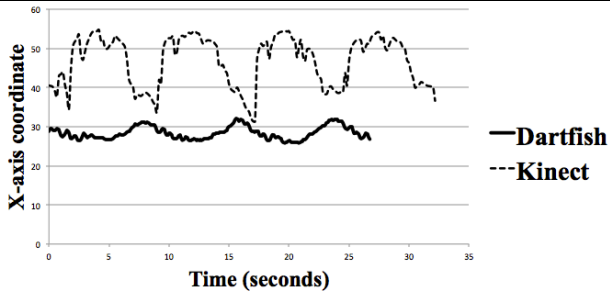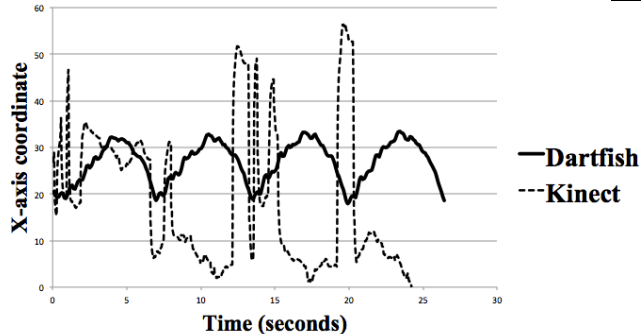
Analysis

Comparing Dartfish and Kinect time plots. We compared the time-plots of the x and y coordinates of the body positions depicted in table between the two tracking technologies in order to visually assess how well the Kinect tracked compared to Dartfish. We rated the tracking performance of the Kinect based on how closely it matched the movement pattern depicted in the Dartfish reference plot using the rating-scale in table 3. Since the participants played four repetitions of the scale for each test, the x-axis time plots typically reflected four similar movement cycles as the participant moved their torso toward and away from the piano.

Table 3

Qualitative rating scale for assessing the Kinect tracking performance

Rating	Description	Visual example
1. Excellent	Kinect plot is identical to or smoother than the Dartfish tracking plot	
2. Good	Pattern clearly visible in the Kinect plot, with a similar magnitude to Dartfish. No more than two large tracking errors	
3. Average	Dartfish pattern partially visible in the Kinect plot, but with 3-5 significant diversions or a magnified movement	
4. Poor	Pattern invisible and/or tracking incomplete and/or frequent loss of object during Kinect tracking	

Note. The time-plots used in the examples above were taken from the following tests from the top down: (1) MF1 *x*-axis coordinates of head during session 1, (2) FN1 *y*-axis coordinates of elbow in session 2, (3) GW1 *x*-axis coordinates of elbow in session 2, and (4) FN1 *y*-axis coordinate of elbow in session 1.

Comparing average posture values. We calculated the average values for the

single-plane postural variables in table 2 for the pre- and post-test recording sessions of each

participant using the coordinate values reported by both tracking methods. We subtracted the

average value of each posture variable in session 1 from the average value of the same

posture variable in session 2 for both the Kinect and Dartfish tracking data. We compared the

difference between session 1 and 2 for the Kinect against the baseline measurements attained

using Dartfish.

RESULTS

Research question 1: Comparing Dartfish and Kinect time-plots

Figure 3 illustrates the distribution of x and y plots according to tracking quality as

rated using the scale presented in table 4. It can be clearly seen that the Kinect appears to

track at an "excellent" or "good" level more frequently in the x-axis compared to the y-axis.

Out of a total of forty tracking sessions, twenty-five y-axis plots qualified as 'poor' tracking

examples. No y-axis plots were rated as excellent, and only four were rated as 'good'. Only

x-value plots received 'excellent' rankings, but 60% of the x-axis tests were categorized as

'average' or 'poor', with the remaining 40% split evenly between 'excellent' and 'good'.

Table 4 illustrates that some skeletal points were tracked reliably more often than others. For

example, the head and C7 (shoulder centre) positions were rated "good" or "excellent" more

frequently than the elbow, wrist, and right shoulder. Tracking of the right shoulder was the

least reliable, receiving only "average" or "poor" ratings. These results suggest that the

quality of Kinect tracking is highly dependent on both the body position being tracked, and

the plane of movement being examined.
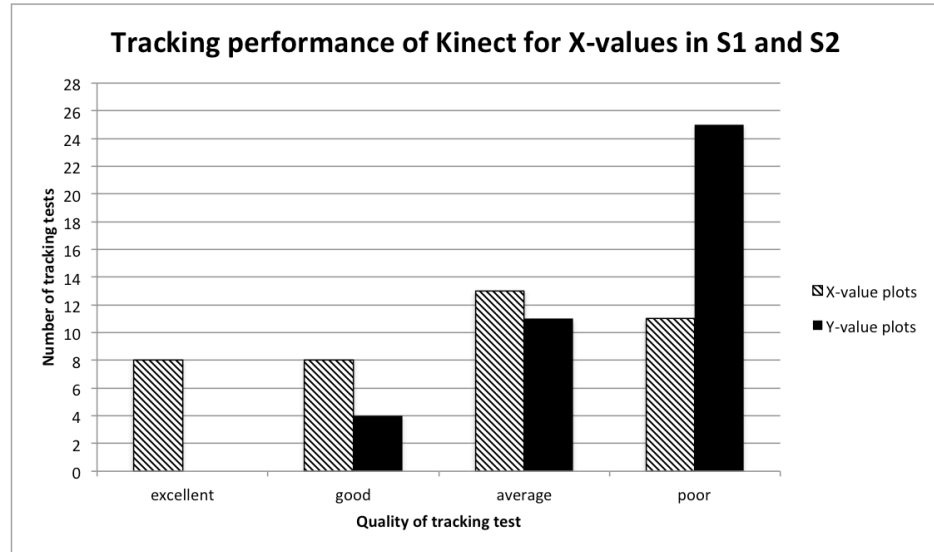
Figure 3. Distribution of *x* and *y*-axis time plots according to tracking quality

Table 4
Distribution of Kinect tracking performance ratings for different body positions

	Ranking				
Position	Excellent	Good	Average	Poor	Total
Head	5	1	5	5	16
C7 (shoulder centre)	3	5	1	7	16
Elbow	0	4	4	8	16
Wrist	0	2	7	7	16
Right shoulder	0	0	7	9	16

Although the majority of Kinect tracking sessions qualified as poor in comparison with Dartfish, a few of the *x*-axis time plots of the head and shoulder centre illustrate that the Kinect appeared to match or exceed Dartfish performance in some isolated instances.
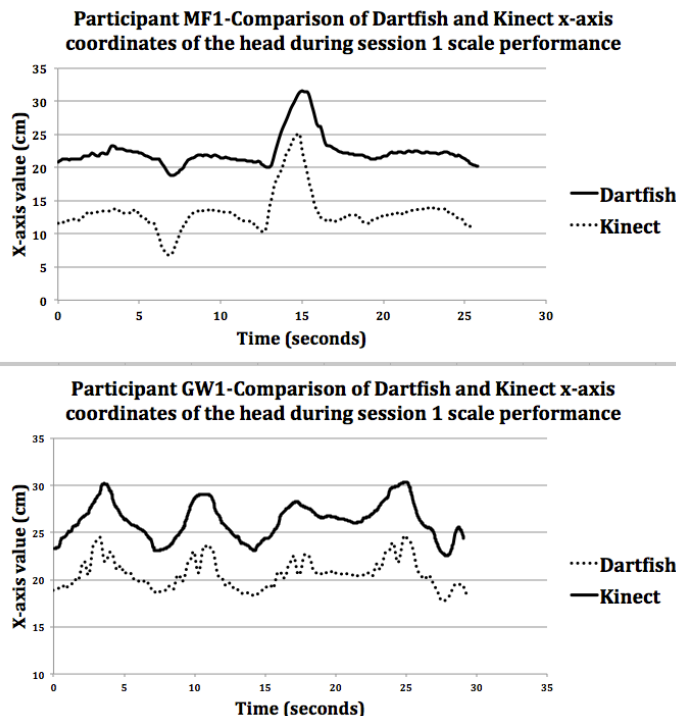
Figure 4. Best-case tracking scenarios for Kinect motion tracking of the head during scale performance.

Research question 2-Comparing Posture Variables

Forward head angle. Table 5 presents the average angle of forward head position for each participant in each recording session, along with the difference in angle size between the two sessions. Results indicate that the calculation of changes in average forward head angle from session one to session two did not yield similar measurements between Kinect and Dartfish tracking methods. According to our previous reliability testing (Beacon, 2015a), differences in angle measurements need to be greater than 2.5 degrees to be considered outside of measurement error for Dartfish measurements. Only participant MF1 exhibited a change well outside the measurement error for angles in Dartfish, with a decrease in forward head angle of 5.0 degrees from session one to session two. Since the magnitude and direction of this measurement exceeds this threshold of measurement error, this data strongly suggests that participant MF1 held his head farther forward in relation to his C7 in session two. Unfortunately, the Kinect reported a 19.1 degree *decrease* in forward head position from

session one to session two for the same participant, which would suggest the opposite

result—that he held his head much more erectly. As can be seen in table 6, even when the

horizontal head displacement on the *x*-axis is considered separately from the *y*-axis, (since

our time-plot comparisons revealed tracking to be less consistent in the *y*-axis), the changes

from session one to session two are still not similar in either magnitude or direction between

the two tracking methods. This supports our hypothesis that although measurable differences

in posture variables may be observable for some participants, Kinect is not in agreement with

Dartfish about the direction and magnitude of the change.

Table 5
Comparing forward head angle measurements from Dartfish and Kinect

	Kinect forward head angle (degrees)			Dartfish forward head angle (degrees)		
Participant	Session 1	Session 2	Difference	Session 1	Session 2	Difference
DS1	82.9	77.1	-5.7	33.5	32.1	-1.3
FN1	85.9	74.6	-11.3	27.6	30.0	2.4
GW1	71.2	69.7	-1.5	32.5	35.2	2.7
MF1	70.9	90.0	19.1	27.5	22.4	-5.0

Table 6
Comparing pre- and post-test average horizontal distance between the head and shoulder centre markers
from Kinect and Dartfish coordinates

	Kinect distance between shoulder centre and head on the *x*-axis (cm)			Dartfish distance between ear-tragus and C7 on the *x*-axis (cm)			
Participant	Session 1	Session2	Change	Participant	Session 1	Session 2	Change
DS1	2.1	3.9	1.8	DS1	12.7	12.4	-0.3
FN1	1.4	4.2	2.8	FN1	12.5	10.4	-2.1
GW1	5.9	7.0	1.1	GW1	12.9	11.6	-1.3
MF1	5.5	0.0	-5.5	MF1	14.7	14.3	-0.4

Head and C7 height. Table 7 presents the differences in average head and C7 height above

the hips/bench between session one and two as measured by Kinect and Dartfish. Results

indicate that the changes in average head and C7 height above the hip from session one to

session two do not correspond between the two measurement methods. As can be seen below

in table 6, the Dartfish values for participants GW1 and MF1 appear to report similar

changes in average height from S1 to S2 in both C7 and the ear-tragus, and that these differences are of a magnitude outside of the range of measurement error of +/- 0.5 cm established in our reliability testing (Beacon, 2015a). Therefore, it is likely that these two participants did display a decrease in head height and C7 height from session one to session two. The Kinect values do not seem to correspond with the Dartfish data. In fact, the Kinect data appears to indicate that participant GW1 sat higher by about 5 centimeters, instead of lower by about 5 cm, as reported by Dartfish.

Table 7

Comparing Dartfish and Kinect measurements of change in average height of head and C7 above the hip from session one to session two (cm)

Participant	Difference in head above hip height from session one to session two		Difference in C7 above hip height from session one to session two	
	Kinect	Dartfish	Kinect	Dartfish
DS1	-1.6	-0.1	-2.1	0.5
FN1	-6.0	-2.1	-2.5	-1.6
GW1	5.8	-5.4	4.1	-5.4
MF1	-1.3	-5.7	-1.6	-4.0

DISCUSSION

Research question 1: Comparing Dartfish and Kinect time-plots

As we hypothesized, the Kinect tracking of the head, shoulder center, right shoulder, elbow, and wrist was of inferior quality and reliability when compared to the Dartfish tracking system. However, the examination and comparison of individual time-plots helped us to get a more detailed look at how the Kinect performance varied significantly according to the body part being tracked and the axis of the coordinate. Results indicate that the *x*-axis coordinates are tracked more consistently than the *y*-axis coordinates. Results also show indicate that tracking of the head and shoulder centre positions is more consistent than tracking for the wrist, elbow, and shoulder. Examining the time-plots helped us to observe specific types of tracking errors that can help us learn how future software can be modified to

improve tracking quality. In the following sections I describe specific types of tracking errors commonly observed during analysis and provide recommendations for possible solutions.

Types of tracking errors commonly viewed in time-plots.

Momentary loss of tracking. The Kinect occasionally loses track of a body segment momentarily and reports extremely high or low values that appear as "noise" on the time-plots, as pictured in the upper-right plot in figure 5. Frequent occurrences of these uncharacteristically high or low values can corrupt averaging data needed to make generalizations about trends in posture change over time. Changes should be made to our current software platform that could filter out unrealistically high or low values generated from momentary loss of tracking in order to smooth out the tracking line and improve the validity of calculations of average values, as has been done in other studies using the Kinect to measure posture (Clark et al., 2012; Fernández-Baena et al., 2012; Tao et al., 2013).

Amplification of movement magnitude. The coordinates reported by the Kinect often reflect the appropriate direction of the movement, but at a greatly amplified magnitude. For example, the range of motion for the horizontal movements of the elbow for participant GW1 in figure 5 ranges from 5 to 6 centimeters in the Dartfish plots, whereas the same motion appears to have a range of 18 to 23 centimeters in the simultaneous Kinect tracking plot. This type of amplification makes it difficult to comprehend the true range of a movement and makes comparison of movement range from pre and post-test sessions impossible. This type of magnification has also been observed in other studies (Obdržálek et al., 2012; Clark et al., 2012; Tao et al., 2013). A potential solution would be to make changes to the software that could apply a scaling factor to the specific body positions that get amplified by the Kinect.

Unrealistic pose-estimation. Sometimes the Kinect reports coordinates that reflect a movement that would be impossible to perform in reality, or that does not reflect the real

anthropomorphic measurements of a participant. For example, in figure 5 it can be seen that participant DS1's head suddenly increases in its average height by 22 centimeters. In this example, it is possible that the Kinect mistook a lower part of the torso, such as the shoulders, for the head at first, but located the round shape of the head at the appropriate level further on in the tracking. The evidence of these unrealistic scenarios illustrates how the values reported from the Kinect as belonging to a specific body position might actually have been tracked from an entirely different position. Furthermore, the Kinect will continue updating its predication of the location and size of the body segment it is tracking, even if the object is very still. This results in plots similar to the example on the bottom left of figure 5. Here, the Dartfish plot illustrates that participant GW1's shoulder did not move at all in the vertical axis, but the simultaneous Kinect plot makes it appear that the shoulder moved up and down through an expansive range of about 15 centimeters. Examples like these make it difficult to trust that the data from the Kinect reflects the actual movement that took place, unless an external reference is used for comparison. Obdržálek and colleagues have explored errors in Kinect pose estimation (Obdržálek et al., 2012), and found that errors often occur as a result of body parts being occluded by other body parts or by objects in the frame, such as chairs. They also found that more reliable systems for human pose estimation, such as Impluse, by PhaseSpace Inc., tend to have customizable features that allow the researcher to record the bone lengths of individual participants. In the Kinect algorithm, the bone lengths are not consistent, and often vary frame to frame, even if a participant is not moving.
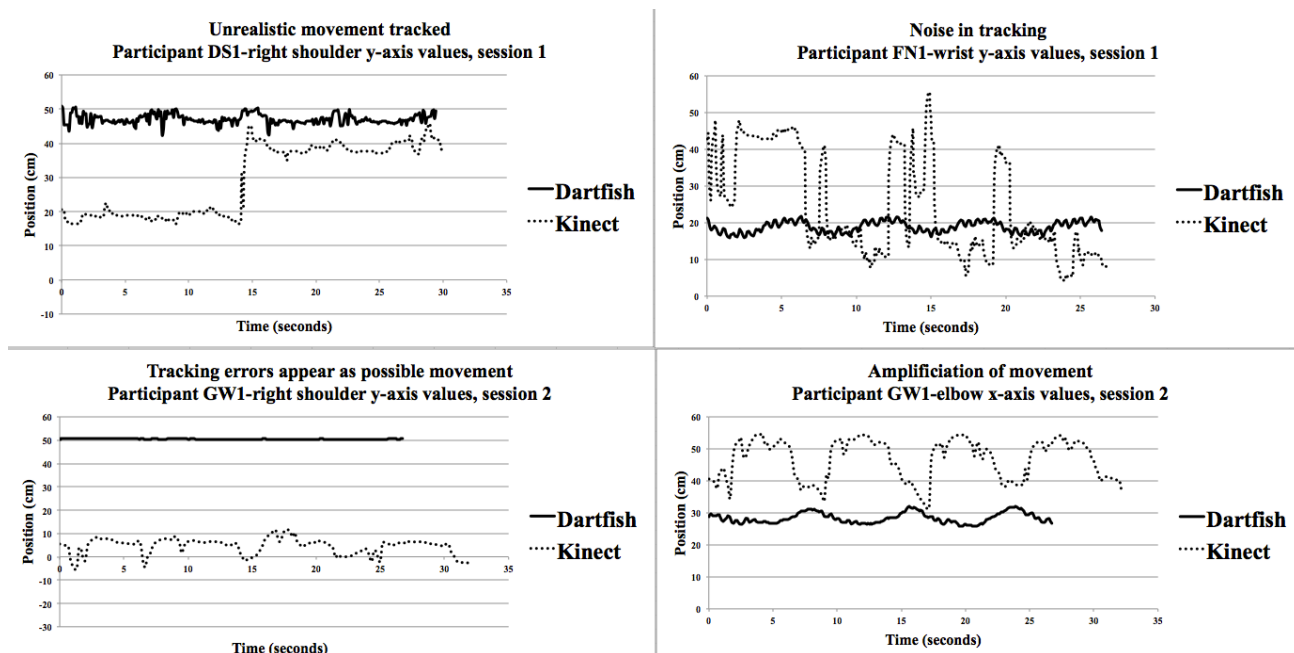
Figure 5. Examples of common Kinect tracking errors.

Accounting for Kinect Error

The error found in Kinect measurements can be attributed to a variety of factors. One source of error is the Kinect's pose estimation system, which has been shown to incorrectly identify poses more frequently than other, more detailed systems, especially in the sagittal plane, or in positions where one joint position might occlude another (Obdržálek et al., 2012; Kurillo, Ofli, Bajcsy, Seto, Jimison, & Pavel, 2012). Some evidence suggests that tracking is more reliable in the frontal plane as opposed to the sagittal plane (Obdržálek et al., 2012; Huber et al., 2014) and that accuracy diminishes as the unit is moved farther away from the object (Alnowami et al., 2012; Dutta, 2012; Pedro & Caurin, 2012). The repeatability of Kinect results is higher for objects centered in the frame, and the standard deviation of results increases predictably in the periphery of the image and as the distance of the object from the Kinect increases (Pedro & Caurin, 2012). Multiple studies have provided evidence that a proportional bias exists in the size of some Kinect tracking measurements, especially in the sternum region (Obdržálek et. al, 2012; Clark et al., 2012; Tao et al., 2013). The Kinect also

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appears to track more reliably in the *x* and *y*-axes compared to the *z*-axis, and error tends to vary between different joint positions or angles (Pedro & Caurin, 2012; Webster & Celik, 2014).

Overall, researchers will have more with skeletal tracking if their software allows for customizable bone length for individual participants, and set limitations on ranges of motion for specific joints to avoid extreme tracking results that represent movements that could not realistically be performed by a human body. The examples of the Kinect tracking plots "best-case-scenarios" illustrate that tracking performance in the *x*- axis can at times be comparable to Dartfish, especially for the head and shoulder centre, and could possibly be used for gaining qualitative information about movement patterns of the head and torso, perhaps for research on gesture and timing with musical phrasing. That being said, tracking performance seemed to vary significantly from trial to trial and participant to participant even within a given body part, and it is possible that environmental factors, such as ambient lighting conditions, or anthropomorphic characteristics of participants contributed to the unpredictable tracking performance. It is possible that unpredictable tracking performance might persist despite changes to software, potentially making data collection unpredictable and frustrating.

Research question 2: Kinect Suitability for Assessing Posture Changes

Although some good tracking results could be observed with the Kinect, especially for the head and shoulder centre positions, the Kinect was not able to detect changes of similar magnitude or direction as Dartfish for the single plane posture variables we measured, contrary to the expectations of our pilot testing (Payeur et al., 2014). The fact that Dartfish measurements reported significant decreases in head height as much as five centimeters, (well outside the range of measurement error for the tool), for three participants

suggests that for some individuals, height of the head and upper back were measurably different from session one to session two. Kinect results did not report changes in the same direction or in the same magnitude, and it can therefore be expected that the current resolution is not high enough to quantitatively measure changes in posture variables over time. Most of the variables of interest in assessing posture require accurate measurement of changes to the vertical position of body markers, since researchers are interested to know if the height of positions on the body change as people move through more slouched or more erect body positions. It is possible that if a point external to the body had been used for taking height measurements, the two methods might have achieved more similar results for the head and C7 height variables. Similar to Obdržálek and colleagues (Obdržálek et. al, 2012, p.1190), we noticed that the position of the hip was often projected unrealistically high or low, and using the Kinect tracking position of the hip as the point for reference for collecting height data is likely a source of the discrepancies between the two systems. In research with pianists it would be possible to set the position of the hip, (greater trochanter), a constant, since pianists generally keep their body in place on the bench while playing, rotating at the hip joint. Again, this problem could likely be significantly diminished with improvements to the pose estimation algorithm that would allow for customizable lengths of the skeletal segments for individuals, so that these parameters do not change from frame to frame. The variability and lack of precision in the y-axis coordinates of the Kinect in comparison to Dartfish discount it as a tool for measuring posture variables quantitatively for the purpose of assessing somatic training.

CONCLUSION

Summary of results

Our results suggest that Kinect does not currently have a high enough resolution to measure quantitative differences in average posture variables for the purposes of ergonomic assessment in somatic training interventions using our present software. Comparison of the Kinect and Dartfish time plots for corresponding body positions revealed frequent loss of tracking in the Kinect, and a general amplification of the true magnitude of some movements in comparison with Dartfish. The difference in the average postural values from session one to session two for head height, C7 height, and forward head angle did not correspond between the two tracking methods. We also noted superior Kinect tracking in *x*-axis compared to the *y*-axis, and for the head and C7 vertebral positions compared to the shoulder, elbow and wrist. Kinect tracking was particularly poor for the right shoulder, with all 16 tracking trials rated as 'average' or 'poor'. However, time-plots of the head and shoulder centre points were frequently rated 'excellent' or 'good' in comparison with Dartfish, indicating that the suitability of the Kinect as a tracking tool depends on which part of the body the researcher is interested in studying.

Recommendations for future research

At present, Kinect technology is best suited for tracking general movement trajectories of the head and shoulder centre that involve a range of motion of greater than about 5 centimeters. For instance, by tracking the head and shoulder centre researchers could get a good representation of horizontal torso movement during piano playing, which may be useful in studies investigating expressive movement during performance. However, as the examination of tracking plots revealed in our study, tracking errors are common, and future researchers should continue working to modify software to minimize tracking errors or filter them out of collected data. A particularly effective way to do this is modify the software to allow for manual setting of bone lengths that can be maintained throughout tracking for all

participants, or to program the software to omit results that do not fit the range of possible anatomical range of motion for a given movement. As has been shown in the literature, analyses that make use of data filters to remove outlying data points resulting from tracking errors will generally report much better results (Clark et al., 2012; Tao et al., 2013). Such improvements to the software would drastically improve the quality of tracking plots, allowing researchers to get a clearer, qualitative impression of movement patterns. It would be valuable for future research studies to compare Kinect tracking with another 3D method motion tracking, such as Vicon.

Present limitations should not deter future research on depth sensors for human movement quantification. Markerless movement tracking is still a promising tool for investigating musician movement non-invasively in live performance situations. Future research should continue to explore how depth sensor technology could be improved to allow for more accurate and reliable human motion tracking for research purposes, perhaps using a more anatomically accurate skeletal framework to allow for more accurate posture measurements or working directly with the depth map instead of estimating skeletal points. Researchers could also try to work with more recent versions of the Kinect sensor to see if improvements to pose estimation have been addressed in the more current technology. Perhaps in the future, depth-sensing units will be designed by researchers specifically to collect detailed information about human movement, and researchers will not have to work to modify technology that was initially developed for video gaming.

Limitations of this study

This study had some significant technological limitations. For instance, we used a large 1000-watt spotlight to ensure the Kinotape markers were visible in the videos for easy tracking. It is possible that this lamp interfered with the wavelength necessary for the IR

camera to create an accurate depth map, and future studies requiring comparison to video-data should try to use cool LED lights instead. Furthermore, since our Kinect had trouble initiating tracking, we had to move it to various positions throughout testing. Future studies should try to record video data and Kinect data from identical vantage points, perfectly perpendicular to the participants, possible by using the video data that can be generated by the Kinect itself instead of using an external video camera. Another limitation of our study inherent to Dartfish is that the origin of the coordinate system has to be set manually by the measurer, and small deviations in the position of the point of origin between the two videos could contribute to differences in posture variable measurements regardless of potential differences in positioning.

CHAPTER 6: CONCLUSION

The results from our three studies in this thesis provide important information about the suitability of Dartfish and Kinect as quantitative measurement tools for examining the impact of somatic training on the movement and posture of pianists. In the first two sections of this chapter I discuss conclusions relating to Dartfish (studies one and two), and Kinect (study three) respectively, each with subsections that summarize the results and limitations of the studies, before moving into important methodological considerations and recommendations for future research for each measuring tool. In the final section I present three important points that summarize the contributions of our three studies to the field of music pedagogy research.

6.1 Dartfish

6.1.1 Summary of results from studies 1 and 2. Our results indicate Dartfish tracking is reliable across different measurers within 0.5 cm (+/- 0.25 cm) and accurate to within 0.4 cm (+/- 0.2 cm) (Beacon, 2015a). Total analytical error is estimated to be +/-0.25 cm, indicating that Darfish is accurate and reliable enough to be used to quantitatively measure changes in pianist posture of a magnitude of 0.5 centimeters or more. Since the spine angle measurements are calculated from three tracked coordinate points, angle measurements must incorporate the error of two line segments. Therefore, the error for angle measurements is higher, can be considered accurate to within about five degrees.

Results of the second study revealed that Dartfish is an effective tool for tracking anatomical markers on pianists to measure posture variables for comparison across different measurement sessions. While the semi-automatic tracking procedure is effective, researchers must consider that it is time consuming, and that multiple trained users and a few copies of the software may be required for efficient data collection. Results from the measurement of

posture variables revealed no group trends for posture change in post-somatic recording sessions. However, examination of time plots revealed significant changes to movement quality of the head and torso for some individuals. The most notable examples come from participant AP1, who achieved a greater range of motion and smoother integration in the head, torso, and pelvis during scale performances. Another notable example is participant KP2, who exhibited a new pattern of head movements of a greater range for performances of scales and *Für Elise* in session two. These results indicate that some individuals may experience changes to movement and posture habits after a single FI lesson, and further testing is warranted to determine if the effects were related to the somatic training, or were merely expressions of natural posture variability.

6.1.1.1 Limitations of study 1. The primary limitation of the first study is that only three measurers instead of four were available to track the balls mounted on the aluminum rail at the second height, one centimeter above the baseline. Similarly, only two measurers were available to track the swinging ball in the third video. Ideally all four measurers would have been available for each test to allow for a more comprehensive comparison across different software users. It is also possible that the aluminum rail was slightly rotated so that it was not perfectly perpendicular to the camera, despite using a floor grid system and a plumb bob to help position the equipment. Finally, our method of error estimation was utilitarian, and future researchers could attempt a similar study with more comprehensive statistical analysis.

6.1.1.2 Limitations of study 2. The primary limitation of the second study is the small sample size. We only examined fifteen participants, which is too few to look for trends that could be generalized across larger populations. There was also a lack of homogeneity between participants, since we investigated both male and female participants

of any age, as long as they had met the necessary playing qualification of Grade 10 RCM. As such, participants varied between fourteen and fifty years of age. This is not ideal because research has shown that older individuals modulate posture differently (Shumway-Cook & Woollacott, 2000; Lacour, et al., 2008), and often have a greater degree of forward head position than younger adults (Raine & Twomey, 1997). We also observed some inconsistency in the level of preparedness and skill across the participants. For instance, four participants had not adequately memorized *Für Elise* on the day of data collection. As a result, the *Für Elise* test condition did not contain strictly memorized performances. Furthermore, one participant found the playing tests significantly more difficult than the other participants, despite having the appropriate credentials for participation in the study. His performances were much slower, and were not comparable in preparation or quality to the other participants. As a result we collected data from pianists of more disparate abilities than was originally intended when the methodology was devised.

We also experienced limitations with the tracking procedure that could have impacted results slightly. For instance, markers used on participants on the first day of data collection were only a single colour, whereas the markers used on subsequent days of data collection were red stickers mounted on a green background. This made tracking for the first four participants more challenging, since Dartfish was not easily able to track the pixel colour of the markers. As a result, the software users had to track slowly, often adjusting the position of the tracking marker frame by frame. Furthermore, the size of anatomical markers varied slightly, since they were cut by hand from Kinotape. However, since the coordinate is reported as the centre of a circular tracking marker, this should not have impacted the results significantly. Since the point of origin for the coordinate system had to be set manually in each video, it is possible that it was placed in a slightly different position in pre and post-test

videos due to manual error. However, this error is likely less than five millimeters, since the

origin was clearly marked with a green sticker on the piano bench. Finally, the duration of

the FI lesson varied between thirty and forty minutes for each participant, since Alan Fraser

occasionally spent more time talking with the participant about factors relating to their

personal experience of pain or discomfort. The small discrepancy in lesson duration between

participants is not likely to have had a significant effect on posture outcomes. It should be

noted that although the FI lessons were all similar, each participant's lesson contained

movements or manipulations specific to their individual needs, which resulted in a necessary

and expected variation in lesson content between FIs of different participants.

6.1.2 Methodological considerations for measuring pianist posture with Dartfish.

6.1.2.1 Recommendations for experimental set-ups using Dartfish with pianists. In

order for the reported levels of accuracy and repeatability to be achieved using Dartfish

tracking, the video cameras must be carefully levelled and the distance of the camera to the

participant must be kept constant between pre and post-test data. This is important, since

differences in the camera distance for a given participant may result in skewed distance

measurements as a result of the camera distortion. The point of origin also must be clearly

marked in the same spot relative to the participant in each testing session, otherwise the

coordinates will shift according to the difference in origin position in videos from different

sessions. For this reason, it might be preferable in future studies to mark a point of origin

directly on a body part of the individual that remains stationary during piano playing, such as

at the greater trochanter, (hip joint). The use of floor grid systems and laser levelling and

squaring carpenter's tools could also be helpful to ensure that cameras are level and square in

relation to the participant.

6.1.2.2 Choosing and managing playing tests. Generally speaking, it is best to choose a playing test that is simple and easy to learn, or that is well known so that playing quality is as consistent as possible across different participants' performances. However, in order to keep the parameters of performances as consistent as possible, future researchers should consider using a metronome to remind participants of the required tempo before the testing begins, since it is possible that pianists might use different posture and movement patterns for different performance tempos of the same piece. Since video analysis with Dartfish is time consuming, researchers could consider identifying specific phrases of interest from pieces, or ask the pianists to play a piece that repeats the same phrase multiple times, and measure posture only during particular measures on each repetition. This would allow for multiple trials of the same musical material to be taken over the course of one testing session and limit the amount of video data for analysis. Similarly, participants could be asked to play a longer portion of the piece without knowing that the researcher intends to measure posture at only a specific point of interest. This would allow researchers to study posture during specific technical or musical phenomena in the context of a live performance.

6.1.2.3 Ensuring reliability and accuracy in Dartfish tracking procedures. Dartfish tracking results for distance measurements are accurate and repeatable (Beacon, 2015a). However, optimal reliability and accuracy of Dartfish tracking can only be achieved when the markers are highly visible and contrast well with the surrounding pixel colours. In our first and second studies, we found that white balls on a dark blue background worked very well. Researchers should carefully consider the colour of the markers used, and consider using different colours depending on the skin tone of the participants being measured. Generally, we found opaque markers with low reflectivity are preferable. Highly reflective material, such as bike tape, can be difficult to track, since white flashes of light are

occasionally reflected back toward the camera as the person moves in front of a light source. This makes the marker appear white in the video momentarily, which can cause the software to lose track of the marker.

We found no significant differences between the tracking results of the new or more experienced users in our first study, illustrating that Dartfish is easy to use, and can be learned quickly by research assistants. This suggests that future researchers can confidently use different measurers during data collection. The main disadvantage to using Dartfish to measure posture variables is that tracking is only semi-automatic and is quite time consuming. Generally, it takes about fifteen minutes to assign a coordinate origin, carefully track a marker, and export coordinates for a given point of interest for one minute of video data. Tracking is best done in slow motion to ensure that the tracking marker remains over the point of interest continually, since it will frequently slip or jump off target if not monitored. Although it is possible for the software to track more than one point at a time, we do not advise tracking multiple markers simultaneously, since it can be difficult for a software user to carefully monitor two or more points at once. As a result, researchers should carefully consider how many trained users will be available for data collection, and consider getting access to multiple copies of the software so that different users can measure at the same time.

Dartfish software is designed to analyze in a 2D video workspace and is therefore best suited to analyze movements that take place primarily in one plane. Three-dimensional analysis is possible by combining data from two or more cameras, but the experimental set-up and analysis for such an endeavour would be very demanding. Researchers interested in investigating more complex pianistic movement incorporating the arms and hands should find an alternative 3D means of measurement. For instance, Simi Reality Motions systems

(http://www.simi.com/en/) is an eight camera, 3D motion capture system that gives

researchers the option of tracking with markers or by generating a 3D silhouette without the

use of markers. Both processes can be done simultaneously. Unlike Vicon, this system uses

video cameras instead of infrared cameras to collect data. Although Dartfish accuracy and

reliability is likely to remain stable or improve over the coming years as software continues

to be developed, and as the processing speeds of computers and resolution of digital video

cameras improve, ultimately its usefulness is limited by the difficulties of manually

controlling the camera positions in relation to the tracked object and each other and

triuangulating the coordinate data, which is handled automatically by more sophisticated

systems.

Finally, based on our results we suggest that it may be preferable to measure posture

variables in such a way that involves distance as opposed to angles. In our second study,

angles were calculated from two or three tracked points, resulting in a higher degree of

estimated measurement error compared to distance measurements. This is somewhat

problematic, since the changes in spine angles observed in this study were quite small,

(mostly around two to three degrees), which is below the threshold of measurement error

estimated for angles using our measurement procedure. It should be noted that Dartfish has a

function for tracking angles automatically, but we did not test the accuracy and reliability of

this function in any of our studies. Future researchers could evaluate the reliability and

accuracy of this angle tracking function to determine how precisely and reliably angles can

be tracked with Dartfish.

**6.1.3 Recommendations for future research studies using Dartfish with

musicians.** The results of the first and second studies of this thesis have contributed to a

greater understanding of how Dartfish, (or similar video-based 2D tracking software), could

be best applied in research with pianists and postural outcomes of somatic training. Based on the results discussed in the research papers and the previously discussed methodological considerations, I would like to recommend the following three categories of possible research methodologies that could effectively incorporate Dartfish as a postural measuring tool for pianists.

6.1.3.1 Dartfish in mixed-method case studies. Most of the case studies examining the impact of somatic training on individuals currently available in literature are of limited reliability because they tend to contain only subjective impressions from practitioners and students and do not incorporate objectively measured data. Case studies could be improved by incorporating data from objective measurement tools like Dartfish. Future researchers could consider using Dartfish to measure posture and movement in case studies that track individual pianists during long-term participation in somatic training. Quantitative measurements of body positioning could be collected alongside practitioner and participant reports of personal experiences, or questionnaires about physical and psychological outcomes of somatic training. This type of study has been successfully conducted by Staes et al. (2006) who tracked changes to a singer's posture as a result of prolonged exposure to physiotherapy. The basic methodology of Staes and colleagues' study could be modified to use the motion- tracking feature of Dartfish instead of taking posture measurements from isolated video frames. This type of mixed-method case study would address the current need for objective data on body positioning in somatic training research, while respecting the individual nature of various participants' unique experiences with somatic training.

6.1.3.2 Dartfish as a measuring tool in large-scale studies of pianists and somatic training. Dartfish would also be suitable as a measurement tool in large-scale studies that compare posture variable measurements across a multitude of participants. Researchers could

consider examining one or two specific posture variables in thirty to forty pianists before and after a somatic training regimen. In order for this type of study to be reliable, researchers should devise a way to take comprehensive baseline measurements of posture variables over the span of a week or more to clearly establish how naturally variable the specific postures are for each participant. Furthermore, future studies should use control groups, ideally with participants matched in age and gender to those in the intervention group. Control groups could either receive no intervention, or be required to do another activity of a similar nature, such as a meditation session or a dance lesson. Finally, researchers conducting large-scale studies should consider taking posture measurements at various points throughout the duration of longer-term participation in somatic training over the course of weeks or months. Results from our second study did not reveal any group trends in posture change, and it is likely that more substantial changes to posture may be observed after longer periods of committed practice. Researchers might consider investigating ATM lessons instead of FI lessons in large-scale studies, since many participants can attend an ATM class with a single practitioner simultaneously. It is also easier to control the structure and content of an ATM lesson compared to an FI lesson, allowing researchers to strictly control the parameters of the intervention to ensure all participants receive very similar training. This type of study would allow researchers to learn more about how likely it is for somatic training to impact specific posture variables in larger populations of pianists.

6.1.3.3 Dartfish as a feedback tool for teaching somatic training in piano pedagogy.
Although we have examined Dartfish in its capacity as a quantitative measurement tool in the three studies of this thesis, the software was originally developed as a performance analysis tool for coaches. Therefore researchers could also consider investigating its suitability as a feedback tool in the context of learning somatic training as an aspect of piano pedagogy.

Since it is easy to collect video data quickly using webcams, smartphones, or portable video cameras, Dartfish could be used as a feedback tool to help somatic practitioners or piano teachers instruct students about body positioning during piano lessons. Future studies could investigate if the effectiveness of somatic lessons provided in the context of piano lessons could be enhanced using visual feedback and measurement data gathered from Dartfish. For instance, researchers could measure posture before and after a group of piano students undergo regular somatic training in conjunction piano lessons for a set period of time. One group could receive somatic training lessons that incorporate visual feedback from Dartfish as a part of their piano training, while another other group could receive the same intervention without any visual feedback. This could help researchers understand if Dartfish could help piano students more effectively integrate somatic training principles into their playing.

6.2 Kinect

      6.2.1 Summary of results from study 3. Results from our third research project confirmed that Kinect tracking is of inferior quality to Dartfish, and that it does not currently have a high enough resolution to measure small changes in posture variables for the purposes of evaluating somatic training outcomes. Examination of Kinect time plots of posture variables revealed that only sixteen out of forty time plots could be rated as achieving good or excellent quality tracking when compared with the corresponding time-plot from Dartfish. Tracking of the head and shoulder positions was more consistent than tracking for the shoulder, elbow, and spine positions. Furthermore, it appears that tracking in the x-axis is more consistent than tracking in the y-axis. The Kinect time-plots showed evidence of frequent tracking errors. For example, the Kinect often magnified movement patterns in coordinate data, resulting in data that reflected much larger ranges of motion that actually

took place (Beacon, 2015c). Furthermore, the Kinect often momentarily lost track of certain body positions, or momentarily mistook one part of the body for another, resulting in many outlying data points that show up as noise in a Kinect tracking plot. Calculations from Dartfish tracking data revealed post-somatic differences in posture measurements of a magnitude outside the threshold of measurement error for forward head position, C7 height, and head height in some of the weeklong Feldenkrais workshop participants, but these measurements did not correspond in magnitude or direction with the results from the Kinect.

   6.1.2.1 Limitations of study 3. We encountered many technical limitations during data collection for the third study of this thesis. The most significant issue was that the Kinect was often unable to locate the participant to initiate tracking, even if the participant moved around in front of the sensor. We had to move the Kinect closer to or further from the participant when this situation arose. Therefore, the position of the Kinect in relation to the piano was not consistent across all participants, and occasionally it had to be moved between testing sessions of the same participant. This is a major limitation, since the Kinect sensor acts as the origin for the coordinate system that the tracking results are reported on. However, since distances and angles were calculated between tracked coordinate positions, and no measurements were made in reference to points external to the participants in our third study, the error due to positioning in distance and angle measurements is likely minimal. Furthermore, the height of the Kinect remained consistent for each participant, so vertical coordinates would have been tracked based on the same origin position in the y-axis for each participant. We hypothesize that a possible explanation as to why the Kinect had difficulty initiating tracking may have been the bright spotlights used to ensure the visibility of anatomical markers used for simultaneous Dartfish tracking. It is possible that the wavelength of these lights may have interfered with the depth sensor,

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although Microsoft reports that the Kinect will function well in any ambient lighting

conditions, (Microsoft, 2015a). Future studies should avoid using hot halogen lamps, and

instead use cool LED lights, or conduct testing in a lab brightly lit with fluorescent lighting.

6.2.2 Methodological considerations for measuring pianist posture with Kinect.

6.2.2.1 Software development. At the present point in its development, tracking

errors are likely to occur with the Kinect even if it is optimally positioned. The overview of

Kinect literature revealed that other researchers have had greater success with human

movement quantification using Kinect if software is developed to filter out tracking errors.

For instance, filters can be applied to the data that would remove any unnaturally high or low

results based on criteria established by the programmer. Scaling factors could be used to

proportionally adjust the range of movement for variables that the Kinect magnifies. Many of

the Kinect tracking errors could be significantly reduced if the software was developed to

allow researchers to manually set the bone lengths of each body segment according to

anatomical measurements of each participant. Presently, Kinect software constantly re-

estimates bone lengths as it predicts body positions, meaning that the bone length of skeletal

segments can change from frame to frame. If researchers could set bone lengths according to

actual anatomical measurements of participants, these distances would not have to be

estimated, and tracking would be more accurate. Researchers must consider that the

suitability of Kinect as a motion-tracking tool depends largely on the quality of the software,

and should work with a team of experienced programmers to customize software needs for

the project at hand.

6.2.3 Recommendations for future research using Kinect with musicians.

Presently, the technology is best suited for gaining qualitative information about the position

of the head and shoulder centre, or general movement trajectories that involve a range of

motion of greater than about 5 centimeters. Since our results show that the Kinect appears to track the head and shoulder centre positions most consistently, it is possible that researchers could use tracking data from these two skeletal points to gain qualitative information about movement patterns during musical performance. For instance, researchers could use tracking data from the head in the *x*-axis to track cuing or expressive movements of pianists, perhaps while they are playing chamber music or performing with an orchestra. However, if detailed information about movement is required, a different tracking technology should be used, such as Dartfish, or an optical-based 3D system.

Present limitations should not deter future research on depth sensors for human movement quantification. Markerless movement tracking is still a promising tool for investigating musician movement non-invasively and in real performance situations. Future research should continue to explore how depth sensor technology could be improved to allow for more accurate and reliable human motion tracking for research purposes. One area of immediate interest for researchers would be to work directly with the depth maps created by the Kinect to get real 3D images to be processed instead of relying on the Kinect skeletal alogrithms, which are often imprecise. Researchers could also work with more recent versions of the Kinect sensor to see if improvements to pose estimation have been addressed in the more current technology. However, ultimately the Kinect will always be limited as a tool for precise movement quantification because it is developed for the control of avatars in video games and not as a measurement tool. Perhaps in the future, depth-sensing units will be designed specifically to collect detailed information about human movement, and researchers will not have to work to modify technology that was initially developed for video games.

6.3 Concluding Discussion

Taken together, the results from the three studies in this thesis present researchers in piano pedagogy with important information about the suitability of Kinect and Dartfish as alternatives to optical-based tracking tools in studies on the impact of somatic training on the posture of pianists. I would like to conclude this thesis by briefly discussing the following three points to contextualize the significance of our results in a more global context pertaining to the fields of piano pedagogy and performance research.

6.3.1. The value of motion tracking technology in music performance and pedagogy research. The core ambition behind the pursuit of this thesis was to explore tools that would allow researchers to examine the posture and movement of pianists in greater detail. Our success with the Dartfish software has illustrated that video-based software is an excellent tool for quantitatively examining pianistic movement. Although we used Dartfish to answer research questions specific to somatic training outcomes on posture and movement, we made many intriguing observations during data analysis that raised questions outside of the scope of our present studies. For instance, examination of back-view videos revealed that the strongest performers in our study tended to have much lower average angles of elbow extension, tending to keep their upper-arm parallel with their torso, while weaker performers tended to keep their elbows extended away from the body while playing. We also found that the angle of elbow extension was much greater on the right side compared to left for all pianists during the performance of contrary motion-C major scales. It was also intriguing to find that individual pianists seemed to have different preferred head positions depending on if they were performing *Für Elise,* the scale test, or the sight-reading test. Furthermore, examining the time plots of coordinates from different anatomical markers allowed us to view a graphical representation of expressive movements of the head and torso,

and it was fascinating to compare these time plots with audio data of the performances to see how the movements corresponded with musical phrasing. These examples illustrate that quantitative analysis of pianistic movement using motion tracking technology can give rich insight into body-use during performance, and that it could be used in many applications to help researchers examine aspects of movement that are not easily observable by the naked eye or discover how other aspects of the performers' experience are related to their movement. For instance, motion-tracking data from various body positions could be compared alongside other physiological factors monitored during performance, such as heart rate, breathing, skin conductivity, EEG, and sEMG recordings of muscle activity. Motion-tracking data could also be plotted against factors such as sound amplitude, musical texture, range, articulation, cadences points, or even mood/affect to learn how various body movements are related to the musical and technical aspects of the performance. Most of a musician's training focuses on refining their ability to predictably and reliably translate movement into sound. How a musician uses their body will determine the quality of their playing, and will also influence their risk for developing playing-related pain disorders. Therefore, future piano pedagogy researchers should capitalize on motion tracking technology to examine pianistic movement in greater depth, thereby stimulating new research on body-use in performance, and shaping new pedagogical strategies and technical approaches to piano playing. It is my hope that one of the major contributions of this thesis is to highlight the usefulness of motion tracking in music performance and pedagogy, and to promote its use in future research endeavours.

      6.3.2 The necessity of examining individuals in Feldenkrais research. An integral motivation behind my pursuit of this thesis was the urgent need for new research that objectively examines somatic training outcomes, since most evidence suggesting that

somatic training can lead to improvements in playing related pain or musical expression

comes from subjective sources. The Feldenkrais Method, among other somatic approaches,

has helped many musicians feel more comfortable when performing, and increasing

awareness about these methods may help to improve the quality of life of many performers,

especially students who experience tremendous workloads and high degrees of physical and

emotional stress during their degrees (Kelly, 2015). However, universities and conservatories

will need more credible evidence from research about the benefits of these methods to defend

the cost of incorporating them into programming. Furthermore, somatic training lessons are

often not covered by medical insurance plans and are therefore not always affordable for

musicians who may benefit from them. Improved research could pave the way for the

eventual coverage of somatic training by insurance plans or may at least help students

become informed about the potential benefits of somatic training, should they choose to

invest their time and money into learning them. At first it might seem that the best way to

address the need for objective research would be to conduct rigorous scientific studies with

many participants to search for trends that would give an indication about how often positive

changes to variables of interest are seen in a greater population. As was demonstrated in the

literature review, large-scale clinical studies of this nature have been conducted on non-

musician populations to investigate the suitability of somatic training as an intervention for

musculoskeletal pain (Lundblad et al., 1999; Kendall et al., 2001; Malmgren-Olsson &

Bränholm, 2002 Little et al., 2008; Yardley et al., 2010). Unfortunately, most of these studies

have not been able to draw clear conclusions about the ability of somatic training to

influence musculoskeletal pain symptoms or body functionality, (although results do clearly

indicate that somatic methods can have a positive psychological impact on participants' self-

efficacy for pain management in comparison with more standard treatment modalities, such

as physiotherapy). Usually these studies compare results across participants of a variety of ages, with many different types of musculoskeletal complaints, and researchers struggle to find ways to meaningfully measure the experience in such a way that can be reliably compared across a group of participants.

In our second study, comparing the results of posture measurements across the group of participants did not reveal any trends in posture change, since the posture changes across participants and playing tests were highly variable in both the pre- and post-test sessions. It is possible that longer-term studies involving more participants may reveal clear trends in changes to alignment similar to those observed in the head position of non-musicians undergoing eight weeks of Alexander Technique training in the previously discussed study by Kutschke (2010), (see section 1.3.3). However, the most interesting results from our second study came from examining *individual* cases of participants and seeing how their *specific* movement characteristics appeared to be different or similar between the first and second recording sessions separated by the FI lesson. Using coordinate data we were able to view details about how movement became more integrated throughout the torso during scale performances for participant AP1. We also viewed larger, graceful head movements in participant KP2's session two recordings, when her head was held almost perfectly still in session one. Although more than two measurement sessions would be required to determine if the changes observed reflect natural variability in movement habits or changes induced by somatic training, these examples are intriguing and warrant further investigation.

Since each individual presents with their own habits of movement, history of pain or injury, and specific musculoskeletal needs, Feldenkrais practitioners must connect with their students on a very personal level, exploring the responses of their central nervous system to various controlled movements to find out the specific needs of the individual. The

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Feldenkrais method is better characterized as a style of communication that seeks to promote motor learning, instead of a set of prescribed manipulations or exercises that can easily be transferred from one individual to another. Therefore, future researchers investigating the impact of Feldenkrais training on posture and movement are likely to learn the most by conducting detailed observations of individuals' particular responses in case studies. The most interesting data is likely to come from an intersection of detailed knowledge of a participant's baseline measurements and habits, experiences with pain, previous injury, participant impressions of treatment, while incorporating quantitative posture and movement measurements as an important source of data. Studies that insist on looking for trends in large groups are not only unlikely to get clear results, but also rusk overlooking the essence of individual communication at the core of the Feldenkrais method. The most meaningful and authentic research on somatic training will make attempts to preserve the focus on the individual as an integral component of the methodology.

   6.3.3 The importance of researching posture in the context of movement. Perhaps the most important issue raised by this thesis is the limitations inherent in studying posture as a static position. As was outlined in the literature review, piano posture has traditionally been taught as a static, upright and lengthened position of the back and neck (Bastien, J. & Bastien, J. S., 1985; Barden, Kowalchyk, & Lancaster, 2009; Vogt & Bates, 2001; Curie, 1985; Fletcher, 2012). Similarly, most attempts to quantitatively measure posture for research purposes have taken measurements from static standing or seated positions (Raine & Twomey, 1997; Szeto et al., 2002; Dunk et al., 2005; Pownall et al., 2008). Up until recently, researchers have tended to prioritize attempts to define ideal or average measurements for resting angles in spine curvature or head positions in methodologies, but have thus far been unable to agree on standardized measurement protocols, making it

difficult to compare results across different studies (Peterson et al., 1997). Furthermore, even

when posture variables are successfully measured, researchers have yet to reach a consensus

about which range of measurements should constitute healthy posture or problematic posture.

With the exception of forward head position, which has been linked to higher incidences of

neck pain (Szeto et al., 2002; Ruivo et al., 2014), researchers have been unable to link other

specific posture attributes, (such as thoracic and lumbar kyphosis, or rounded shoulders) to

higher incidences of musculoskeletal pain (Peterson et al., 1997; Grob, et al., 2007; Claus et

al., 2009). These confusions illustrate that although superficially it may seem like an easy

task to create criteria for judging posture quality and to choose posture variables for

measurement in posture research, the many divergent opinions presented in the literature

pose significant challenges to researchers seeking to determine if various interventions can

improve or impact posture.

Although specific posture variables can be measured, ultimately they represent

average positions that tell us little about how a person actually uses their body during

movement. Somatic training methods, such as the Feldenkrais Method, seek to influence

motor control habits of individuals and are concerned with functionality of the body, and not

with achieving specific postural positions. Feldenkrais believed in a principle of dynamic

equilibrium, by which posture is not a position, but rather a process through which the

central nervous system solves balance problems in different movement situations through

proprioceptive and sensory feedback (Feldenkrais, 1982). Therefore, the most profound

changes to motor control strategies mediating posture are likely to be observed when the

body is in motion instead of when it is at rest, manifesting as changes to movement quality,

such as smoothness, range of motion, and new ways of integrating various parts of the body.

If this is the case, data collected from tracking technologies like Dartfish, Kinect, or optical-

based systems, may not be best analysed by measuring average values of posture variables, but by developing new analytical techniques that seek to comment on movement quality and patterns. Future researchers could focus on developing analytical techniques to statistically and mathematically describe changes to movement patterns using coordinate data retrieved from tracking systems. This type of perspective would align more closely with newer pedagogical approaches to posture in dance research that seek to incorporate movement, balance, and imagery exercises into pedagogical strategies to help dancers improve alignment, instead of focusing solely on encouraging dancers to improve alignment through volitional effort (Franklin, 1996; Krasnow et al., 2001). Similarly, analytical techniques focusing on movement quality would fit well with a developing theory of motor control called dynamic systems theory, which posits that human behaviour emerges as a result of the interaction of multiple subsystems in the nervous system, allowing flexibility and stability of motor behaviour to coexist due to neuroplasticity (Ginsburg, 1999; Buchanan, 2001). These newer currents of thought seem to suggest that simplistic models of posture involving vertical plumb lines, or directives to 'sit up taller' may not be highly useful in the context of movement (Woodhull et al., 1985; Woodhall et al., 1990). Just as piano pedagogues have taken issue with traditional teaching approaches that characterize playing posture as a position to be attained and maintained, so should posture researchers take issue with analytical approaches that seek to examine posture outside of the context of movement.

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APPENDIX A

Advertisements for participant recruitment

Poster for Alan Fraser's Piano Technique Institute

Poster for participant recruitment

Email correspondence sent to teachers from the Ontario Registered Music Teachers Association

Dear <mark>piano teacher,</mark>
I would like to inform you about an opportunity to participate in an exciting research project that I will be conducting at the Piano Pedagogy Research Laboratory at the University of Ottawa for my masters thesis. The project seeks to help researchers and piano teachers better understand the impact of Feldenkrais training on aspects of piano playing.

In order to investigate this question we are looking for volunteer pianists to come to our lab between July 14 and 20 for a 90-minute experimental session during which participants will receive a FREE one-on-one lesson with renowned piano pedagogue and Feldenkrais Teacher, Alan Fraser. This is a perfect opportunity to try a somatic training lesson for individuals who are curious about what this type of training involves and what it has to offer. More information about Alan Fraser can be found at his two websites:
   http://alanfraser.net/
   http://www.pianotechnique.net/AlanFraserInstitute/

Please see the attached letter of information and poster to get more details about this exciting opportunity. For more information and to find out how you can participate, please contact the primary researcher, Jillian Beacon or the research supervisor, Dr. Gilles Comeau:

Sincerely,

Primary Researcher
Jillian Beacon
B.Mus-Integrated Studies (piano)
Masters Diploma in Piano Pedagogy Research

MA candidate (University of Ottawa)
Research Supervisor:
Dr. Gilles Comeau, Ph.D.
Faculty of Graduate Studies- School of Music
University of Ottawa

APPENDIX B

Letters of Information, Consent Forms, Demographic Forms

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LETTER OF INFORMATION (Study 2 & 3)

Dear piano teacher/piano student:

I am conducting an exciting, collaborative research study to investigate the impact of participation in Feldenkrais training on aspects of piano playing. This method has become popular with pianists to help improve movement and alignment at the piano, and as interventions or preventative measures for playing related musculoskeletal pain. Unfortunately, scientific research validating the outcomes of participation in Feldenkrais training is scarce, and researchers have few tools to help them track changes in pianists' movement or performance. I hope to address these concerns in this study by exploring 2D video analysis and 3D motion tracking as tools to measure changes in pianistic movement and positioning in response to somatic training.

The research study will be undertaken as my masters thesis project and involves collaboration between the University of Ottawa Piano Pedagogy Research Laboratory, and the Department of Engineering.
We are currently recruiting participants to take part in the study and receive a Feldenkrais session, free of charge, between July 14 and 20, 2014. Below you will find a description of the study and the tasks involved. Should you wish to volunteer to take part in the study, or if you would like more information, please do not hesitate to contact the primary researcher, Jillian Beacon or the research supervisor, Dr. Gilles Comeau.

Project Title: Investigating visual methods of assessing and measuring changes in the physical aspects of piano performance in response to Feldenkrais training

Primary researcher:
Jillian Beacon, MA Candidate
Faculty of Graduate Studies-School of Music
University of Ottawa

Research Supervisor:
Dr. Gilles Comeau, Ph.D.
Faculty of Graduate Studies- School of Music
University of Ottawa

Objective: The objective of the study is to better understand how a session of somatic training can influence aspects of piano playing and to explore how video analysis and tracking technologies can be used to measure pianistic movement.

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Criteria for Participation:

You are eligible to participate if you:

- Have achieved a playing level of grade 10 RCM or are studying piano at a university level.
- Have no previous experience with Feldenkrais training.
- Are currently taking piano lessons, or in the case of older students or graduates, spend a minimum of three hours a week practicing piano OR play or teach piano as an aspect of their career.
- Are 16 years of age or older

Participation:

As a participant, you will be asked to perform a four-minute set of playing tests before, immediately after, and thirty-minutes after receiving a free, 30-minute Feldenkrais training lesson, one-on-one with a licensed practitioner. Performances of these playing tasks will be video recorded from vantage points behind and to the right of you and audio data will also be recorded using the MIDI-recorder in a Disklavier piano. The set of playing tasks will include:

-contrary motion C major scales (in sixteenth notes at 84 bpm), 3 octaves, repeated 4 times
-C major triads, hands together, 5 octaves(in quarter notes with a quarter rest between, at 84 bpm)
-a short sight-reading excerpt of about grade 5-6 level.
-The "A"section of Für Elise and Robert Schumann's "The Wild Rider" from memory.

Participants will be asked to bring their own black pants and a tight fitting, sleeveless, dark-coloured fitness top to wear during testing. Fifteen-minutes prior to the first playing test, a qualified research assistant will position round, non-toxic, adhesive markers to points to participants' face, arms, neck, back, torso, and hips. Small marks may be drawn on participants' skin using a non-toxic body pencil to ensure the anatomical points can be found again, should markers fall off during testing or during the Feldenkrais training lesson. These markers will help researchers make accurate measurements using video analysis software. Participants will also be asked to fill out a short demographic information form prior to testing.

Total testing time will last 90 minutes. Sessions will be scheduled at a time convenient for you in communication with the research coordinator. All sessions will take place in room 208 of Pérez Hall at the University of Ottawa.

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Time/Location: All testing will take place at the Piano Pedagogy Research Laboratory **July 14-20, 2014** at the University of Ottawa:
Pérez Hall
50 University Private
Room 204
Ottawa, Ontario
Canada, K1N 6N5

Appointments for 90 minute testing sessions will be scheduled based on the availability of the participant.

Funding: The University of Ottawa will pay for all costs. No cost will be transferred to participants. Participants will not be compensated.

Practitioner information: All somatic training lessons will be given by licensed practitioners who are currently offering professional services and who have a minimum of 5 years of experience.

Risks: Participants will undergo a Feldenkrais training lesson, which requires performing slow and gentle movements or and gentle manipulations of muscle tissue and joints by a registered practitioner. Your participation carries with it a very low risk of physical discomfort due to potential muscle fatigue, strain, or the aggravation of pre-existing injury. Participation in this project will also involve live performance of music in front of researchers and a Feldenkrais practitioner. As such, there is a risk that you may feel mild emotional or psychological discomfort due to shyness or performance anxiety. Every effort will be made to minimize these risks by ensuring that only experienced, registered practitioners interact with participants. A debriefing session will also be offered to you at the conclusion of testing during which you may ask questions or raise any concerns you may have.

Benefits of project: Participants will directly benefit by receiving a somatic training lesson from Alan Fraser, a licensed Feldenkrais practitioner and professuinal pianistπ, free of charge. Research on the outcomes of somatic training is scarce, and this project will help shed light on the specific physical benefits pianists may experience as a result in somatic training. Your participation will help researchers further investigate the role of Feldenkrais training in music pedagogy and injury prevention/intervention.

Voluntary participation: Participation in this project is completely voluntary and participants reserve the right to withdraw from the study at any time, for any reason and do not need to provide justification for withdrawal.

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Ethics clearance: This project has been reviewed and has received ethics clearance by the University of Ottawa Social Sciences and Humanities Research Ethics Board. Any questions regarding the ethical conduct of this study may be addressed to the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON K1N 6N5
Tel.: (613) 562-5387
Email: ethics@uottawa.ca

Please keep this form for your records.

Thank you for your time and consideration.

Jillian Beacon

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LETTER OF INFORMATION FOR PARENTS (Study 2)

Dear parent:

I am conducting an exciting, collaborative research study to investigate the impact of participation in Feldenkrais training on aspects of piano playing. This method has become popular with pianists to help improve movement and alignment at the piano, and as interventions or preventative measures for playing related musculoskeletal pain. Unfortunately, scientific research validating the outcomes of participation in Feldenkrais training is scarce, and researchers have few tools to help them track changes in pianists' movement or performance. I hope to address these concerns in this study by exploring 2D video analysis and 3D motion tracking as tools to measure changes in pianistic movement and positioning in response to somatic training.

The research study will be undertaken as my masters thesis project and involves collaboration between the University of Ottawa Piano Pedagogy Research Laboratory, and the Department of Engineering. **We are currently recruiting participants age 16 and older to take part in the study and receive a Feldenkrais session, free of charge.** Below you will find a description of the study and the tasks involved. Should you wish to allow your child to volunteer to take part in the study, or if you would like more information, please do not hesitate to contact the primary researcher, Jillian Beacon or the research supervisor, Dr. Gilles Comeau.

Project Title: Investigating visual methods of assessing and measuring changes in the physical aspects of piano performance in response to Feldenkrais training

Primary researcher:
Jillian Beacon, MA Candidate
Faculty of Graduate Studies-School of Music
University of Ottawa

Research Supervisor:
Dr. Gilles Comeau, Ph.D.
Faculty of Graduate Studies- School of Music
University of Ottawa

Objective: The objective of the study is to better understand how a session of somatic training can influence aspects of piano playing and to explore how video analysis and tracking technologies can be used to measure pianistic movement.

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Criteria for Participation:

Your child is eligible to participate if he/she:

- Has achieved a playing level of grade 10 RCM
- Has no previous experience with Feldenkrais training.
- Are currently taking piano lessons
- Are 16 years of age or older

Participation:

As a participant, your child will be asked to perform a four-minute set of playing tests before, immediately after, and thirty-minutes after receiving a free, 30-minute Feldenkrais training lesson, one-on-one with a licensed practitioner. Performances of these playing tasks will be video recorded from vantage points behind and to the right of your child and audio data will also be recorded using the MIDI-recorder in a Disklavier piano. The set of playing tasks will include:
-contrary motion C major scales (in sixteenth notes at 84 bpm)
-C major triads, hands together, (in quarter notes with a quarter rest between, at 84 bpm)
-a short sight-reading excerpt of about grade 5-6 level.
-an excerpt from a prescribed piece of grade 8-9 level, given ahead of time.

You will be required to provide your child with black pants and a tight fitting, sleeveless, dark-coloured fitness top to be worn during testing. Fifteen-minutes prior to the first playing test, a qualified research assistant will position round, non-toxic, adhesive markers to points on your child's face, arms, neck, back, torso, and hips. Small marks may be drawn on your child's skin using a non-toxic body pencil to ensure the anatomical points can be found again, should markers fall off during testing or during the Feldenkrais training lesson. These markers will help researchers make accurate measurements using video analysis software. Your child will also be asked to fill out a short demographic information form prior to testing.

Total testing time will last 90 minutes. Sessions will be scheduled at a time convenient for you in communication with the research coordinator. All sessions will take place in room 208 of Pérez Hall at the University of Ottawa.
Time/Location: All testing will take place at the Piano Pedagogy Research Laboratory at the University of Ottawa:
Pérez Hall
50 University Private
Room 204

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Appointments for 90 minute testing sessions will be scheduled based on the availability of the participant.

Funding: The University of Ottawa will pay for all costs. No cost will be transferred to you, should your child volunteer to participate. Participants will not be compensated.

Practitioner information: All somatic training lessons will be given by licensed practitioners who are currently offering professional services and who have a minimum of 5 years of experience.

Risks: As a participant, your child will undergo a 30-min Feldenkrais session, which involves slow and gentle movements or and gentle manipulations of muscle tissue and joints by a registered practitioner. Your child's participation carries with it a very low risk of physical discomfort due to potential muscle fatigue, strain, or the aggravation of pre-existing injury. Participation in this project will also involve live performance of music in front of researchers and a Feldenkrais practitioner. As such, there is a risk that your child may feel mild emotional or psychological discomfort due to shyness or performance anxiety. Every effort will be made to minimize these risks by ensuring that only experienced, registered practitioners interact with your child. A debriefing session will also be offered to you at the conclusion of testing during which you may ask questions or raise any concerns you may have.

Benefits of project: Your child will directly benefit by receiving a somatic training lesson from a licensed practitioner, free of charge. Research on the outcomes of somatic training is scarce, and this project will help shed light on the specific physical benefits pianists may experience as a result in somatic training. Your child's participation will help researchers further investigate the role of Feldenkrais training in music pedagogy and injury prevention/intervention.

Voluntary participation: Your consent and your child's participation in this project is completely voluntary and participants reserve the right to withdraw from the study at any time, for any reason and do not need to provide justification for withdrawal.

Ethics clearance: This project has been reviewed and has received ethics clearance by the University of Ottawa Social Sciences and Humanities Research Ethics Board. Any questions regarding the ethical conduct of this study may be addressed to the Protocol Officer for

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Email: ethics@uottawa.ca

Please keep this form for your records.

Thank you for your time and consideration.

Jillian Beacon

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PARTICIPANT CONSENT FORM (Study 2)

Title of study: Investigating visual methods of assessing and measuring changes in the physical aspects of piano performance in response to weeklong Feldenkrais training

Primary researcher:
Jillian Beacon, MA Candidate
Faculty of Graduate Studies-School of Music
University of Ottawa

Research Supervisor:
Dr. Gilles Comeau, Ph.D.
Faculty of Graduate Studies- School of Music
University of Ottawa

Invitation to Participate: I am invited to participate in the abovementioned research study conducted by Jillian Beacon. This study is conducted under the supervision of Dr. Gilles Comeau and is being undertaken as Ms. Beacon's masters thesis project.

Purpose of the Study: The purpose of the study is to better understand how a session of Feldenkrais training can influence aspects of piano playing and to explore how video analysis and tracking technologies can be used to measure pianistic movement.

Participation: My participation in this project will involve performing an 8 minute set of playing tests before and after a weeklong piano institute incorporating Feldenkrais training with Alan Fraser, a licensed practitioner and professional pianist. My performances of these playing tasks will be video recorded from vantage points behind and to the right of me and audio data will also be recorded using the MIDI-recorder in a Disklavier piano. The set of playing tasks will include:

-contrary motion C major scales (in sixteenth notes at 84 bpm), 3 octaves, repeated 4 times
-C major triads, hands together, 5 octaves(in quarter notes with a quarter rest between, at 84 bpm)
-a short sight-reading excerpt of about grade 5-6 level.
-The "A"section of Für Elise and Robert Schumann's "The Wild Rider" from memory.
-a 45 second excerpt from a piece of my choosing that I will work on with Alan

I will be required to bring black pants and a tight fitting, sleeveless, dark-coloured fitness to be worn for testing. Fifteen-minutes prior to the first playing test, a qualified research assistant will position round, non-toxic, adhesive markers to points to my face, arms, neck, back, torso, and hips. Small marks may be drawn on my skin using a non-toxic body pencil to ensure the anatomical points can be found again, should markers fall off during testing. These markers will help researchers make accurate measurements using video analysis software. I will also be asked to fill out a short demographic information form prior to testing.

Total testing time will last 90 minutes. Sessions will be scheduled at a time convenient for me in communication with the research coordinator. All sessions will take place in room 208 of Pérez Hall at the University of Ottawa.

Risks: My participation in this study will entail that I participate in a Feldenkrais training lesson, which requires performing slow and gentle movements or having my joints gently manipulated by a registered practitioner. I recognize that participation carries with it a very low risk of physical discomfort due to potential muscle fatigue, strain, or the aggravation of pre-existing injury. Participation in this project will also involve live performance of music in front of researchers and a Feldenkrais practitioner. As such, there is a risk that I may feel mild emotional or psychological discomfort due to shyness or performance anxiety. I have received assurance from the researcher that every effort will be made to minimize these risks by ensuring that only experienced, registered practitioners will interact with me. A debriefing session will also be offered to me at the conclusion of testing during which I may ask questions or raise any concerns I may have.

Benefits: My participation in this study will allow me to gain quantitative insight into changes that take place in my performanc and body positioning over the course of the institute. Research on the outcomes and benefits of Feldenkrais training is scarce, and my participation in this project will help shed light on the specific physical benefits pianists may experience as a result of Feldenkrais training. Armed with greater knowledge about somatic training outcomes, future research can help to further refine the role of somatic training interventions in music pedagogy and injury prevention/intervention.

Confidentiality and anonymity: I have received assurance from the researcher that the information I will share and the video and audio data of my performances will remain strictly confidential. I understand that all data will be used for analysis in this research study only and that my confidentiality will be protected. **Anonymity** will be protected in the following manner: My name will not be associated with any data, and I will be assigned a numeric code to be used by the researcher as a reference. Only the principle researcher and research supervisor will have access to the codes or pseudonyms that would link data to my identity. My face will be blackened out of any of the videos/images of me that may be used in presentations or publications. My identity will not be revealed in any publications.

Conservation of data: The video, audio, and demographic data collected on digital storage devices (such as SD cards, floppy discs, DVD's), paper forms, and stored on computer hard-drives will be kept in a secure manner. All original data will be stored in locked filing cabinets in the Piano Pedagogy Research Laboratory, room 204, Pérez Hall, at the University of Ottawa for five years following the completion of the thesis in September, 2013. This lab is monitored by administrators during all office hours, is kept locked when unoccupied, and is equipped with an active alarm system at all times. Access to the data will be restricted to Professor Gilles Comeau, Jillian Beacon, and authorized research assistants who have signed a confidentiality form. At the conclusion of the five-year conservation period all paper documents will be shredded, all DVD's and SD cards will be destroyed, and any electronic files will be deleted.

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Voluntary Participation: I am under no obligation to participate and if I choose to participate, I can withdraw from the study at any time and/or refuse to answer any questions, without suffering any negative consequences. If I choose to withdraw, all data gathered until the time of withdrawal will be destroyed. Digital video and audio files will be deleted from digital storage devices, and demographic forms will be shredded.

Acceptance: I, _____ agree to participate in the above research study conducted by Jillian Beacon of the Department of Music, Faculty of Graduate Studies, at the University of Ottawa. This research is under the supervision of Dr. Gilles Comeau.

If I have any questions about the study, I may contact the researcher or her supervisor.

If I have any questions regarding the ethical conduct of this study, I may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON K1N 6N5
Tel.: (613) 562-5387
Email: ethics@uottawa.ca

There are two copies of the consent form, one of which is mine to keep.

Participant's signature: Date:

_____
_____

Researcher's signature: Date:

_____
_____

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PARTICIPANT CONSENT FORM (Study 3)

Title of study: Investigating visual methods of assessing and measuring changes in the physical aspects of piano performance in response to weeklong Feldenkrais training

Primary researcher:

Jillian Beacon, MA Candidate Faculty of Graduate Studies-School of Music University of

Research Supervisor:

Dr. Gilles Comeau, Ph.D. Faculty of Graduate Studies- School of Music University of Ottawa

Invitation to Participate: I am invited to participate in the abovementioned research study conducted by Jillian Beacon. This study is conducted under the supervision of Dr. Gilles Comeau and is being undertaken as Ms. Beacon's masters thesis project.

Purpose of the Study: The purpose of the study is to better understand how a session of Feldenkrais training can influence aspects of piano playing and to explore how video analysis and tracking technologies can be used to measure pianistic movement.

Participation: My participation in this project will involve performing an 8 minute set of playing tests before and after a weeklong piano institute incorporating Feldenkrais training with Alan Fraser, a licensed practitioner and professional pianist. My performances of these playing tasks will be video recorded from vantage points behind and to the right of me and audio data will also be recorded using the MIDI-recorder in a Disklavier piano. The set of playing tasks will include:

-contrary motion C major scales (in sixteenth notes at 84 bpm), 3 octaves, repeated 4 times - C major triads, hands together, 5 octaves(in quarter notes with a quarter rest between, at 84 bpm) -a short sight-reading excerpt of about grade 5-6 level. -The "A"section of Für Elise and Robert Schumann's "The Wild Rider" from memory. -a 45 second excerpt from a piece of my choosing that I will work on with Alan

I will be required to bring black pants and a tight fitting, sleeveless, dark-coloured fitness to be worn for testing. Fifteen-minutes prior to the first playing test, a qualified research assistant will position round, non-toxic, adhesive markers to points to my face, arms, neck, back, torso, and hips. Small marks may be drawn on my skin using a non-toxic body pencil to ensure the anatomical points can be found again, should markers fall off during testing. These markers will help researchers make accurate measurements using video analysis software. I will also be asked to fill out a short demographic information form prior to

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testing.

Total testing time will last 90 minutes. Sessions will be scheduled at a time convenient for me in communication with the research coordinator. All sessions will take place in room 208 of Pérez Hall at the University of Ottawa.

Risks: My participation in this study will entail that I participate in a Feldenkrais training lesson, which requires performing slow and gentle movements or having my joints gently manipulated by a registered practitioner. I recognize that participation carries with it a very low risk of physical discomfort due to potential muscle fatigue, strain, or the aggravation of pre-existing injury. Participation in this project will also involve live performance of music in front of researchers and a Feldenkrais practitioner. As such, there is a risk that I may feel mild emotional or psychological discomfort due to shyness or performance anxiety. I have received assurance from the researcher that every effort will be made to minimize these risks by ensuring that only experienced, registered practitioners will interact with me. A debriefing session will also be offered to me at the conclusion of testing during which I may ask questions or raise any concerns I may have.

Benefits: My participation in this study will allow me to gain quantitative insight into changes that take place in my performanc and body positioning over the course of the institute. Research on the outcomes and benefits of Feldenkrais training is scarce, and my participation in this project will help shed light on the specific physical benefits pianists may experience as a result of Feldenkrais training. Armed with greater knowledge about somatic training outcomes, future research can help to further refine the role of somatic training interventions in music pedagogy and injury prevention/intervention.

Confidentiality and anonymity: I have received assurance from the researcher that the information I will share and the video and audio data of my performances will remain strictly confidential. I understand that all data will be used for analysis in this research study only and that my confidentiality will be protected. **Anonymity** will be protected in the following manner: My name will not be associated with any data, and I will be assigned a numeric code to be used by the researcher as a reference. Only the principle researcher and research supervisor will have access to the codes or pseudonyms that would link data to my identity. My face will be blackened out of any of the videos/images of me that may be used in presentations or publications. My identity will not be revealed in any publications.

Conservation of data: The video, audio, and demographic data collected on digital storage devices (such as SD cards, floppy discs, DVD's), paper forms, and stored on computer hard-drives will be kept in a secure manner. All original data will be stored in locked filing cabinets in the Piano Pedagogy Research Laboratory, room 204, Pérez Hall, at the University of Ottawa for five years following the completion of the thesis in September, 2013. This lab

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is monitored by administrators during all office hours, is kept locked when unoccupied, and is equipped with an active alarm system at all times. Access to the data will be restricted to Professor Gilles Comeau, Jillian Beacon, and authorized research assistants who have signed a confidentiality form. At the conclusion of the five-year conservation period all paper documents will be shredded, all DVD's and SD cards will be destroyed, and any electronic files will be deleted.

Voluntary Participation: I am under no obligation to participate and if I choose to participate, I can withdraw from the study at any time and/or refuse to answer any questions, without suffering any negative consequences. If I choose to withdraw, all data gathered until the time of withdrawal will be destroyed. Digital video and audio files will be deleted from digital storage devices, and demographic forms will be shredded.

Acceptance: I, _____ agree to participate in the above research study conducted by Jillian Beacon of the Department of Music, Faculty of Graduate Studies, at the University of Ottawa. This research is under the supervision of Dr. Gilles Comeau.

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Email: ethics@uottawa.ca There are two copies of the consent form, one of which is mine to keep.

Participant's signature: _____ Date: _____

Researcher's signature: _____ Date: _____

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PARTICIPANT DEMOGRAPHIC FORM

Identifiers	
Name	
Email address	
Phone number	
Alpha-Numeric Codes (for office use only)	
Physical Characteristics	
1. Height (in cm)	
2. Weight (in kg)	
3. Age/year of birth	
4. Gender	
History of Piano Playing/Lessons	
1. How many years of piano lessons have you had?	
2. Age that study of piano commenced:	
3. Are you currently studying piano?: Y/N Location/teacher	
4. Highest level of music training attained (degree/RCM certificate/etc):	
5. Do you play the piano as an aspect of your career? Y/N	
6. Approximately how many hours a week do you spend practicing/playing piano?	
7. Do you have any history with any form of somatic training, (such as Alexander Technique, Body Mapping, Eutony, etc), either one-on-one, or in a group)?	
8. If so, please describe your previous participation in somatic training (length of time, frequency, type etc).	
9. Do you participate in any fitness/physical conditioning activities, such as, but not limited to sports, yoga, dance, swimming, etc?	
10. If so, please describe briefly and estimate the total number of hours per week spent on physical fitness/conditioning activities:	
11. Do you have any history/experience	

with playing-related musculoskeletal pain? If so, please describe briefly, including the location of the pain, approximate time of onset, whether it has resolved or is ongoing, and whether you sought or are seeking treatment:	
10. Why are you interested in participating in this study?	