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Breathing Patters of Advanced Pianists While Executing Four Performing Tasks

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Breathing patterns of advanced pianists while executing four performing tasks

by

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Abstract

Over the last fifty years, researchers have taken an interest in the breathing of different musicians. Little is known on the breathing patterns of pianists, however. Two main studies on the subject determined that a variation in meter affects breathing rhythms and that breathing rate might be linked to tempo and musical gestures, but we do not know whether a relationship exists between pianists' respiratory cycles and the movements they make when playing, or between breathing and specific musical elements such as rhythm, meter, tempo or phrasing. Eight pianists played the C major scale, the C major arpeggio, a Hanon five-finger exercise, the *Minuet in G major* by Petzöld, and *Für Elise* by Beethoven on a Yamaha Disklavier. During their performances, respiration was monitored by an inductive plethysmography system (RIPmate Respiratory Effort System). Although the results were not consistent across participants, it was clear that for some pianists breathing and performing were related.

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Contents

List of Tables

List of Figures

Chapter 1

Introduction

The primary function of the respiratory system is the intake of oxygen and the release of carbon dioxide that occur between the lungs and the environment. Other than gas exchange, the respiratory system is involved in the regulation of pH balance in tissues, the protection of respiratory surfaces from the environment, the participation in the olfactory sense and the production of speech or song. Sound production and speech result from a combination of the different pressures and flows as well as the constriction of certain respiratory structures. Voice intensity, vocal frequency, linguistic stress and speech division are regulated by the respiratory pump during verbalization (Hixon, 1991). As with its use during speech and song, the respiratory system is put into practise when playing certain musical instruments.

1.1 Breathing of Wind Players and Singers

The art of playing a musical instrument has been studied from many standpoints. Many research studies have been done on the psychological, neurological (Harrer & Harrer, 1977), anatomical (Conable, 2000; Weiss, 1996) and physiological (Andrews, 2005; Schneck & Berger, 2006) aspects of musicians. As research has accumulated on the various physiological demands of being a musician, breathing has emerged as a point of interest.

Much work has been done on the respiratory patterns of wind players (Bouhuys, 1964; Cossette, Monaco, Aliverti, & Maclem, 2008; Cossette, Sliwinski, & Macklem, 2000; Kelly, 1997; Gilbert, 1998; Shemann, 2000) and singers (Thomasson & Sundberg, 2001; Thorpe, Cala, Chapman, & Davis, 2001). Breathing is essential for the sound production when playing a wind instrument or singing, as air is the energy source required to make the elastic material vibrate. Because of that necessity, wind players and singers train their breathing which results in an increased awareness of respiration. Their breathing becomes a conscious act that is governed by the phrasing in the score, and changes according to pressure or flow requirements of the instrument.

In contrast to wind players, the breathing of string musicians or pianists does not have to be voluntary or used consciously for sound production. Consequently, piano teachers do not often include respiratory exercises or comments in their lessons and rarely discuss breathing in the context of music expression. Two studies have directly investigated the respiration of pianists (Ebert, Hefter, Binkofski, & Freund, 2002; King, 2006), looking at the relationship between meter, tempo, structure and physical movement and breathing while playing. However, extensive research still needs to be done to learn more about the topic, as well as to investigate the effects of experience level on the respiration of pianists.

1.2 Piano Pedagogy Material

Although the majority of piano pedagogy material does not discuss how to integrate breathing into a teaching context, the topic of respiration has been addressed (Bernstein, 1981; Mark, 2003; Sandor, 1981). Despite the fact that there is not a great deal of research into breathing at the piano, the documentation of breathing and piano playing in pedagogical material clearly demonstrates its importance. From their pedagogical points of view as teachers, some authors discuss common breathing problems that pianists face, such as trying to get air in the belly, tightening the abdominal wall, tightening the throat muscles, expanding the chest forward, tensing up the diaphragm, heavy breathing and breath holding (Mark, 2003; Sandor, 1981). One could hypothesize that they might be mainly linked to tension. However, these issues have not precisely been investigated by these authors.

Gyorgy Sandor (1981) discusses breathing in piano playing from an expressive and physiological standpoint. He mentions how tension caused by excessive muscular contractions in and around the respiratory system can result in a malfunction of the breathing apparatus which consequently affects various musical elements like phrasing, rubato, tempo and accentuation. Sandor points out the importance of the diaphragm as a respiratory muscle during a piano performance, since more oxygen is required to meet the demands of the body functions. Also, he discusses how the diaphragm can participate in staccato playing. He makes a link between the diaphragm action in singers or wind players and the rapid contractions of the diaphragm in piano playing. He emphasizes that the overall muscular tension seen during playing can also affect the diaphragm, leading to inefficient breathing, and addresses the topic of coordination between the fingers, arms, body and breathing. Sandor mentions that upward motions are associated with inhalation and downward motions with exhalation. In the scientific literature, no studies have examined the diaphragm during piano playing but many controversies exist on this topic regarding wind instrumentalists and singers.

Two other authors that deal with breathing in piano playing are Thomas Mark and Seymour Bernstein. Mark (2003) addresses the physiological requirements of a pianist in *What Every Pianist Needs to Know about the Body.* He tries to raise awareness of the importance of breathing and clarifies certain often-taught breathing myths such as "sucking in the gut" when you want to inhale. Interestingly, Mark brings up the topic of breathing with the phrase. He states that singers and wind players coordinate their respiration with musical phrases whereas pianists do not necessarily choose to follow this rule. If the pianist decides to breathe with the musical phrase, Mark recommends mapping breathing throughout the piece. Bernstein (1981) looks at correct breathing from an interpretive point of view in *With Your Own Two Hands.* He believes that under certain conditions it is important to learn how to control one's breathing. He quotes Lowen (1975): "Just as strong emotions stimulate and deepen one's breathing, the stimulation and deepening of respiration can evoke strong emotion." (p.37). Bernstein deduces that correct breathing would help the pianist feel the music and recommends some general breathing exercises common to singers.

The presented examples clearly demonstrate the importance given to breathing within pedagogical works. In order to integrate this knowledge in a pedagogical context and solidify its validity and accuracy, we would need to specifically verify these issues through empirical research. This will be covered in this thesis which is divided into 6 parts. The following section, the review of literature, will provide an overview of the respiratory system, basic concepts in coordination and survey contemporary literature on breathing. Since there are relatively few studies dealing with breathing at the piano, the review will also cover the research on the coordination of respiration with various small muscle movements and the breathing of musicians such as string players. The chapter concludes with a summary and critique of existing literature, and a discussion of the specific research goals and hypotheses that will be examined in this study. Afterwards, the three articles in preparation for submission to journals will be presented. A general discussion will review the results and conclude this thesis followed by the authors' contribution.

Chapter 2

Review of Literature

In order to understand the literature on breathing, it is important to cover some basic concepts on the respiratory system and on coordination which will recur in the various research studies discussed later in this thesis.

2.1 Basic Concepts

The first part of this section presents respiratory processes and respiration regulation; the second part addresses the concept of coordination.

2.1.1 Respiratory System

It is impossible for human beings to survive without oxygen. The millions of cells in the body need a constant uptake of oxygen and removal of carbon dioxide (CO_2). This exchange allows the cells to generate energy in order to fulfill the various metabolic needs and maintain homeostasis[1]. Physiologists define the process of respiration as the oxy-

[1]Homeostasis is defined as the constant internal equilibrium state which the body maintains despite external environmental changes and disturbances. (Marieb, 1992)

genation resulting from the exchange of gases between an organism and its environment (Davies & Moores, 2003).

Respiratory Processes

The principle role of the respiratory apparatus is to supply the body structures with oxygen and to get rid of the CO_2. The respiratory apparatus is divided into two sections. The pulmonary apparatus contains the airways and the lungs (Figure 2.1). Its role is the conduction of air required for gas exchange (Hixon, 2006). The second section is the chest wall that encases the pulmonary apparatus and contains also the rib cage wall, the diaphragm, abdominal wall, and abdominal content (Figure 2.1) (Hixon, 2006). With these various components, the respiratory system performs four different processes: pulmonary ventilation, which includes inhalation and exhalation; external respiration, which is the exchange of gases in the lungs; internal respiration, which is the exchange of gases in the tissues; and the transport of respiratory gases (Marieb, 1992). This thesis will focus mainly on the pulmonary ventilation part of the respiratory system as it relates to movement.

The following description of pulmonary ventilation, the exchange of air between the lungs and the environment through inspiration and expiration, is based on a text by De Troyer (1991). To perform this task, the respiratory system uses active forces, requiring the participation of muscles, and passive forces, which depend on gravity and physical properties of the tissues (Hixon, 2006). Inspiration is usually active and necessitates the action of many muscles except when it begins at a lower lung volume than the functional residual capacity (Figure 2.4), for example at residual volume. The diaphragm is the primary muscle of inspiration. This dome-shaped muscle divides the thorax from the abdomen (Figure 2.1). When it contracts during inspiration, it descends, increasing the volume of the thorax. This in turn, lowers the pressure under the atmospheric pressure

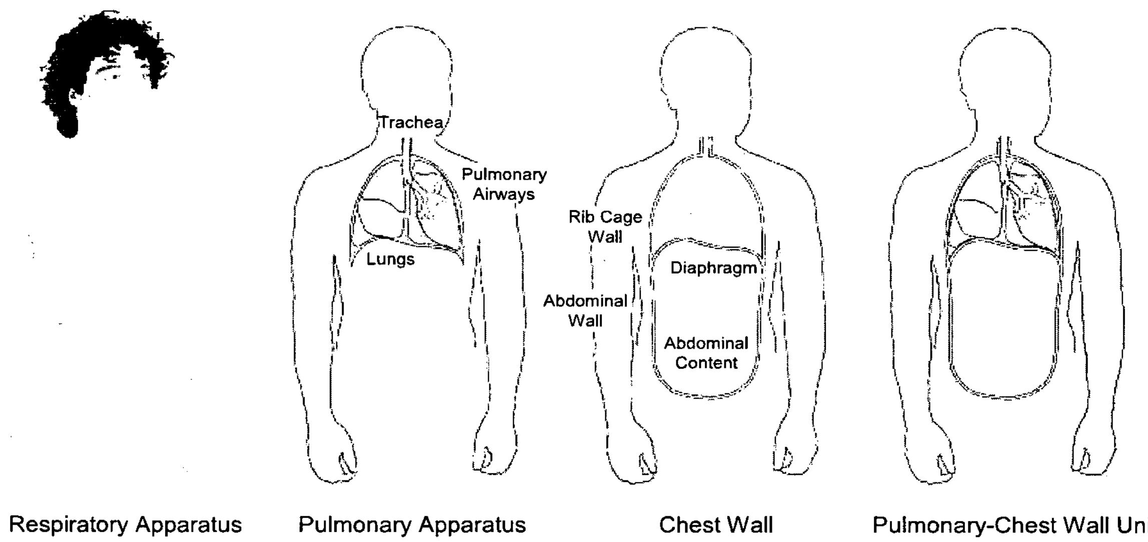

Figure 2.1: Components of the human respiratory apparatus. (Hixon, 2006)

consequently making the air rush in. As a result of its contraction, the descent of the diaphragm increases the abdominal pressure. Because of this pressure and since the abdomen contains liquid that cannot be compressed, the abdominal wall expands and goes outwards producing the "belly out" effect. The external intercostal muscles are also crucial to inspiration (Figure 2.2). These muscles lie between the ribs and lift them when they contract, helping to expand the volume of the rib cage. The last muscles involved in inspiration during quiet breathing are the scalenus muscles located on the side of the neck (Figure 2.2). They assist the diaphragm action by elevating the two first ribs thus completing the thoracic elevation for inhalation. When forced breathing is used, the sternocleidomastoid (Figure 2.2), an accessory muscle which contributes to the elevation of the rib cage, is contracted. The contraction of all these muscles increases the volume of the thoracic cavity. Boyle's law[2] states that the product of pressure and volume for a gas in a chamber is constant under isothermal conditions (Lerner, 1996). In accordance

[2]Boyle's law states that at constant temperature the volume of gas in a chamber is inversely proportional to its pressure over a wide range of pressures. This relationship is defined by the equation: P $P_1 \cdot V_1 = P_2 \cdot V_2$. (Lerner, 1996)

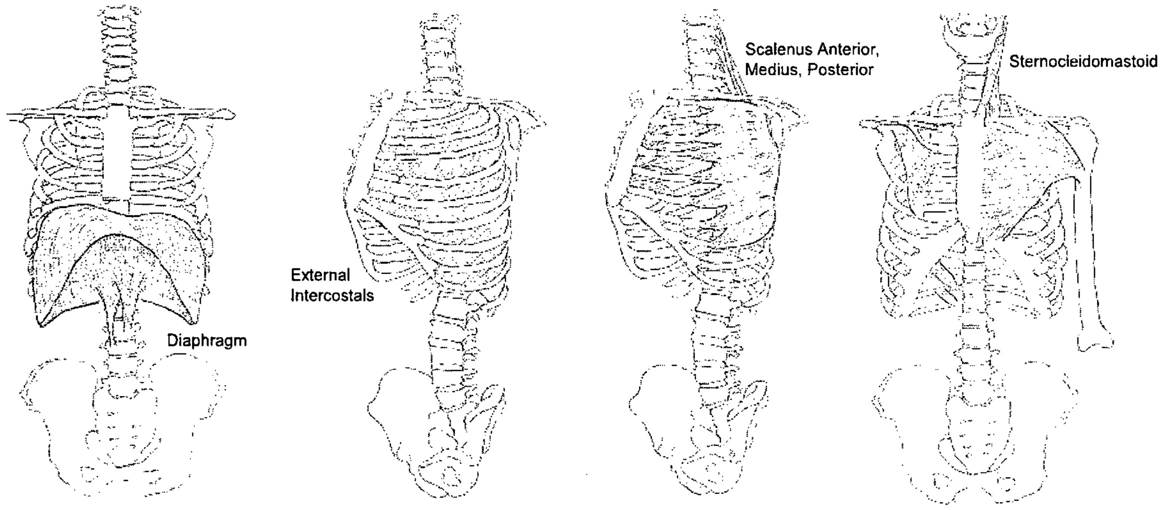

Figure 2.2: The main muscles involved in inspiration (diaphragm, external intercostals, scalenus, sternocleidomastoid). (Hixon, 2006)

with this rule, the enlargement of the thoracic cavity resulting from the contraction of the muscles creates a drop in pressure causing air to flow in to fill the void until the intrapulmonary pressure is equal to atmospheric pressure (West, 2000).

Expiration is the respiratory system's way of removing carbon dioxide from the body. During quiet breathing, expiration is passive and relies on gravity and the natural physical properties of the various muscles and structures such as the recoil of the lungs or rib cage and the surface tension in the alveoli. The diaphragm relaxes back into its upper position, the external intercostals relax and gravity pulls the thorax down into its original position (De Troyer, 1991). These changes cause the pressure in the thoracic cavity to increase, resulting in the air flowing out until intrapulmonary pressure equals atmospheric pressure. For active expiration, certain additional muscles are required. The abdominal wall muscles (Figure 2.3) such as the rectus abdominis, internal and external obliques and transversus abdominis contract, which force the repositioning of the diaphragm into its elevated position (De Troyer, 1991). The action of these muscles in addition to the

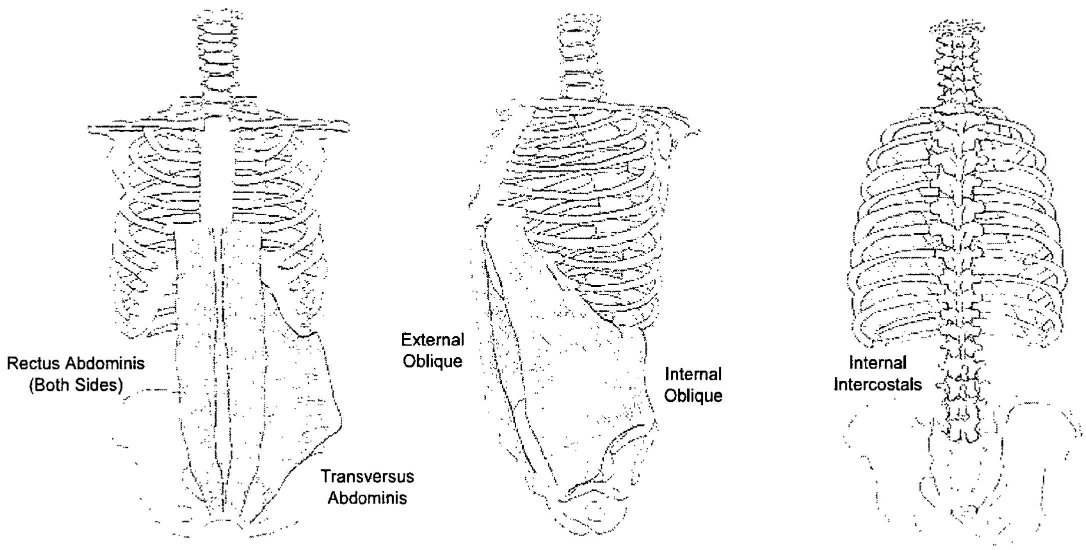

Figure 2.3: The main muscles involved in forced expiration (rectus abdominis, transversus abdominis, external obliques, internal intercostals). (Hixon 2006)

contraction of the internal intercostals (Figure 2.3) causes an increase of pressure in the thorax which makes airflow rush outwards.

After ventilation, external respiration is the process of converting the deoxygenated blood, coming from the right side of the heart, to oxygenated blood (Marieb, 1992). Because of the differences in partial pressure gradients, oxygen diffuses rapidly from the alveoli to the blood in the pulmonary capillaries. Finally, during internal respiration, there is gas exchange between the capillaries and the tissue cells. Because of the partial pressure differences between the arterial capillaries and the interstitial area, the cells take up the oxygen through diffusion and release the CO_2 that they had produced. The steps described above form a continuous respiratory cycle which is regulated through many pathways.

The processes of inspiration and expiration cause volumes of gas within the lungs to constantly change (Figure 2.4). The following descriptions of the pulmonary volumes are largely inspired by the text from Wanger and colleagues (2005). The tidal volume (TV) is the amount of air that the lungs exchange with the environment with each respiratory cycle. At rest, tidal volume increases compared to exercise conditions (Martin & Weil, 1979). The residual volume (RV) is the amount of air that stays in the lungs even after a forced expiration. The maximum amount of air that can be forcibly exhaled after a normal expiration is the expiratory reserve volume (ERV). Similarly, the maximum amount of air that can be forcibly inhaled after a normal inspiration is the inspiratory reserve volume (IRV). It is possible to calculate various lung capacities by adding together two or more lung volumes. The total lung capacity (TLC) is the amount of air in the lungs after a maximum inspiration. Inspiratory capacity (IC) is the total volume of air that can be inspired. Functional residual capacity (FRC) is the volume of air left in the lungs at the end of tidal respiration. The measurement of this plateau can be used as a reference point to determine changes in respiratory patterns. Kinesiology studies confirm that FRC decreases during physical activity (Johnson, Weisman, Zeballos, & Beck, 1999). Vital capacity (VC) is the maximum amount of air expired after a forced inspiration since it includes all the lung volumes except residual volume. Lung volumes change with different conditions (at rest, position, exercise) and characteristics such as height, weight, ethnicity, health and age (Pellegrino et al., 2005; Ruppel, 2001; Stocks & Quanjer, 1995). For the purposes of this thesis, we will measure the functional residual capacity to determine if there are changes in respiratory patterns at rest and during the various performing tasks.

Respiration Regulation

The regulation of respiration is a complex phenomenon that involves many different pathways. There are three basic elements of the respiratory system: the sensors, the central controller in the brain, and the effectors, which are the respiratory muscles. The sensors

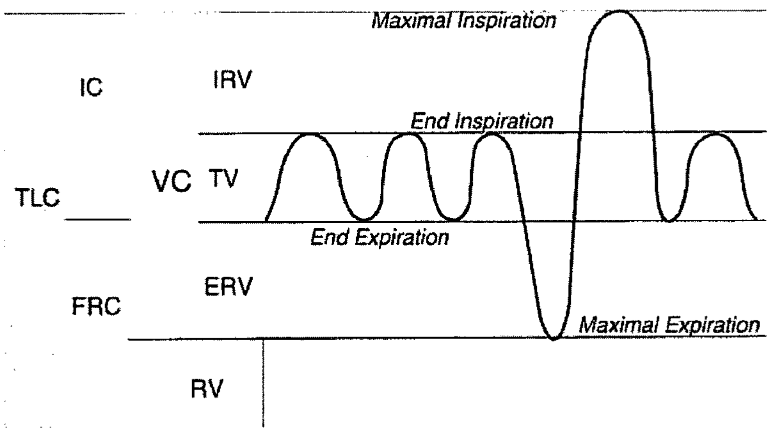

Figure 2.4: The various lung volumes and capacities: total lung capacity (TLC), inspiratory capacity (IC), functional residual capacity (FRC), vital capacity (VC), inspiratory reserve volume (IRV), tital volume (TV), expiratory reserve volume (ERV), residual volume (RV). (Ruppel, 2001)

gather information and send it to the central controller in the brain, which organizes the information and sends impulses to the effectors (West, 2000). For the purpose of this thesis, information on the central controller as well as brief information on sensors is given in this section.

Depending on whether breathing is automatic, voluntary or caused by emotions, respiration regulation is controlled in different parts of the central nervous system. The main component of this system is located in the medulla oblongata of the brainstem, also known as the respiratory control center. In this central controller, there are three main groups of neurons: the medullary respiratory center (which includes the inspiratory and expiratory area), the apneustic area and the pneumotaxic area. Tidal respiration or quiet breathing is automatic and is regulated by the inspiratory area. The neurons of that area create a central pattern generator producing rhythmic respiration in order to insure that the right amount of arterial blood gas is present for maintaining homeostasis (West, 2000). The brainstem can also send contraction commands to the respiratory

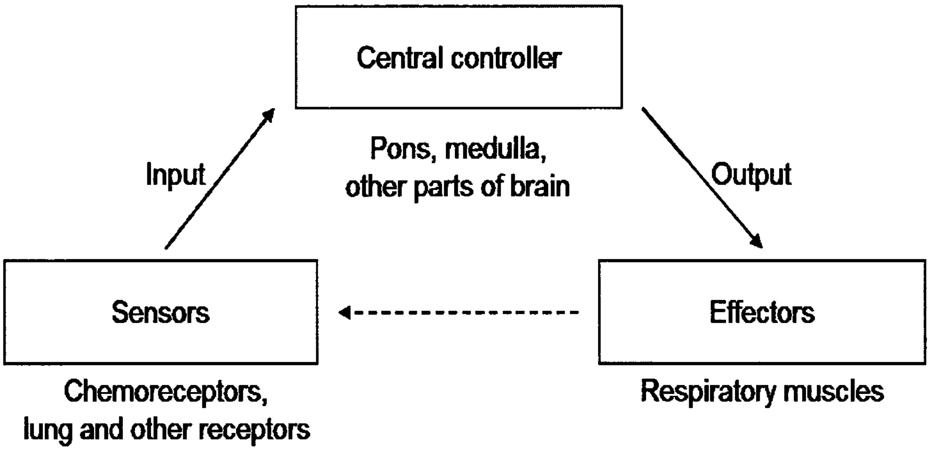

Figure 2.5: Interactions between the basic elements of the respiratory control system. The solid lines represent a positive feedback and the dotted line a negative feedback. (West, 2000)

muscles through peripheral nerves. These commands are performed unconsciously, or consciously-when we feel the need to breathe. Special acts of respiration, other than the maintenance of homeostasis, can be highly conscious (breath holding, guided respiration) or slightly conscious (wind instrument playing, singing). They are controlled by the higher brain centers since they involve a motor plan (Hixon, 2006). The expiratory area is utilized during forceful breathing. The impulses from this area activate the contraction of muscles used in exhalation. Impulses from the apneustic area result in prolonged breaths (West, 2000). Finally, the pneumotaxic area shortens the duration of inhalation and has a role in the control of inspiratory volumes (West, 2000). The activity of the higher brain centres can override the activity of the brainstem respiratory centre up to a certain point. Breath holding is a good example of this since it can be voluntarily controlled until the signals from the chemoreceptors[3] become too strong to counteract and normal respiration has to resume.

[3]A chemoreceptor is defined as a receptor that responses to chemical changes of the surrounding fluid. (West, 2000)

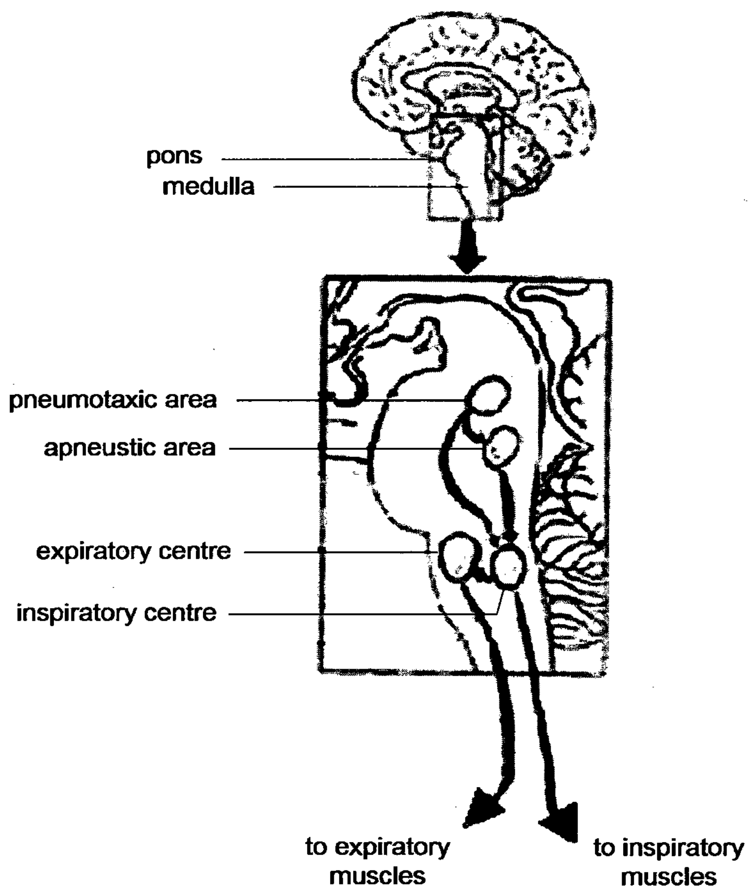

Figure 2.6: Respiratory central controller. (Marieb, 1992)

Sensors also play a major role in the regulation of breathing. Changes in PCO_2 and PO_2 (the partial pressures of CO_2 and O_2, defined as the amount of carbon dioxide or oxygen dissolved in the blood) and in pH, all of which are detected by the chemoreceptors, influence the regulation of respiration. A decrease in arterial PO_2, as well as a decrease in pH or an increase in PCO_2 affects them. Any of these changes causes them to send a signal to the central nervous system and leads to an eventual increase of ventilation (West, 2000). Lung receptors and other receptors in the body are also types of sensors. The receptors found in the lungs are the pulmonary stretch receptors, the irritant receptors and the J receptors. Other receptors that contribute to regulation are the nose and upper airway receptors, the joint and muscle receptors, the gamma system, the arterial baroreceptors, and the pain and temperature receptors (Leff & Schumacker, 1993; West, 2000).

Various factors affect the respiratory rate of individuals such as age (Leblanc, Ruff, & Milic-Emili, 1970; McFadden, Price, Eastwood, & Briggs, 1982; Rusconi et al., 1994), physical activity (Rossi, Plicchi, Canducci, Rognoni, & Aina, 1984; Rowland & Green, 1988), sleeping (Snyder, Hobson, Morrison, & Goldfrank, 1964; Tusiewicz, Moldofsky, Bryan, & Bryan, 1977) and an individual's emotional state (Boiten, Frijda, & Wientjes, 1994) amongst others. Kinesiology studies confirm that respiratory rate during the performance of physical activity is higher than at rest (Arai et al., 1989). Furthermore, it has been shown that even smaller limb movements can cause an increase of breathing rate (Ebert, Rassler, & Hefter, 2000; Wilke, Lansing, & Roger, 1975) even though small muscular motions require less energy. The metabolic demands of the body vary a lot. For example, metabolism increases significantly due to muscular work related to exercise. As oxygen consumption increases, so does carbon dioxide output. Consequently, alveolar ventilation must increase to eliminate the excess of carbon dioxide. Necessary increasing or decreasing of ventilation caused by variations in the chemical drive is achieved by changes of tidal volume and of breathing rate.

Coordination

Another important concept in this thesis is coordination, which refers to the relationship between two rhythms - for example, between breathing and pianistic gestures. Holst pioneered the research on coordination in 1939 when investigating the locomotor rhythms of fish. He defined coordination as a tuning of temporal patterns during which one oscillator imposes its tempo and phasing onto another oscillator (Holst, 1939). In other words, there is a fixed time relationship between phases of two rhythmical movements. This coordination indicates the entrainment of one rhythm on the other. Holst also distinguished between absolute and relative coordination. When absolute coordination is present, the phase relationship between the two or more interacting components is constant whereas in the case of relative coordination there might sometimes be a drift between the coordinating components (Kelso, DeGuzman, & Holroyd, 1991; Perségol, Jordan, & Viala, 1991).

Coordination is often used to study the relationship between the breathing cycle and various rhythms. The coordination between breathing and various bodily rhythms is complex since respiration is linked to many motor subsystems by neuronal interactions (Ebert et al., 2000). Certain movements can cause breathing patterns to change for long periods of time. In some cases, the respiratory rhythms end up following the tempo frequency of the simultaneous movement (Wilke et al., 1975).

In order to study coordination, phase intervals are typically used (Figure 2.7) (Ebert et al., 2000; Ebert et al., 2002; Fabre, Perrey, Arbez, & Rouillon, 2007). This involves the measurement of the time difference between a specific point of the movement cycle and a specific point of the respiratory cycle, such as expiration or inspiration for example. This thesis will use phase intervals to determine if coordination occurs between breathing and various movements during different piano performance tasks.

2.2 Literature on Breathing

Since there are few studies directly addressing the relationship between pianistic gestures and breathing during a performance, it is important to review the broader literature on breathing and movement. Therefore, the following section will examine the literature on the coordination of breathing with smaller movements before dealing with the breathing of string players and pianists. Finally, this section will include a review of the tools

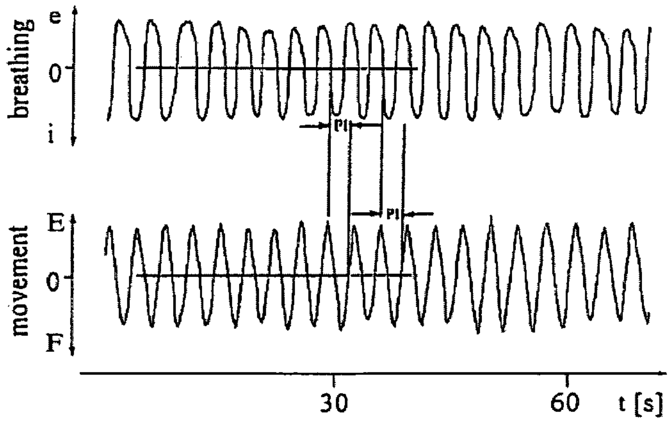

Figure 2.7: Phase intervals found to determine coordination between breathing and regular forearm movements during sinusoidal tracking. (Ebert et al., 2000)

commonly used in respiration-related studies.

2.2.1 Coordination of Breathing with Small Movements

Relationships between breathing and body rhythms leading to respiratory entrainment have been studied in both animals and humans (Bramble & Carrier, 1983). Movement characteristics such as type (Bechbache & Duffin, 1977), frequency (Perségol et al., 1991) and work load (Bernasconi & Kohl, 1993) have been said to affect the degree of entrainment between movement and breathing. Moreover, factors like movement familiarity (Bramble & Carrier, 1983) and various environmental conditions (Paterson, Wood, Marshall, Morton, & Harrison, 1987) can also have an effect on the entrainment. Many studies have been done on the entrainment of breathing with larger movements such as those seen during exercise. These studies have established a coordination between breathing and walking rhythms (Rassler & Kohl, 1996), running rhythms (Bramble & Carrier, 1983), cycling rhythms (Kohl, Koller, & Jäger, 1981), cross-country skiing rhythms (Fabre et al., 2007) and rowing rhythms (Mahler, Hunter, Lentine, & Ward, 1991). For actions on a smaller scale, there is information on the entrainment of breathing with limb movements (Agostoni & D'Angelo, 1976), forearm tracking (Ebert et al., 2000), eye and head movements (Rassler & Raabe, 2003) and finger movements (Rassler, 2000; Rassler, Bradl, & Scholle, 2000; Rassler, Ebert, Waurick, & Jaughans, 1996; Wilke et al., 1975). Since piano playing requires the use of smaller limb movements with the fingers, hand, wrist, forearm, upper arm, shoulder and back (Mark, 2003), the focus of the first part of the review of literature will be on the coordination of breathing and smaller-scaled motions and on how the understanding in this area is relevant to the study of pianistic gestures and breathing.

Breathing and Head and Eye Movement

Rassler and Raabe (2003) investigated the effects of muscle-group size and the intention of movement (voluntary versus involuntary) on breathing entrainment. They conducted this study by asking subjects to perform different head and eye movements, some voluntary, others involuntary. The six conditions used were: rest, active head movement with eyes opened, active head movement with eyes closed, active eye movement, passive turning with eyes opened and passive turning with eyes closed. While the subjects were performing the specific tasks, their breathing was monitored with a pneumotachograph that kept track of the time of inspiration, the time of expiration and the total breathing cycle time. Results demonstrated that breathing entrainment is possible even in the absence of voluntary rhythmical movements. Breathing and active head movements with closed eyes showed the most coordination. They also concluded that the size of the muscle group did not necessarily have an effect on the entrainment. Most importantly, this study re-confirmed that coordination is an unconscious phenomenon that does not depend on mechanical or intentional factors.

Eye movements and head movements are an important part of piano playing. The eyes are constantly in movement while reading and following the score. In addition, pianists will not only look at the score during a performance, but also at their hands moving from one end of the keyboard to another. In some cases, the eyes have to follow the hand at the extremities of the piano. When this happens, the visual stimulus is located too far away, forcing the head to rotate (Bartz, 1966). Head movements in a performance are also sometimes present for the performer's expressive purposes. For example, at the beginning of a performance, the pianist might bow his head and close his eyes to gain concentration (Van Zile, 1988). All pianists express the music in their own way and head movements have been shown to be a means of music expression (Clarke & Davidson, 1998; Dahl & Friberg, 2004; Davidson, 1993). Consequently, similarities can be seen between Rassler and Raabe's (2003) experiments on head and eye movement and the movements that occur during a piano performance, even though they are not regular. Despite the fact that this study is important to include in this review because it leads one to wonder whether or not eye and head movement are factors that affect breathing during a performance, such an experiment goes beyond the objectives of this thesis. However, the topic could be considered in future studies.

Breathing and Finger Movements

Some research has addressed the coordination of breathing and finger movements. In a recent article on the mutual nervous influences between breathing and precision finger movements, Rassler (2000) discussed the effects of precision short-term finger tracking on the respiratory cycle and vice versa. The right-handed subjects had to perform short spontaneous and pre-determined flexion and extension finger movements while their respiration was being recorded. The results indicated that there is an association between short-term finger tracking and modulations of the respiratory cycle. Short-term finger tracking movements caused changes in the pattern of the current breath, also affecting the next breath cycles. Since no respiratory muscles were required for the task, Rassler assumed that these modifications of breathing were the result of central nervous interactions. Other studies (Iscoe & Polosa, 1976; Nishino & Hiraga, 1991) had already demonstrated that motor actions during inspiration shortened the simultaneously occurring breath. When analyzing the influence of breathing on movement precision, Rassler found that during late expiration, flexion movements were less precise and during late inspiration, extension movements lost precision. The loss of precision caused more finger-tracking mistakes during those instances. He noted that this phenomenon is more noticeable for finger flexions than for finger extensions.

Rassler, Bradl & Scholl (2000) looked at the interaction of breathing and motor control of the postural regulation of the fingers to determine if the interactions previously seen between breathing and small motor acts are also present during the postural motor regulation of the fingers. Seventeen subjects had to flex their stretched fingers against a constant preload and maintain them in a 30° position. At random moments, additional torque loads were applied forcing the subjects to adapt to the new torque level. During the task, the respiration was monitored with a face mask attached to a pneumotachograph. Results showed a relationship between breathing and the regulation of finger posture. The subjects reacted faster to a torque load at the beginning of inspiration and responded more precisely when the torque load was added during mid-expiration. The motor response to torque load led to changes in the breathing time course.

Wilke and colleagues (1975) studied finger tapping and respiration. The main purpose of the study was to determine whether changes in the frequency of a motor act using smaller muscles not related to respiration would affect breath timing and breathing frequency. Another objective was to investigate the difference in coordination between breathing and simultaneous finger tapping when the subject was breathing voluntarily and involuntarily. Breathing at rest was first measured. Basal breathing rate was calculated and divided by five. The college-age subjects were asked to tap on a button

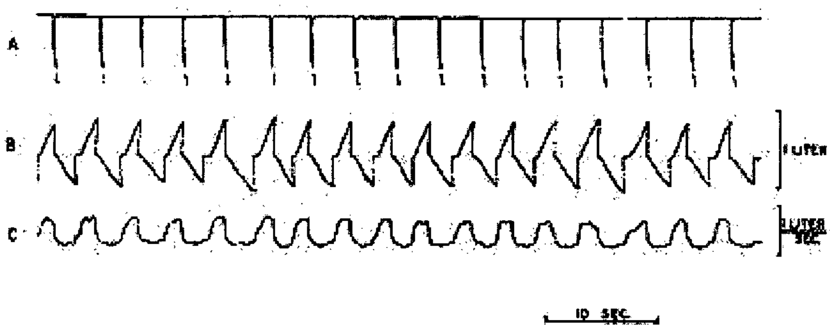

Figure 2.8: The phase synchronization of tapping and breathing. Row A) Each vertical line represents a finger tap. Row B) Respiratory volumes where inspiration is upward. Row C) Air flow where inspiration is upward. (Wilke et al., 1975)

following a signal every five beats meaning that they were tapping at the same frequency as their own breathing rate. By asking the participants to tap every five beats, the researcher was sure that the subject's information processing capacity was occupied, so he or she would not be thinking about breathing and would concentrate on the motor task. The researcher would then slightly change the speed of the signal to see if breathing rate would change with the speed of the motor act. An obvious entrainment occurred between finger tapping and involuntary breathing for a certain range of change (Figure 2.8). For example, during slower tapping rates, an abnormally slower respiratory rate was noticed for a few breaths. An extra breath would be taken and synchronicity would resume. When tapping rate moved out of the range of effect by becoming too fast or too slow, synchronicity no longer occurred.

For the second part of the experiment, the subjects were asked to synchronize their breathing with the finger tapping and signal beats while being acutely aware of what they were doing. The researcher presented the same tapping rates as in the first experiment. Interestingly, there was a decrease of synchronicity when the subjects followed these latter instructions compared to when they were asked simply to concentrate on finger tapping. The participants were having difficulty in controlling their breathing to the rhythm and often anticipated the signal. It took an average of four minutes of practise for the subjects to accurately synchronize their breathing with the tapping and the signal whereas during involuntary breathing, the entrainment developed much faster.

These three studies focus on the relationship between breathing and different finger motions and involve similar finger extensions, flexions and torque as those seen in piano playing. The flexions and extensions are needed to reach the notes that are spaced at different interval distances on the piano. Also, finger torque is required to press down the piano keys. The participants in both studies were asked to perform a movement that required precision and accuracy. Rassler (2000) observed that loss of movement precision and tracking mistakes occurred at certain points of the respiratory cycle. Knowing this, one might wonder if the finger-action precision in piano playing is likewise affected. Wilke and colleagues (1975) were interested in the finger tapping movement. Playing the piano involves the same motion since going from one note to the other requires constant up and down movement of the carpo-metacarpal joints where the fingers start. Wilke and colleagues found that coordination occurred between tapping and respiration within a certain range of speed. Participants in the study were asked to tap on a set beat given by a signal, whereas each note is not necessarily on a beat when playing the piano and there can be many notes played within the time frame of one beat. The study by Wilke and colleagues is important because it could be closely linked to the performing of a scale, since a steady pace is set for each note. A piano-performing-related question emerges from these three studies addressing finger movement and respiration. Would the same entrainment seen in Wilke and colleagues' study be noted during the performance of a scale? This question leads to a first experiment proposed for this study. Breathing during lateral movement will be analyzed through the performance of a scale at a specific metronome speed. This experiment will provide information on whether or not a coordination is present between breathing and finger movement at certain points in the performance of a scale.

Breathing and Forearm Movements

Ebert and colleagues (2000) conducted a study to determine if there is a coordination that occurs between breathing and forearm movement. A secondary purpose of their study was to establish whether the breathing-at-rest rate would change during the forearm movement. The subjects were asked to trace sinusoidal shapes along a precise circuit, unavoidably causing flexions and extensions of the forearm of 15°. Respiration was simultaneously monitored with a pneumotachograph. Sinusoidal graphs of the breathing pattern and the arm motion were obtained and compared to find phase intervals. Using the frequency of coordination as a measure for coupling strength, the study showed that entrainment happens between breathing and tracking movements. Furthermore, breathing rate increased during the experiment compared to breathing at rest. To explain the results, Ebert and colleagues proposed a model (Figure 2.9) that showed the possible interaction between the respiratory centers and the sensorimotor system in control of the rhythmical arm movement. They hypothesize that a neuronal exchange takes place between the two centers which causes eventual coordination. This neuronal exchange would be controlled by a third element, a comparator. The latter would act as a mediator between the two processes by comparing the time parameters. Stemming from this phenomenon, Ebert and colleagues suggested two possible pathways. The first is that the signals from the motor system indirectly reach the brainstem and act as a pacemaker to the respiratory centre. The second option is that the comparator provides feedback to the respiratory centre, again resulting in the pacing of respiration. The two proposed pathways are identified by thicker lines in Figure 2.9.

Use of the forearm is important in piano playing. The elbow lets the forearm move laterally, allowing pianists to play at the extremities of the keyboard. Another move-

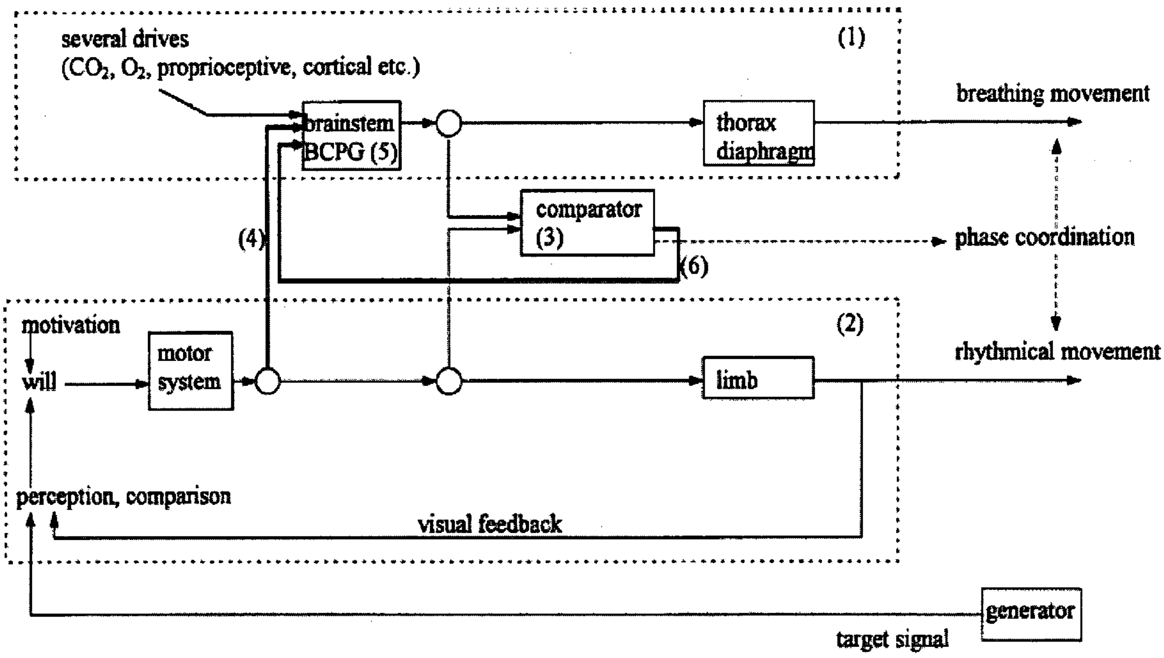

Figure 2.9: Hypothetical signal flow diagram for the interaction between breathing and the extremity motor subsystems. (Ebert et al., 2000)

ment of the forearm is rotation which is constantly used during playing. A rotation of the forearm allows the pianist to place his hand in a pronated playing position (Mark, 2003). When playing scales or arpeggios, the forearm should be aligned with the wrist and it should guide the direction of the movement along the keyboard. In cases where the thumb needs to pass under the third or fourth finger, the forearm is lifted and pronated to allow this movement to happen (Wristen, 2000). The sinusoidal tracking movements we see in Ebert and colleagues' study (2000) are similar to pianistic forearm movements. However, those participants were doing the sinusoidal tracking movements while following a cursor, so the movement was done at a set pace. In piano playing, the flexion and extensions of the forearm would not be as regular and calculated in most performance tasks. Certain pianistic tasks such as scales, triads or arpeggios require regular and controlled movements of the forearm. The overall forearm movement of pianists would be slower than the one performed in Ebert and colleagues' study; would this movement have a similar effect on breathing? Ebert and colleagues' study justifies the first experiment while introducing a second experiment which will require participants to play an arpeggio several times up and down the piano. With the execution of this repetitive task it will be possible to determine if a coordination is developed between regular forearm movement and specific points of the breathing cycle during the performance of a common technical pianistic exercise.

2.2.2 Breathing of Musicians

When addressing the topic of breathing and musicians there is a tendency to automatically think of wind players or singers since respiration is an essential factor in their performance. This review will not cover literature that addresses the breathing of those musicians since they train their respiratory apparatus to produce sound on their instrument. Instead, the focus of this part of the review will be on the breathing of musicians who do not directly use breathing for sound production, such as string players and pianists. For these musicians, respiration is often seen from an interpretive point of view.

Breathing of String Players

As early as 1963 the investigation of the breathing of violinists seemed to emerge as an interest. Because of noted signs of exhaustion from violinists during a performance, Stadler and Szende (1963; 1965a; 1965b) wanted to study the respiration of these musicians. They also wanted to study the relationship between breathing, the motor act of violin playing and the musical message.

In *The Rhythm of Respiration during Violin Playing* (1963), Szende & Stadler observed the time sequence, rhythm and pattern of respiration in violin players. To measure air flow, the subjects wore a face mask that covered their nose and mouth in an airtight manner. Ten violinists, including teachers, performing artists, violinists in an orchestra and students, participated in the study. The participants came from different backgrounds but the level of experience was not taken into consideration when analyzing the results. Participants were asked to play the first minuet of Bach's *Solo Sonata for Violin No. 6* while wearing the face mask and being recorded. The different bowing requirements had been noted on the subject's score so the position of the right arm could be determined at any given point in the piece. As the musician performed, times of inspiration and expiration as well as bow positions during inspiration were noted on the score. By doing this, it was possible to see whether there was a relationship between certain bowing arm movements and inspiration. To analyse the data they categorized movements of the bowing arm according to three positions on the violin: when the bow is at the nut, the arm and forearm form a 45-60° angle; when the bow is at the point, the arm and forearm are at a 180° angle; when the bow is in the middle, the arm and forearm are at a 90-130° angle. Results showed a tendency to inspire when raising the bowing arm and to expire when lowering it. Furthermore, inspiratory rate was higher when chords were played or when the bow shifted to play on the lower strings. The most important observation was that inspiration coordinated most often with changes in bow direction. Based on the results, the researchers associated breathing tendencies in violin playing to upward and downward motor acts of the right arm.

In a second project (Stadler & Szende, 1965a), the same researchers attempted to answer three further questions about violin playing. The first was to see whether or not the different respiratory parameters (breathing rate, pulmonary ventilation) maintain their respective levels of rest. The second looked at whether the number of breaths per minute increases, tidal volume increases or both increase during playing. The third asked what can be concluded on breathing economically during violin playing. They used the same face mask as in the previous study but this time it was connected to a spirograph. Ten subjects between the ages of 18 and 42 participated in the study. Measurements were taken at rest and during the violin performance. Some subjects played different pieces allowing the researchers to compare style, tempo, mood and technical difficulty. They analysed the results by comparing a tape recording of the performance, the spirogram and the musical score, and learned that violin playing caused an increase in pulmonary ventilation and respiratory rate compared to rest. They concluded that the increased respiratory rate was not due to oxygen inhalation but caused by a pattern of breathing peculiar to violin playing. They hypothesized that these changes in respiratory patterns resulted from the positioning of the violin on the clavicle, stage-fright or a lack of preparation. They also observed deeper respiration during some of the musical pauses which indicated the use of breathing as a tool to express music. Szende and Stadler suggested that these pauses were like punctuation when talking. They concluded that when playing the violin, the performers adopted a respiratory pattern that matched motion and consequently matched the composition. Consequently, they proposed that respiration should be planned when learning a piece to minimize use of energy and facilitate the physiological aspects of playing the instrument.

Oxygen Consumption and Respiratory Function in Violin Playing (Stadler & Szende, 1965b) looked at how oxygen consumption during a performance was related to skill level, psychic condition or exhaustion of the violinist. Additionally, the researchers were interested in whether or not they could draw physiological and pedagogical conclusions from the pattern of oxygen consumption. They used the same methodology as in the previous studies. Subjects had to perform pieces by Bach, Paganini and Veracini three times each with breaks of 1.5-2 minutes between each performance. The results indicated that oxygen consumption always increased during playing. It was noted, however, that the change of oxygen consumption was only slightly dependent on the technical difficulty level of the piece. In the cases where the subject had made a mistake during the performance, oxygen consumption seemed to increase. This indicated that psychic condition such as embarrassment had an effect on oxygen consumption. In general, the participants achieved a continuous performance with a lower oxygen level consumption. A primary conclusion was that it is important to practise playing longer compositions to adjust to the oxygen consumption levels that are eventually required for the actual performance.

Igarashi, Ozaki and Furukawa (2002) studied respiration during cello performance. The general purpose of the study was to discover the specific characteristics of respiration during the performance by these instrumentalists using inductive logic programming, a combination of machine learning and logic programming. This type of machine learning had already been used in a previous study in order to find rules of musical expression during a Rachmaninoff piano performance (Dovey, 1995). Igarashi and colleagues measured respiration with a belt-shaped sensor that detected changes in abdominal circumference caused by the subject's breathing. Four experienced cellists participated in the study and performed Luigi Boccherini's *Rondo* six times at a uniform tempo of 84 per quarter note.

The study was composed of three experiments. The goal of the first experiment was to determine when cellists breathe by looking at their inhalation and exhalation during a performance. Results showed that respiration followed a regular and consistent pattern during a musical performance. As they analyzed the musical performances, they established many rules of respiration. One important observation was that exhalation and inhalation were alternated on a beat-by-beat basis. Secondly, the same respiratory pattern was present in excerpts that had similar musical structures. A last observation was that the subjects would inhale on a beat when the key changed after the beat. The first experiment studied the different states of respiration (inspiration, expiration and no respiration) whereas the second experiment addressed the changes in respiratory states. Breathing was seen as a whole and not subdivided into inhalation or exhalation events.

Results agreed with the first experiment. They showed evidence that the performer breathed similarly during a musical segment that is repeated and that key changes had an effect on breathing. In the final experiment of the study, the researcher analyzed the breathing phrases of each subject. They looked at how often a subject breathed during the performance and the duration of the breaths. Although subjects varied in terms of breath duration, the total number of breaths for each subject was nearly equal. Two general observations were made with regard to breath phrasing. Firstly, it seems that players hold their breath during a technically difficult passage. Secondly, performers had the tendency to play one musical structure as one breathing phrase. The authors suggest that further research could be done from a pedagogical point of view and that different levels of performers could be taken into consideration.

The first three studies on violinists emphasise the effects of physical motions and physical states on breathing whereas the last project focuses on the idea that performers adopt a breathing pattern to match the musical structure of the music. In this study, we will be looking at the breathing patterns of pianists when performing repertoire pieces to determine if there is a relationship between breathing and phrasing. Although no experiments in this thesis will be stemming directly from the studies on string instrumentalists, a review of the research on these musicians is important since their respiration may be similar to what would be observed on pianists.

Breathing of Pianists

Since respiration is not a primary requirement to produce sound on the instrument, the specific topic of breathing at the piano remains largely unexplored-few articles have been published on the topic. However, there are two important studies (Ebert et al., 2002; King 2006) that directly address the subject of breathing at the piano with regard to meter, tempo, structure and physical movement.

Figure 2.10: Beginning of the exercise (modified Hanon, #21), presented in quarter notes and grouped by five different meters. (Ebert et al., 2002)

Ebert and colleagues (2002) have conducted the most important research done in this field, addressing the coordination between breathing and groupings of piano finger movements. Since there is documented coordination between breathing and many different movements, these researchers were interested in seeing whether there is a similar entrainment of breathing during piano playing-in other words during fast movements of the extremities. Since individual pianistic movements are much faster then a normal breathing pattern, they wondered if there is a regulation of breathing according to groupings of notes. Therefore, the purpose of this study was twofold and addressed the coordination between breathing and finger movements and the effects of meter on this coordination. The authors proposed that respiration would be affected by pianistic movements and breathing would vary with the different meters.

Six piano subjects participated in the study. The authors used a five-finger-space Hanon exercise as the score. As seen in Figure 2.10, this sequence of notes was transcribed into five different meters (3/4, 4/4, 5/4, 6/4, 7/4). The pianists were asked to practice the musical excerpts for a few days before the day of the experimentation. On the actual day, the subjects had to perform the exercise at their preferred speed in the left hand, right hand and hands together on a Yamaha-Disklavier that recorded each stroke as MIDI data. During their performance, the subjects were wearing a respiration thermistor[4] that recorded respiration. After conversion of the recorded data, the MIDI-file output from the Disklavier and the data from the thermistor could then be compared with the help of sequencer software. To analyze the results, they compared the finger strokes recorded by the piano, the marking of the real first strokes in a measure and the breathing curves. From this data, they calculated phase intervals to determine if there is a relationship between the meter and breathing patterns. Results indicated that breathing rate increased as soon as the subjects started playing. Furthermore, meter rate (or tempo) decreased with increasing time signature (3/4, 4/4, 5/4, 6/4, 7/4). Additionally, the phase intervals illustrated the occurrence of coordination. A breath cycle seemed to last the length of a bar (1:1 coordination) when the meter used was 5/4, 6/4, 7/4. A breath cycle lasted two bars (1:2 coordination) when the meter used was 6/4 or 4/4. Lastly, pooled data indicated that coordination between breathing and meter was found more frequently in 7/4 meter and less frequently with a 4/4 meter. The researchers tried to explain this phenomenon by stating that when asymmetric musical meters such as 3/4, 5/4 or 7/4 are played, increased mental effort by the performers is necessary, resulting in persistent coordination. Their main conclusions were that there is coordination between the first stroke in a meter and inspiration, and that the variations of the meter unconsciously affect the breathing rate. In addition, previous studies reveal that breathing rate during performance is higher than at rest. Ebert and colleagues assume that the higher breathing rate during performance is not related to changes in carbon

[4]An electrical resistor whose resistance varies with temperature changes (Mish, 2002)

dioxide in the same way other muscular movements affect respiration. They make this statement on the basis that, unlike greater exercise movements, piano finger movements only require small muscular effort and little energy. Therefore, this should not affect carbon dioxide levels. Consequently, the authors hypothesize that the mental effort required to play uncommon meters causes the regulation of the neurons involved in the respiratory rhythm.

Since Ebert and colleagues (2002) looked at the relationship between finger movement and the breathing of pianists when meter is varied, this study is directly related to our work. However, the fact that tempo was not held constant in their experiment could be seen as a limitation, and Ebert and colleagues suggest that the variation of tempo could be of interest in a future study looking at coordination of meter and breathing in pianists. Another factor the authors did not take into consideration in this experiment is the level of experience of the subjects. Age and skill level were not controlled. Participants varied between the ages of 22 and 43. Furthermore, some were students while others were experienced players. In light of the methodological limitations of this study, our research will repeat this experiment with participants of a similar musical background and with a different Hanon exercise in the hope of obtaining comparable results. In contrast to Ebert and colleagues' protocol, participants will be asked to play at the same tempo.

In addition, while Ebert and colleagues' study addressed the relationship between breathing and finger movement markers, which differ according to meter, there is no research in the field of piano performance investigating the relationship between breathing and the passage of the thumb or pitch finger movement markers. Therefore, reverting to the two previously proposed experiments, the current study will explore whether coordination develops between breathing and finger movements during the performance of the scale and arpeggio targeting three types of markers. The first type, the metric marker, is similar to what Ebert and colleagues examined. In a scale or arpeggio, metric markers are every four notes as scales and arpeggios are typically divided. The second type of markers is determined by the position of selected pitches. The third marker is identified by the passage of the thumb which occurs during the performance of a scale or arpeggio.

King (2006) conducted a pilot project that looks directly at breathing and pianists from a musical perspective. King was interested in the influence of tempo, musical structures and physical movements on pianists' breathing rhythms. She monitored the breathing of two professional pianists and a university piano major during performance to enable a comparison based on experience level. The subjects were asked to learn and then play three pre-selected contrasting pieces: Bach's *Two-Part Invention No.8 in F Major, BWV 779*; Beethoven's *Sonata in C Minor, Mvt II, Op. 13*; and Poulenc's *Movements Perptuels, Mvt II.* The pianists performed on a Yamaha Disklavier while their respiration was simultaneously being monitored with a portable ergospirometer. Additionally, a video camera filmed the right-side profile of the pianist. Time of inspiration and time of expiration were noted on the musical score. A breath to beat ratio was used to determine the relationship between respiration and tempo. King noticed that the performers had a tendency to take a deep inspiration right before they started to play. Although a specific tempo to breathing rate relationship was not found, tempo did affect the breathing rate on a consistent basis for each individual performer. The relationship between breathing and physical movement seemed to vary but remained unclear. It became evident that respiration is unique in each performance but that the breathing of the pianist develops a certain pattern throughout the piece. The musical features seemed to have an impact on the performer's breathing.

King's study is very pertinent to this study since it touches directly the topic of breathing during a piano performance. However, the results of her investigation are difficult to interpret. This may be because the research question was very complex, but in addition, the experiment had too many variables and the methodology lacked the control for them. The use of complex pieces of music and the small number of subjects are also limitations. Other than a comparison of breathing changes according to meter when playing a Hanon exercise (Ebert et al., 2002) no study has compared the breathing of pianists across the performance of different tasks. Based on this fact and King's study, we want to inquire about changes between the breathing patterns of pianists at rest and during various performing tasks. How do melodic complexity, meter, tempo and phrasing affect respiratory patterns? Do pianists consistently take a deep breath before starting a performance as observed in King's experiment? In sum, the last experiment in this study will repeat King's experiment but with a specific focus on the relationship between breathing and specific musical features.

2.2.3 Monitoring Respiration

Many tools have been developed to monitor the various parameters and time intervals of the respiratory cycle generally measured in respiration-focused research, depending on the purpose of the study. Volumes such as tidal volume, inspiratory reserve volume and expiratory reserve volume are commonly seen in these studies, as well as time intervals between the various volumes, such as expiratory time (the duration of expiration), inspiratory time (the duration of inspiration) and minute ventilation (the quantity of air exchanged per minute).. Devices commonly used include the following: face mask, spirometer, helium dilution method and pneumotachograph. Spirometry measures volumes included in the vital capacity only whereas the helium dilution method allows the measurements of all volumes included in the total lung capacity (Wanger et al., 2005). For the purpose of this study, most of these measures are not needed. In addition, most of these instruments would not be appropriate for this research because they are either invasive or could affect the performance of the pianists.

In past research involving pianists, two different techniques have been used. In one study, the respiration of pianists was recorded by a thermistor placed in front of a nostril (Ebert et al., 2002). This instrument qualitatively gives information on the inspiratory and expiratory airflow but it does not accurately measure volumes. In the second study (King, 2006), the tool used to monitor pianists' respiratory patterns was a portable ergospirometer. For these two studies, the respiration recording device was placed in close proximity to the face, making it possibly uncomfortable for the pianist. Additionally, the devices used did not allow the measurements of vital capacity required for our study. Therefore, to maintain performance conditions closest to normal and to obtain the desired data, a non-invasive inductive plethysmography system (RIPmate Respiratory Effort System) will be used, a technique also seen in other studies monitoring respiration (Clarenbach, Senn, Brack, Kohler, & Bloch, 2005).

Table 2.1: Summary of the literature reviewed.

Literature		References	Research Interests	Main Findings
Piano Pedagogy Material		Sandor (1981); Mark (2003); Bernstein (1981)	Observing the breathing of pianists	Observations on: - some common breathing problems faced by pianists - the importance of breathing - breathing with the music Note: All are based on observations and have not been scientifically researched.
Kinesiology	Large Movements	Rassler & Kohl (1996); Bramble & Carrier (1983); Kohl, Koller, & Jäger (1981); Fabre et al. (2007); Mahler, Hunter, Lentine, & Ward (1991)	Coordination between breathing and large repetitive body movements.	Coordination between breathing and repetitive: - walking movements - running movements - cycling movements - cross-country skiing movements - rowing movements
	Small Movements	Rassler & Raabe (2003); Rassler (2000); Rassler, Bradl, & Scholle (2000); Ebert et al. (2000); Rassler, Ebert, Waurick, & Jaughans (1996); Wilke et al. (1975)	Coordination between breathing and smaller repetitive body movements.	Coordination between breathing and repetitive: - head and eye movements - finger movements (extensions, flexions, torque, tapping) - forearm movements
Music	Violinists	Stadler & Szende (1963; 1965a; 1965b)	Respiration rhythm Respiratory parameters Oxygen consumption	- Bowing arm affected breathing (ex. inspiration often coincided with changes in bow direction) - Increase of breathing rate and pulmonary ventilation - Increase of oxygen consumption
	Cellists	Igarashi, Ozaki, & Furukawa (2002)	Characteristics of respiration during a cello performance	- Key changes had an effect on breathing - Breathing was similar during a musical segment that was repeated - Cellists held their breath during a difficult technical passage
	Pianists	Ebert et al. (2002); King (2006)	Breathing at the piano with regard to meter, tempo, structure and physical movement.	- Increase of breathing rate as soon as participants started playing - Coordination between breathing and the beginning of a bar: 1:1 coordination (5/4, 6/4, 7/4), 1:2 coordination (6/4, 4/4) - Pianists took a deep inspiration before starting to play - Tempo affected breathing rate - Although respiration is unique in each performance, each pianist developed a certain pattern throughout the piece.

2.3 Summary and Research Problem

This review of literature has focused on two areas of importance for this study: the coordination that occurs between breathing and various movements, and the research that has been done on the breathing of various musicians. We have seen that when looking at smaller limb movements, a coordination is found between breathing and head and eye movements, various finger actions and forearm tracking. The studies addressing breathing and string players concluded that there is a relationship between the musicians' actions and breathing. The two projects on the breathing of pianists indicated that breathing is affected by meter and tempo. King noted that a pianist's respiration remains consistent, but there seemed to be a variation in the breathing pattern when comparing pianists to each other.

The general purpose of this study is to examine how the breathing of pianists is affected by different musical elements such as tempo, meter, rhythm, accentuated notes, melodic complexity and phrasing. More precisely, the first goal of this thesis is to determine if breathing rate and functional residual capacity change from resting condition to performing conditions and if these parameters vary according to tempo. Secondly, the experiment will determine if a coordination develops between breathing and different finger movement markers during the performance of a scale and arpeggio. Finally, the third objective is to determine the observable variations in the respiratory pattern of pianists with regards to specific musical elements such as phrasing. Will the breathing pattern change when the pianists are performing different musical tasks? To answer these questions four experiments will be conducted following approval of the Ethics Committee of the University of Ottawa (Appendix A). During each, respiration will be monitored while the subject is executing the different performing tasks:

1) Repetitive performance of the C major scale (Appendix B)

2) Repetitive performance of the C major arpeggio (Appendix B)

3) Performance of the Hanon #10 five-finger exercise transcribed in 5 different meters (Appendix C)

4) Performance of two repertoire pieces: 1) *Minuet in G major* by C. Petzold (Appendix D), and 2) *Für Elise* by L. van Beethoven (Appendix E)

Based on passed research, the following results are expected concerning the first objective of this thesis. Firstly, since breathing rate seems to increase even during small limb movements (Ebert et al., 2000; Wilke et al., 1975), it is expected that similar trends will be observed during a pianist's performance. In addition, it is anticipated that breathing rate will proportionally increase with faster tempi. Research has proven that FRC decreases during physical activity (Johnson et al., 1999), therefore similar trends are expected during a pianist's performance.

Regarding the experiments on coordination, hypotheses are drawn from the studies on forearm movement (Ebert et al., 2000) and pianistic finger movements (Ebert et al., 2002). Since the pitch markers are evenly spaced and involve a consistent opening and closing movement of the forearm, one would expect to see coordination between breathing and pitch movement markers during the performance of the scale and arpeggio. As observed in Ebert and colleagues' study (2002), it is anticipated that there will be a coordinative relationship between breathing and the metric finger movement markers. Finally, since the passage of the thumb during the performance of these exercises is irregular, it is predicted that it will not be coordinated with breathing.

Concerning the third objective, it is hypothesized that the breathing pattern of the pianists will remain regular and similar to their respiration at rest while playing the scales and arpeggios since they are melodically linear, they require a more mechanical approach and the gestures involved in their performance are repetitive. Based on Ebert's study, we anticipate breathing pattern changes when the pianists will be playing the Hanon exercises in different meters. Also, breathing should vary during the performance of the repertoire pieces. As observed in the King study, it is predicted that pianists will take a deep breath before performing a repertoire piece and use breathing to express the music. Therefore, participants are expected to subconsciously breathe with the phrase during these performances.

Additional information on the subject of breathing and pianists should be useful to piano teachers for both pedagogical and health reasons. From a pedagogical point of view, it would be interesting to observe whether certain breathing patterns are common to advanced pianists, making them better performers and interpreters of the music. If this is the case, it would be useful to determine how these performers breathe in order to guide younger students towards that goal. If piano teachers are aware of the potential beneficial effects that certain breathing tendencies could have on a performance, they could use this as a tool when teaching young pianists. From a health standpoint, it would be beneficial to better understand the breathing of pianists to possibly prevent piano playing-related health injuries. Statistics show that 39% to 47% of adult musicians and up to 17% of high school musicians develop playing-related musculoskeletal disorders (Zaza, 1998). Also, it is known that many pianists eventually suffer playing-related injuries or health problems that may greatly affect their performance and musical career (Russell, 2006). Although there are various causes for these injuries, unnecessary tension of the muscles seems to be important. With regard to the breathing apparatus, Sandor (1981) mentions how tension caused by excessive muscular contractions in and around the respiratory system can result in a malfunction of the breathing apparatus which consequently affects various musical elements like phrasing, rubato, tempo and accentuation. In contrast, when used efficiently, rhythmical breathing can help induce a relaxed state in stressful situations, such as that of performance anxiety (Valentine, 2002). This could be a tool used by piano teachers. In sum, this project will hopefully be beneficial in establishing a base for future studies while providing a clearer understanding of the physiological aspects involved in piano learning, teaching and performing.

Table 2.2: Summary of the goals and hypotheses presented in this thesis.

	Research Goals	Hypotheses	Performing Tasks
Article 1	To investigate the effect of performing various exercises and pieces on the breathing rate and functional residual capacity of pianists.	- The breathing rate during a performance will be faster than at rest. - The breathing rate should proportionally increase with faster tempi. - The functional residual capacity will decrease during the performance compared to the resting condition.	- C major scale - C major arpeggio - Hanon #10 - *Minuet in G major* by C. Petzold - *Für Elise* by L. van Beethoven
Article 2	To determine whether coordination develops between breathing and finger movements made while performing a scale and arpeggio. Finger movement will be defined according to three markers: meter, pitch, passage of the thumb.	Coordination will be present between breathing and: - pitch markers during the performance of the scale at the fastest tempo. - pitch markers during the performance of the arpeggio at the slowest tempo. - meter finger movement markers. Coordination will not be present between breathing and markers identified by the passage of the thumb.	- C major scale - C major arpeggio
Article 3	To examine changes between the breathing patterns of pianists at rest and during various performing tasks while also analyzing the effects of specific musical features such as melodic complexity, meter, tempo and phrasing on respiration.	- The breathing pattern will remain regular and resemble respiration at rest during the performance of the scales and arpeggios. - The breathing pattern will change during the performance of the Hanon exercises in different meters. - Pianists will take a deep breath before performing. - Pianists will subconsciously breathe with the phrasing in the music.	- C major scale - C major arpeggio - Hanon #10 - *Minuet in G major* by C. Petzold - *Für Elise* by L. van Beethoven

Chapter 3

Article 1

This first article will discuss changes in breathing rate and functional residual capacity during the performance of various tasks at the piano. The methodological layout established recorded the breathing of participants with respiratory belts while maintaining playing conditions as close to normal as possible. A visual representation program created in Matlab made it possible to obtain the exact time at the end of each expiration. Breathing rate was then found by calculating the difference between these data points. FRC was obtained by finding the corresponding volume to each time value. Individual and pooled analyses were then conducted.

3.1 Breathing rate and functional residual capacity of pianists during a performance

3.1.1 Abstract

Respiratory parameters are commonly studied in wind players and singers because breathing is essential for sound production of their instrument. However, little is known on the breathing patterns of pianists. Based on research in the field of kinesiology that shows an increased breathing rate and a decreased functional residual capacity (FRC) during physical activity, this study is conducted to examine the breathing rate and functional residual capacity of pianists while playing technical exercises and repertoire pieces. Eight pianists played the C major scale, the C major arpeggio, a Hanon five-finger exercise, the *Minuet in G major* by C. Petzold, and *Für Elise* by L. van Beethoven on a Yamaha Disklavier. During the performances, their respiration was simultaneously monitored by an inductive plethysmography system. Results showed that there was a significant increase between the participants' breathing rate at rest and while playing the exercises or repertoire pieces. Functional residual capacity seemed to show no statistically significant increase from rest to most of the performing conditions.

Keywords: breathing rate, functional residual capacity, pianists, respiration, performing

3.1.2 Introduction

Various factors affect the respiratory rate and functional residual capacity of individuals such as age (Leblanc, Ruff, & Milic-Emili, 1970; McFadden, Price, Eastwood, & Briggs, 1982; Rusconi et al., 1994), physical activity (Rossi, Plicchi, Canducci, Rognoni, & Aina, 1984; Rowland & Green, 1988), sleeping (Snyder, Hobson, Morrison, & Goldfrank, 1964; Tusiewicz, Moldofsky, Bryan, & Bryan, 1977) and an individual's emotional state (Boiten, Frijda, & Wientjes, 1994) amongst others. Kinesiology studies confirm that respiratory rate during the performance of physical activity is higher than at rest (Arai et al., 1989) and that FRC decreases during physical activity (Johnson, Weisman, Zeballos, & Beck, 1999). Furthermore, it has been shown that even smaller limb movements can cause an increase of breathing rate (Ebert, Rassler, & Hefter, 2000; Wilke, Lansing, & Roger, 1975) even though small muscular motions require less energy.

The primary function of the respiratory system is the intake of oxygen and the release of carbon dioxide that occur between the lungs and the environment. Other than gas exchange, the respiratory system is involved in the regulation of pH balance in tissues, the protection of respiratory surfaces from the environment, the participation in the olfactory sense and the production of speech or song. As with its use during speech and song, the respiratory system is put into practise when playing certain musical instruments. The breathing parameters of wind players have been studied because these instrumentalists train their respiration and use it for sound production of their instrument. Studies have examined the changes in lung volumes of these musicians during playing (Bouhuys, 1964; Cossette, Monaco, Aliverti, & Macklem, 2008; Cossette, Sliwinski, & Macklem, 2000). With many wind players, rapid inspirations and deep expirations were observed during a performance (Bouhuys, 1964). Additionally, because of the physical requirements of some wind instruments (i.e. trombone, tuba), almost the whole vital capacity may be used when playing (Bouhuys, 1964).

In contrast to the numerous studies on wind players, little research focused on the breathing of pianists. One study has explored the relationship between pianists' respiration and meter, tempo, structure and physical movement during a performance (King, 2006). Although a specific tempo to breathing rate relationship was not found, there appeared to be a consistent ratio between these two elements for each pianist. Another research observed that the breathing rate of pianists during a performance was significantly higher than their breathing rate at rest (Ebert, Hefter, Binkofski, & Freund, 2002).

Based on their pedagogical experience, a few authors (Mark, 2003; Sandor, 1981) address common breathing problems that pianists face, such as trying to get air in the belly, tightening the abdominal wall, tightening the throat muscles, expanding the chest forward, tensing the diaphragm, heavy breathing and breath holding but there are no studies examining the respiratory volumes of these musicians. More knowledge on the breathing volumes of pianists could help us understand some of these issues. Therefore, the following study was conducted to determine how performing various exercises and pieces at the piano can affect the breathing rate and FRC of these musicians. Since breathing rate seems to increase even during small limb movements (Ebert et al., 2000; Wilke et al., 1975), it is expected that similar trends will be seen during a pianist's performance. Also, one would anticipate that breathing rate will proportionally increase with faster tempi. Finally, since FRC decreases during physical activity (Johnson et al., 1999), similar trends should be noticed during a pianist's performance.

3.1.3 Methodology

In order to conduct this research, we had to establish a protocol to measure breathing during a pianist's performance while maintaining performing conditions as close to normal as possible. Three pilot studies were conducted to determine the most adequate tool for recording respiration and to establish the best procedure. The following protocol was chosen since it was deemed most adequate in terms of the duration, the pianist's comfort level and the efficiency of the data collection method. This methodology section provides information on the participants, the instrumentation, the experimental set-up, the procedure, the data acquisition and the data analysis.

Participants

Eight pianists, (7 female, 1 male; aged 18-28) whose playing level ranged from grade 8 of the Royal Conservatory of Music of Toronto to a Bachelor of Music in piano performance degree, participated in the study. These individuals took part in the experiments following the approval of the Ethics Committee of the University of Ottawa (Appendix A).

[1]These approximate values were calculated with the participant's estimated number of practice hours per week for the first few grades and for the later grades, with the assumptions that they practiced 6 days/week and 40 weeks/year.

Table 3.1: Characteristics of the participants.

Participant	Gender	Level completed	# hours of practice[1]	Years playing the piano	Years of piano lessons	Years since stopped piano lessons
1	F	B. Mus.	2300	18	14	4
2	F	Gr. 9	1400	20	20	0
3	F	Gr. 8	4600	18	3	9
4	F	B mus	5400	21	17	3
5	M	Gr. 9	2900	10	10	0
6	F	B mus	5200	20	16	4
7	F	Gr. 8	2300	12	12	6
8	F	Gr. 10	3000	25	15	7

Instrumentation

Tools commonly used to measure various volumes in respiration-focused research include the following: face mask, spirometer, helium dilution method and pneumotachograph. Spirometry measures volumes included in the vital capacity only whereas the helium dilution method allows the measurements of all volumes included in the total lung capacity (Wanger et al., 2005). These apparatuses would not have been appropriate for this research because they are either invasive or disruptive to the performance of the pianists. In past research involving pianists, two different techniques have been used. In one study, the respiration of pianists was recorded by a thermistor placed in front of a nostril (Ebert et al., 2002). This device qualitatively gives information on the inspiratory and expiratory airflow but it does not measure volumes with accuracy. In the second study (King, 2006), they monitored pianists' respiratory patterns with a portable ergospirometer which was used to measure the timing of inspirations and of expirations during a performance. The pianists wore a ventilation mask and the breathing monitors were attached to them by a smart vest. In both cases, the respiration recording device was placed in close proximity to the face, making it seemingly uncomfortable for the pianist. It has also been shown that wearing a face mask alters the breathing pattern (Askanazi et al., 1980). Moreover, devices used in these previous studies did not allow the measurements of vital capacity required for our study. Therefore, to maintain performance conditions closest to normal and to obtain the desired data, we used a non-invasive inductive plethysmography system (RIPmate Respiratory Effort System), a technique also used in other studies monitoring respiration (Clarenbach, Senn, Brack, Kohler, & Bloch, 2005).

In order to conduct the experiment, sound, images and respiration were recorded simultaneously. The following section describes the equipment that was used.

Recording Sound and Images

Two methods were used to record sound. In accordance with past research in piano performance (Ebert et al., 2002), participants played on a Yamaha Disklavier. As explained on the Yamaha Canada Music website (2005), the 88 key sensing system of this 7'6" grand piano is made of non-contact optical fiber/grayscale shutters which can detect the key position, the keying velocity and the key releasing velocity. A non-contact digital optical system senses the pedal positions. Data obtained from these sensors during a performance are recorded by an integrated MIDI operating system which allows recording and replaying of MIDI files. Secondly, for synchronization purposes, sound was recorded in a waveform audio format with a microphone (Neumann TLM-103) connected to a Digidesign Digi002 sound card[2].

For overall visual recording of the sessions, experiments were filmed by a vertically moveable analogue video camera mounted on accordion brackets attached to the ceiling of the laboratory. The video cassettes could be viewed later for missing information during the data analysis.

[2]Sound card model Digi 002. From Digidesign, a division of Avid Technology Inc., USA.

Recording Respiration

The inductive plethysmography straps (RIPmate Respiratory Effort System[3]) encircled the pianist's rib cage, under the armpits, and around the abdomen, below the 12th rib. The respiratory effort sensors measured inductance changes represented by voltage output, resulting from the circumference displacements of the upper rib cage and abdomen during inspiration and expiration. The signals from the sensors were converted into digital signals by a data acquisition board (DAQ08-Scireq). Prior to gathering the data, calibration was done by simultaneously measuring the circumference displacements (RIPmate) and flow changes through a pneumotachographer (Hans Rudolf- PNPT 3830B- 400L/min) attached to a MicroGard[4]) attached to a Microgard filter. Both were connected to the DAQ08-Scireq[5].

Experimental Set-Up and Data Synchronization

The data acquisition board (DAQ08-Scireq) recorded data from four sources: 1) RIPmate abdominal respiratory belt, 2) RIPmate thoracic respiratory belt, 3) flow, and 4) pressure. A double synchronization set up was used in order to synchronize the participant's respiratory data and the MIDI data from the piano. The first step was to synchronize the waverform audio file (Sound 1) with the analogue signal by using sound and pressure peaks. This was accomplished by striking a polyvinyl chloride tube which created a pressure wave detected (with a negligible resolution of 865μsec) by a pressure sensor and a microphone connected to a sound card (Digidesign Digi002). This wave created a peak in the pressure recording and a peak in the audio file. The second synchronization step was accomplished by synchronizing the MIDI data (Sound 2) and sound. This was achieved by playing a key on the piano which launched the MIDI recording and would be detected by the microphone, connected to the Digidesign Digi002 sound card, creat-

[3]From Sleepmate Technologies, Virginia, USA.

[4]From SensorMedics MicroGard Spirometry Filter. From VIASYS Healthcare, USA.

[5]Scireq Scientific Respiratory Equipment Inc., Montréal, Canada.

ing another peak in the audio file. Matlab algorhythms were subsequently coded into a Graphical User Interface to detect these three peaks (pressure, sound 1, and sound 2) and align them in time, resulting in synchronization of the system.

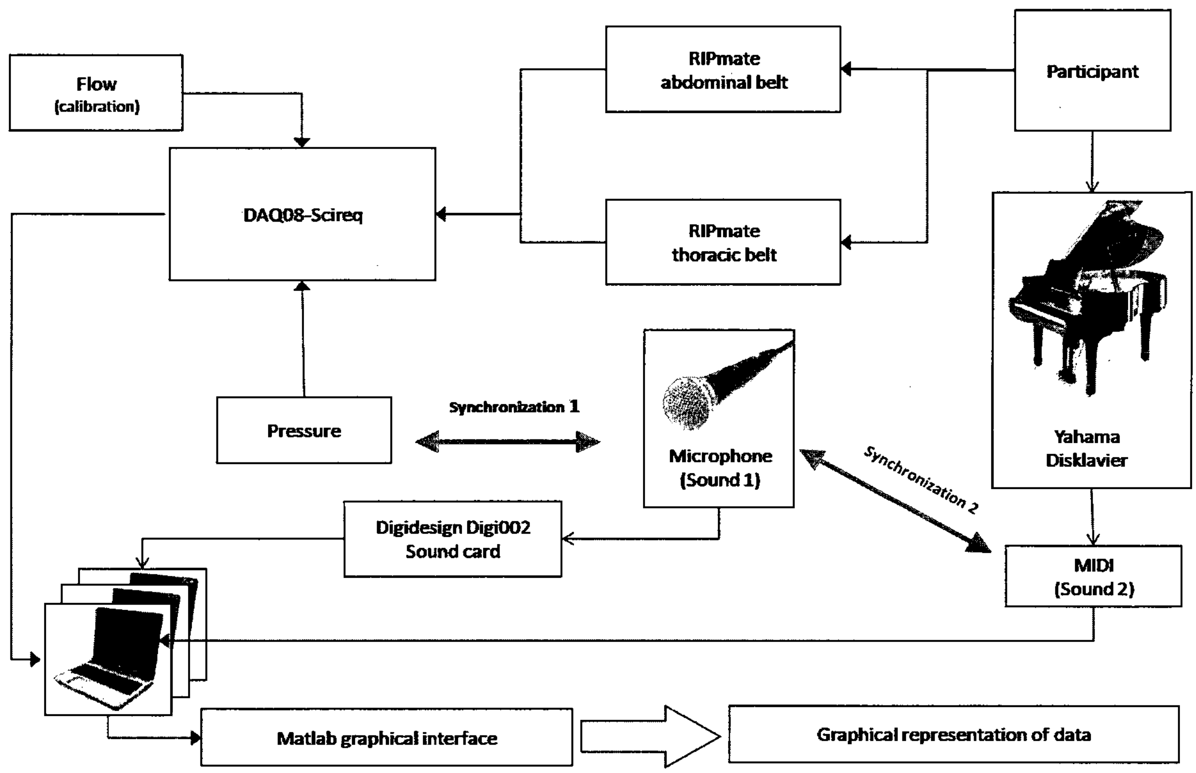

Figure 3.1: Experimental set-up illustrating the double synchronization method.

Procedure

Prior to the experiments, participants were given an information package containing the presentation letter (Appendix A), the consent form (Appendix A), and the musical scores required in preparation for the experimental session. In the letter, participants were asked to practice beforehand so they would be able to perform the scales, arpeggios, the Hanon exercise and repertoire pieces. While it did not directly divulge the purpose of the study, because of the nature of the experiment and the equipment used to collect the data, participants were aware that their breathing was being measured.

On the day of the testing session, participants came to the Piano Pedagogy Research Laboratory at the University of Ottawa at their appointed time. For demographic purposes, the participants answered a questionnaire (Appendix F) with the following information: gender, age, level of piano studies, number of years playing the piano, number of hours of practice per week, number of public performance per year, number of years since they stopped piano lessons, and familiarity with the repertoire pieces that were going to be performed.

Before starting the experiment, a two step equipment calibration procedure based on the literature (Banzett, Mahan, Garner, Brughera, & Loring, 1995; Konno & Mead, 1967; Sackner et al., 1989) was completed. The nose of each participant was plugged and they were asked to breathe in a pneumotach always keeping their hands on the piano in a natural playing position. The two calibration steps were the following:
1) Breathing at rest for 2 minutes which will be referred to as quiet breathing.
2) Vital capacity (VC): taking a breath to maximum capacity and exhaling to maximum capacity (repeated twice).
Afterwards, the participants engaged in a series of experiments that lasted in total approximately 45 minutes. Participants were asked to perform each task as they would during a normal lesson or recital. Between each experiment, breathing at rest was measured during which the participants were asked to read a pre-selected text of random facts which would serve as a distraction.

Scale (Appendix B)

Participants were asked to play repeatedly for 1 minute, 2 octaves of the C major scale ascending and descending, with the right hand, in eighth notes at three tempi: 60bpm, 120bpm, 184bpm.

Arpeggio (Appendix B)

Participants were asked to play repeatedly for 1 minute, 2 octaves of the C major arpeggio ascending and descending, with the right hand, in eighth notes at three tempi: 80bpm, 120bpm, 160bpm.

Five Finger Exercise (Appendix C)

In order to give them time to practice, approximately one week before the experiment participants were given the Hanon #10 five-finger exercise (Berlin, 1945) with no meter indication. This exercise number was chosen because of its adequate difficulty and melodic pattern. Furthermore, the first Hanon exercises were avoided since they are commonly encountered by pianists. On the day of the experiment, participants were asked to play this same exercise transcribed in five different meters 4/4, 3/4, 6/4, 5/4, 7/4 (Figure 3.2). Since the pianists were all advanced, it was expected that they would play the exercise shifting the accent according to the meter. Every participant played the exercises in the same order (4/4, 3/4, 6/4, 5/4, 7/4) at a tempo of 168bpm (per quarter note). The data obtained from this part of the experiment was not analyzed or discussed in this article.

Figure 3.2: Excerpt of the Hanon #10 five-finger exercise transcribed in five different meters.

Minuet in G major by C. Petzold (Appendix D)

Participants were given the *Minuet in G major* by C. Petzold (Palmer, 1992), a grade 3 repertoire piece according to the Royal Conservatory of Music of Toronto, approximately one week before the experiment session which gave them time to practice if they were not already familiar with it. They were asked to perform the first 16 measures of the piece with repeats - the first time without ornamentation and the second time with ornamentation. This was done at three different tempi: 80bpm, 120bpm, 160bpm.

Für Elise by L. van Beethoven (Appendix E)

Participants were given *Für Elise* by L. van Beethoven (Hinson, 1986), a grade 7 repertoire piece according to the Royal Conservatory of Music, approximately one week before the experiment session which gave them time to practice if they were not already familiar with it. They were asked to perform the 22 measure theme with repeats. This was done at three different tempi: 100bpm, 144bpm, 184bpm.

It is important to note that the metronome was on for the first 10 seconds of each task to set the tempo. For the rest of the performance, the metronome was off.

Data Acquisition

With a Graphical User Interface created in Matlab it was possible to obtain a graphical representation of the MIDI recording and of the respiration (Figure 3.3).

Piano Roll

A MIDI toolbox created by Schutte (2009) was used to visualize the MIDI data recorded by the Yamaha Disklavier. Using a piano roll format, the performance is graphically illustrated across time by squares representing each note of the musical excerpt (Figure 3.3). The position and size of each square denote the pitch played and its duration respectively. In addition, the intensity of the notes is displayed with color coding.

Respiration Curve

The RIPmate belts are sensitive to circumference changes from the thorax and abdomen but also other torso or limb movement may be detected by the sensors. Therefore, before quantitatively analyzing the respiratory patterns it was necessary to verify that patterns and peaks in the respiratory curve were in fact caused by respiratory changes and not by a participant's abrupt movement. Since the experiment sessions were filmed, abnormal curves in the breathing pattern were verified by watching the video of the experiment session for upper body movements or arm movements.

From Matlab, the breathing curve for each participant during every activity was traced based on a 2 x thorax + 1 x abdomen equation (Banzett et al., 1995). For respiration to be graphically represented in terms of liters across time, it was first necessary to convert respiration data from voltage to liters. This was achieved by comparing the respiration flow values (in L) obtained with the pneumotach during the calibration step to the electrical signals (in V) output from the RIPmate System. A conversion factor was found between the two sets of data allowing us to represent the amplitude changes in L. Afterwards, by finding the vital capacity for each participant, the y axis of the respiration graphs was converted to percentage of vital capacity allowing for comparisons between participants.

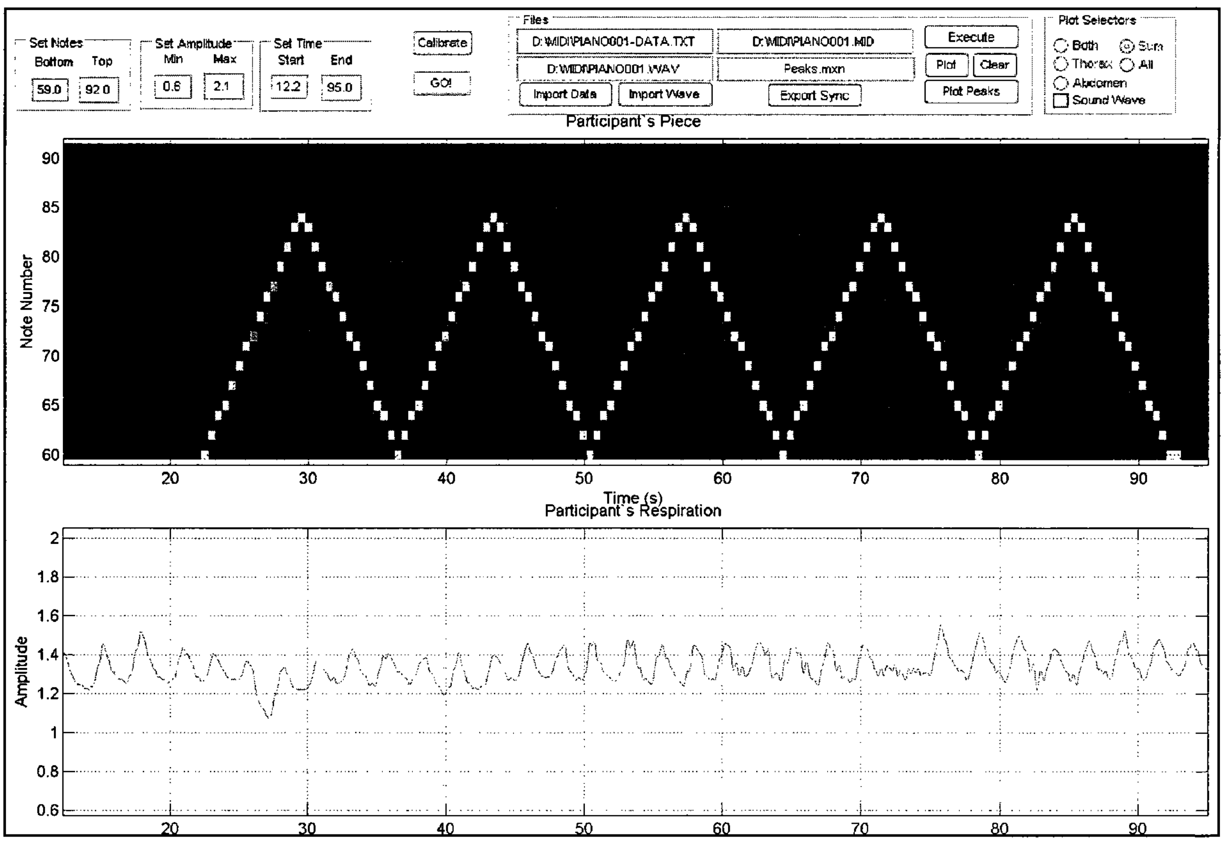

Figure 3.3: A piano roll (upper graph) showing the performance of a scale and the breathing curve (lower graph) as represented in Matlab.

Data Analysis

Data collection was done to obtain the breathing rate (number of breaths/min) and functional residual capacity (L) of each participant during the performance of each exercise at different tempi or meters. This section describes the steps undertaken to conduct data analysis of these measurements.

Breathing Rate

The breathing rate of each participant during the different exercises was calculated from the breathing curve based on the assumption that breathing rate remained constant throughout an exercise. The exact time at the end of each expiration during quiet breathing (FRC) was obtained using Diamov[6]. This Matlab program graphs a visual representation of the data and finds specific data values within a selected area. To find breathing rate (sec/breath) from these values, the time difference between each point was averaged. The breathing rate calculations were only considered when the respiratory pattern was regular.

To compare a participant's respiratory rate at rest and during the performance of each musical task, line graphs with error bars were traced for each exercise or piece played at different tempi (Figure 3.4). Additionally, data were pooled and analyzed statistically to determine group differences by conducting Friedman's tests and Wilcoxon rank tests (Pallant, 2007; Vincent, 2005). Non parametric alternatives were chosen because of the low number of participants and because the data did not always follow a normal distribution.

[6]This is not a commercial product but a program created by a research laboratory. Politecnico di Milano, Department of bioengineering, Milan, Italy.

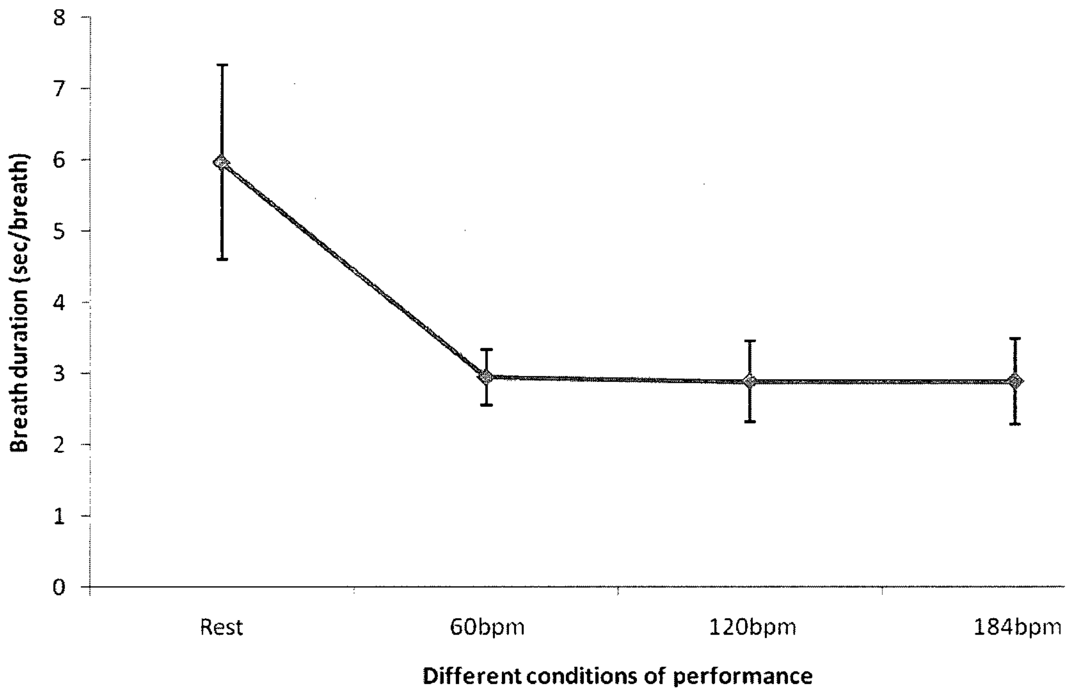

Figure 3.4: A line graph with error bars traced in excel to show changes of a participant's breathing rate at rest and during the performance of a scale.

Functional Residual Capacity

With Matlab, it was possible to find the corresponding volumes (in L) to the time values previously obtained. In order to determine if group differences between FRC at rest and during the piano performances of the exercises at different tempi were statistically significant, Friedman's tests were done followed by Wilcoxon rank tests when needed. Once again, a non parametric alternative was conducted to compensate for the small sample size and for data that did not always follow a normal distribution.

3.1.4 Results

The results for breathing rate and functional residual capacity were analyzed for each participant individually and were also pooled for group analyses.

Breathing Rate

Individual Results

Individual results showed that in most cases, breathing rate during a performance was significantly faster than breathing rate at rest. Additionally, breathing rate did not increase significantly during the performance of the exercises at the different speeds. Participant 7 had the lowest breathing rate at rest (10.05 breaths/min) while participant 5 had the highest breathing rate at rest (25.11 breaths/min). For each exercise, participant 1 seemed to obtain the highest breathing rate overall.

Table 3.2: Participant's breathing rate at rest (breaths/min) and during the performance of the C major scale.

Part.	Rest	60bpm	120bpm	184bpm
1	18.90	27.44	33.25	32.72
2	18.42	27.21	28.81	28.83
3	11.93	15.83	18.35	21.04
4	17.94	20.21	19.58	21.80
5	25.11	22.62	22.08	24.11
6	19.89	24.11	21.86	24.58
7	10.05	20.39	20.81	20.79
8	11.66	16.14	15.99	16.03

Table 3.3: Participant's breathing rate at rest (breaths/min) and during the performance of the C major arpeggio.

Part.	Rest	80bpm	120bpm	160bpm
1	18.90	29.85	29.68	32.20
2	18.42	27.14	27.80	25.67
3	11.93	16.25	22.62	21.73
4	17.94	21.44	19.69	22.71
5	25.11	26.35	23.93	27.31
6	19.89	23.60	25.10	23.75
7	10.05	18.57	20.94	21.29
8	11.66	16.81	16.07	17.94

Table 3.4: Participant's breathing rate at rest (breaths/min) and during the performance of the *Minuet in G major* by C. Petzold.

Part.	Rest	80bpm	120bpm	160bpm
1	18.90	31.67	29.59	32.38
2	18.42	32.65	31.15	32.42
3	11.93	15.98	19.40	24.70
4	17.94	24.76	23.83	38.49
5	25.11	26.85	27.96	27.37
6	19.89	19.57	22.05	23.27
7	10.05	21.59	22.04	24.44
8	11.66	16.69	23.42	23.84

Table 3.5: Participant's breathing rate at rest (breaths/min) and during the performance of *Für Elise* by L. van Beethoven.

Part.	Rest	100bpm	144bpm	184bpm
1	18.90	31.69	33.59	40.30
2	18.42	29.42	28.61	31.83
3	11.93	15.62	17.31	24.50
4	17.94	22.92	21.96	22.47
5	25.11	21.89	14.87	21.02
6	19.89	22.79	23.47	25.35
7	10.05	21.83	19.62	19.87
8	11.66	16.12	18.30	24.25

Pooled Results

A Friedman test was conducted to statistically explore the effect of playing scales, arpeggios, Hanon exercises, the *Minuet in G major*, and *Für Elise* on breathing rate at rest and during the performance of each exercise at a different tempo. Tests were evaluated at the $\alpha = 0.05$ significant level. The results of the test indicated that there are significant differences in the breathing rate values at rest and during the performances of all musical tasks included here:

- Scales: $\chi2(3, n=8) = 10.950$, $p = 0.012$
- Arpeggios: $\chi2(3, n=8) = 14.250$, $p = 0.003$
- Hanon: $\chi2(5, n=8) = 16.000$, $p = 0.007$
- *Minuet in G major*: $\chi2(3, n=8) = 16.950$, $p = 0.001$
- *Für Elise*: $\chi2(3, n=8) = 11.250$, $p = 0.010$

Wilcoxon signed rank tests were conducted to determine between which conditions breathing differed. Breathing rate increased statistically significantly from the performance of the exercise at a slower speed to the performance of the exercise at a faster speed in the following cases:

- Scales: $z = -2.380$, $p = 0.017$

- Arpeggios: $z = -2.100$, $p = 0.036$
- *Minuet in G major*: $z = -2.380$, $p = 0.017$

However, breathing rate did not statistically significantly increase between the performance of *Für Elise* at 100bpm and 184bpm nor between the performance of the scale and arpeggio at the second and third speeds. Breathing rate did not statistically change during the performance of the Hanon exercises in different meters.

Functional Residual Capacity

Table 3.6: Participant's vital capacity and FRC at rest and during the performance of the C major scale.

Part	Vital	FRC level (% of vital capacity)			
	capacity (L)	Rest	60bpm	120bpm	184bpm
1	2.77	30.41	30.33	30.18	29.57
2	3.25	27.63	29.22	30.69	30.89
3	3.88	37.01	36.39	37.13	38.47
4	2.60	31.52	30.78	32.72	33.16
5	3.79	40.47	40.88	41.30	41.60
6	2.35	44.80	46.21	47.54	47.87
7	4.35	36.96	39.29	38.47	39.65
8	3.10	25.81	25.77	26.37	25.83

Table 3.7: Participant's vital capacity and FRC at rest and during the performance of the C major arpeggio.

Part	Vital capacity (L)	FRC level (% of vital capacity) Rest	80bpm	120bpm	160bpm
1	2.77	30.41	29.50	28.35	29.07
2	3.25	27.63	26.22	28.57	28.68
3	3.88	37.01	36.66	37.99	38.18
4	2.60	31.52	32.58	32.54	33.67
5	3.79	40.47	43.40	43.15	43.34
6	2.35	44.80	47.17	47.43	47.38
7	4.35	36.96	37.77	38.47	39.52
8	3.10	25.81	27.51	26.48	27.15

Table 3.8: Participant's vital capacity and FRC at rest and during the performance of the *Minuet in G major* by C. Petzold.

Part	Vital capacity (L)	FRC level (% of vital capacity) Rest	80bpm	120bpm	160bpm
1	2.77	30.41	29.53	29.45	30.51
2	3.25	27.63	27.89	27.04	27.71
3	3.88	37.01	38.49	38.70	38.64
4	2.60	31.52	29.09	30.79	30.43
5	3.79	40.47	43.00	42.13	41.54
6	2.35	44.80	45.26	46.10	44.97
7	4.35	36.96	38.05	37.89	38.88
8	3.10	25.81	25.29	26.47	25.95

Table 3.9: Participant's vital capacity and FRC at rest and during the performance of *Für Elise* by L. van Beethoven.

Part	Vital capacity (L)	FRC level (% of vital capacity) Rest	100bpm	144bpm	184bpm
1	2.77	30.41	26.69	26.79	27.48
2	3.25	27.63	24.63	25.04	24.81
3	3.88	37.01	36.38	35.43	36.85
4	2.60	31.52	30.86	32.38	31.66
5	3.79	40.47	43.13	39.11	41.70
6	2.35	44.80	45.93	46.20	46.11
7	4.35	36.96	38.09	37.88	38.18
8	3.10	25.81	24.72	24.94	25.76

Pooled Results

A Friedman test was conducted to statistically explore the effect of playing scales, arpeggios, a Hanon exercise, the *Minuet in G major*, and *Für Elise* on functional residual capacity at rest and during the performance of each exercise at a different tempo. Tests were evaluated at the $\alpha = 0.05$ significant level. The results of the Friedman test followed by a Wilcoxon signed rank test showed an increase in FRC volume during the performance of the scales at the medium, z = -2.240, p = 0.025 and fast speed, z = -2.240, p = 0.025 compared to FRC volume at rest.

However, the Friedman tests also indicated no statistically significant difference between FRC volume at rest and during the performance of the other exercises.

3.1.5 Discussion

The goal of this experiment was to explore the changes in breathing rate and functional residual capacity of pianists as they are playing various performance tasks. The following section will elaborate on the experimental results and observations noted.

Breathing Rate

In the present study, breathing rate at rest was compared to breathing rate during the performance of each exercise at different tempi. Quiet breathing was monitored twice during the experiment from which an average was done to find mean breathing rate at rest. The length of an average adult breath at rest is 5 seconds, equaling 12 breaths/minute (Comroe, Forster, DuBois, Briscoe & Carlsen, 1963). The breathing rate of three participants followed this rule however, the other participants seemed to have exhibited a respiratory rate much higher than the average. This may indicate that these participants were not completely at rest. Strikinly, the breathing rate of one participant seemed to decrease during the performance. This participant was probably not at rest therefore yielding higher quiet breathing measurements.

As observed in similar research from the field of music (Ebert et al., 2002; Stadler & Szende, 1965a) and kinesiology (Ebert et al., 2000; Wilke et al., 1975), pooled results showed that breathing rate increased significantly when the pianists were performing compared to their breathing rate at rest. This confirms the first hypothesis stated, however, the reason for this is unclear since it may not necessarily be due to changes in carbon dioxide levels that normally result in a higher breathing rate (Ebert et al., 2002). The increased respiratory rate noted in a study conducted on violinists was not associated to oxygen inhalation but rather attributed to a pattern of breathing peculiar to violin playing (Stadler & Szende, 1965b).

By looking at individual results, it was possible to see which participants showed the most increase, the least increase or no increase from breathing at rest to breathing during the performance. All participants exhibiting no breathing rate differences between the rest condition and the performing conditions were very relaxed and comfortable playing in front of people. Interestingly, the individual demonstrating the biggest difference between the various breathing rate measurements was one who was less experienced and less advanced than the others. Although the participant claimed not to be nervous during the performances, uneasiness or anxiety could have led to a much faster breathing rate.

Contrary to what was expected, pooled results surprisingly did not confirm a significant increase of breathing rate during the performance of the exercises across different tempi even though the speeds at which the pianists played were purposely chosen to force extreme performance conditions - from very slow to very fast. In King's study (2006), although a specific tempo to breathing rate relationship was not found, tempo did affect the breathing rate on a consistent basis for each individual performer. Due to these contradicting results, is still not possible to conclude a causal effect relationship between increasing tempo and increasing breathing rate.

Functional Residual Capacity

Functional residual capacity (FRC) is the volume of air left in the lungs at the end of tidal respiration (Wanger et al., 2005). In order to determine changes in breathing volumes, the functional residual capacity of the pianists was measured and compared between the resting and different performing conditions. Results indicated that there was an increase in FRC between breathing at rest and during the performance of the scales at 120bpm and 184pmb. However, although participants took sporadic deeper breaths, tests conducted with the other exercises showed no significant difference between FRC at rest and during the performance. A higher FRC value signifies that there was a bigger volume of air present in the lungs at the end of passive expiration. Consequently, less air would have been exhaled suggesting shallower breathing contrary to what was hypothesized. In future studies, ventilation measurements could confirm presence of more air in the lungs. Other than being the result of increased breathing rate, increased ventilation can also be caused by an increased tidal volume. Ventilation has already been investigated in violinists (Stadler & Szende, 1965a) and could be examined in pianists.

In another study on violinists (Stadler & Szende, 1965b), *Violin playing and respiration: Oxygen consumption and respiratory function during violin playing*, results showed that oxygen consumption and ventilation always increased during playing. It was noted, however, that the change of oxygen consumption was only slightly dependent on the technical difficulty level of the piece. In the cases where the subject had made a mistake during the performance, oxygen consumption seemed to increase. This indicated that psychic conditions such as embarrassment had an effect on oxygen consumption. In general, the participants achieved a continuous performance with a lower oxygen level consumption. A primary conclusion was that it is important to practise playing longer compositions to adjust to the oxygen consumption levels that are eventually required for the actual performance. Similar tests could be conducted on pianists to determine if analogous results emerge.

3.1.6 Conclusion

The purpose of this study was to examine the breathing rate and functional residual capacity changes that occur in pianists as they are performing on their instrument. The methodology established in order to reach this goal proved to be efficient for the measurements needed. The limitations of this study are the small sample size and the heterogeneity of the individuals who participated. In future research, more variables should be held constant in order to determine if a cause-effect relationship exists between breathing rate and breathing volume during piano performances. Ideally, performing history, number of year of piano lessons and current musical involvement should be as consistent as possible across participants. According to Ericsson, Krampe, & Tersch-Römer (1993), 10000 hours of practice or more are needed for a pianist to become a professional performer on their instrument. This value is based on an estimate number of hours of practice per week. The study reinforces the fact that a common determinant in attaining a certain level of expertise in a particular task is the result of intense practice starting at a young age. Therefore, future studies should explore these same parameters in professional pianists to determine if a more consistent trend is present. Furthermore, in addition to the proposed research directions mentionned earlier, investigations could choose to look at different respiratory parameters such as tidal volume or respiratory flow. Additional research on the breathing patterns of pianists could expand the knowledge on the physiological requirements of playing this instrument.

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Chapter 4

Article 2

This second article addresses the relationship between different movement markers and respiration during the performance of a scale and arpeggio at the piano. This experiment repeats the investigation by Ebert and colleagues (2002). In their study, these researches used a nasal thermistor to collect the data whereas in our project inductive plethysmography straps encircled the participant's rib cage and abdomen. With the use of these belts, the experimental layout was designed in order to replicate normal performing conditions as much as possible. After extracting the exact time values at the end of each expiration, phase intervals were calculated and plots were graphed in order to view the data.

4.1 Analysis of coordination between breathing and different movement markers in pianists performing a C major scale and arpeggio

4.1.1 Abstract

In kinesiology, several studies have examined the coordination between breathing and large or small repetitive movements. Entrainment was observed between respiration and cyclic head, eye, forearm and finger movements. Similar repetitive movements are used while performing the piano but there are few investigations on breathing and pianists' movements. One study established a coordinative relationship between breathing and various finger movement markers that changed according to meter. Based on this research, the current experiment explored the coordinative relationship between breathing and three different finger movement markers based on pitch, meter and thumb biomechanics during the performance of repetitive exercises at the piano. Eight pianists played the C major scale and the C major arpeggio on a Yamaha Disklavier. During the performances, their respiration was monitored by an inductive plethysmography system (RIPmate Respiratory Effort System), a non-invasive device which maintained performance conditions closest to normal. Results varied depending on the participant but certain trends were observed. In some cases, the occurrence of the different sets of markers was simultaneous with the maximums (end of inspiration) and minimums (end of expiration) of the breathing curve.

Keywords: coordination, entrainment, finger movement, respiration, pitch marker, meter marker, passage of the thumb, biomechanics, breathing pattern

4.1.2 Introduction

The relationship between breathing and various bodily rhythms is complex since respiration is linked to many motor subsystems by neuronal interactions (Ebert, Rassler, & Hefter, 2000). Coordination is defined as a tuning of temporal patterns during which one oscillator imposes its tempo and phasing onto another oscillator indicating the entrainment of one rhythm by the other (Holst, 1939). It is often used in studies examining the link between the breathing cycle and various rhythms. Relationships between breathing and body rhythms leading to respiratory entrainment have been examined in both animals and humans (Bramble & Carrier, 1983). Movement characteristics such as type (Bechbache & Duffin, 1977), frequency (Perségol, Jordan, & Viala, 1991) and work load (Bernasconi & Kohl, 1993) are said to affect the degree of entrainment between movement and breathing. Moreover, factors like movement familiarity (Bramble & Carrier, 1983) and various environmental conditions (Paterson, Wood, Marshall, Morton, & Harrison, 1987) can also have an effect on the entrainment. Much research has been done on the entrainment of breathing with larger movements such as those seen during repetitive exercises. These studies have established coordination between breathing and walking rhythms (Rassler & Kohl, 1996), running rhythms (Bramble & Carrier, 1983), cycling rhythms (Kohl, Koller, & Jäger, 1981), cross-country skiing rhythms (Fabre, Perrey, Arbez, & Rouillon, 2007) and rowing rhythms (Mahler, Hunter, Lentine, & Ward, 1991). For actions of a smaller scale, there is information on the entrainment of breathing with limb movements (Agostoni & D'Angelo, 1976), forearm tracking movements (Ebert et al., 2000), eye and head movements (Rassler & Raabe, 2003) and finger movements (Rassler, 2000; Rassler, Bradl, & Scholle, 2000; Rassler, Ebert, Waurick, & Jaughans, 1996; Wilke, Lansing, & Rogers, 1975).

Accurate finger movements such as flexions, extensions and tapping movement examined in the previously mentioned studies (Rassler, 2000; Rassler et al., 1996; Wilke et al., 1975), are similar to gestures performed by pianists while playing their instrument.

Ebert, Hefter, Binkofski and Freund (2002) addressed the coordination between breathing and mental groupings of piano finger movements during the performance of a Hanon exercise transcribed in five different meters. Because individual pianistic movements are much faster than a normal breathing pattern, they wondered if there is a regulation of breathing according to groupings of notes. Results showed that a breath cycle seemed to last the length of a bar (1:1 coordination) when the meter used was 5/4, 6/4, 7/4 and a breath cycle lasted two bars (1:2 coordination) when the meter used was 6/4 or 4/4. Pooled data indicated that coordination between breathing and meter was found more frequently in 7/4 meter and less frequently with a 4/4 meter.

While Ebert and colleagues' study (2002) addressed the relationship between breathing and finger movement markers which differ according to meter, there is no research in the field of piano performance investigating the relationship between breathing and the passage of the thumb or pitch finger movement markers. The current study is similar to the work of Ebert and colleagues' (2002) but aims to explore whether coordination develops between breathing and finger movements made while performing a C major scale and arpeggio when targeting three types of specific finger movement markers: 1) meter, the typical rhythmic division of a scale or arpeggio, 2) pitch, the top and bottom note of each exercise and 3) passage of the thumb, the notes pressed by the latter as it is tucked under the other fingers.

Based on past research looking at repetitive forearm movement (Ebert et al., 2000), since the pitch markers are evenly spaced and involve a consistent opening and closing movement of the forearm, one would expect to see coordination between breathing and this movement marker during the performance of both exercises. The length of an average adult breath at rest is 5 seconds based on 12 breaths/minute (Comroe, Forster, DuBois, Briscoe & Carlsen, 1963) and the time interval between pitch markers is 4.89 seconds for the scale at 184bpm and 5.25 seconds for the arpeggio at 80 bpm. Therefore, the coordinative phenomenon is anticipated to occur only at the fastest tempo during the performance of the scale and the slowest tempo when playing the arpeggios. At the other tempi, the markers will either be too far apart or too close together. As observed in the study by Ebert and colleagues (2002), it is anticipated that there will be a coordinative relationship between breathing and the meter finger movement markers. Finally, since the passage of the thumb is irregular, it is predicted that it will not be coordinated with breathing.

4.1.3 Methodology

In order to conduct this research, we had to establish a protocol to measure breathing during a pianist's performance while maintaining performing conditions as close to normal as possible. Three pilot studies were conducted to determine the most adequate tool for recording respiration and to establish the best procedure. The following protocol was chosen since it was deemed most adequate in terms of the duration, the pianist's comfort level and the efficiency of the data collection method. This methodology section provides information on the participants, the instrumentation, the experimental set-up, the procedure, the data acquisition and the data analysis.

Participants

Eight pianists, (7 female, 1 male; aged 18-28), whose playing level ranged from grade 8 of the Royal Conservatory of Music of Toronto to a Bachelor of Music in piano performance degree, participated in the study. These individuals took part in the experiments following the approval of the Ethics Committee of the University of Ottawa (Appendix A).

[1]These approximate values were calculated with the participant's estimated number of practice hours per week for the first few grades and for the later grades, with the assumptions that they practiced 6

Table 4.1: Characteristics of the participants.

Participant	Gender	Level completed	# hours of practice[1]	Years playing the piano	Years of piano lessons	Years since stopped piano lessons
1	F	B. Mus.	2300	18	14	4
2	F	Gr. 9	1400	20	20	0
3	F	Gr. 8	4600	18	3	9
4	F	B mus	5400	21	17	3
5	M	Gr. 9	2900	10	10	0
6	F	B mus	5200	20	16	4
7	F	Gr. 8	2300	12	12	6
8	F	Gr. 10	3000	25	15	7

Instrumentation

Tools commonly used to measure various volumes in respiration-focused research include the following: face mask, spirometer, helium dilution method and pneumotachograph. Spirometry measures volumes included in the vital capacity only whereas the helium dilution method allows the measurements of all volumes included in the total lung capacity (Wanger et al., 2005). These apparatuses would not have been appropriate for this research because they are either invasive or disruptive to the performance of the pianists. In past research involving pianists, two different techniques have been used. In one study, the respiration of pianists was recorded by a thermistor placed in front of a nostril (Ebert et al., 2002). This device qualitatively gives information on the inspiratory and expiratory airflow but it does not measure volumes with accuracy. In the second study (King, 2006), they monitored pianists' respiratory patterns with a portable ergospirometer which was used to measure the timing of inspirations and of expirations during a performance. The pianists wore a ventilation mask and the breathing monitors were attached to them by a smart vest. In both cases, the respiration recording device was placed in close proximity to the face, making it seemingly uncomfortable for the pianist. It has also been shown that wearing a face mask alters the breathing pat-

days/week and 40 weeks/year.

tern (Askanazi et al., 1980). Moreover, devices used in these previous studies did not allow the measurements of vital capacity required for our study. Therefore, to maintain performance conditions closest to normal and to obtain the desired data, we used a non-invasive inductive plethysmography system (RIPmate Respiratory Effort System), a technique also used in other studies monitoring respiration (Clarenbach, Senn, Brack, Kohler, & Bloch, 2005).

In order to conduct the experiment, sound, images and respiration were recorded simultaneously. The following section describes the equipment that was used.

Recording Sound and Images

Two methods were used to record sound. In accordance with past research in piano performance (Ebert et al., 2002), participants played on a Yamaha Disklavier. As explained on the Yamaha Canada Music website (2005), the 88 key sensing system of this 7'6" grand piano is made of non-contact optical fiber/grayscale shutters which can detect the key position, the keying velocity and the key releasing velocity. A non-contact digital optical system senses the pedal positions. Data obtained from these sensors during a performance are recorded by an integrated MIDI operating system which allows recording and replaying of MIDI files. Secondly, for synchronization purposes, sound was recorded in a waveform audio format with a microphone (Neumann TLM-103) connected to a Digidesign Digi002 sound card[2].

For overall visual recording of the sessions, experiments were filmed by a vertically moveable analogue video camera mounted on accordion brackets attached to the ceiling of the laboratory. The video cassettes could be viewed later for missing information during the data analysis.

[2]Sound card model Digi 002. From Digidesign, a division of Avid Technology Inc., USA.

Recording Respiration

The inductive plethysmography straps (RIPmate Respiratory Effort System[3]) encircled the pianist's rib cage, under the armpits, and around the abdomen, below the 12th rib. The respiratory effort sensors measured inductance changes represented by voltage output, resulting from the circumference displacements of the upper rib cage and abdomen during inspiration and expiration. The signals from the sensors were converted into digital signals by a data acquisition board (DAQ08-Scireq). Prior to gathering the data, calibration was done by simultaneously measuring the circumference displacements (RIPmate) and flow changes through a pneumotachographer (Hans Rudolf- PNPT 3830B- 400L/min) attached to a MicroGard[4]) attached to a Microgard filter. Both were connected to the DAQ08-Scireq[5].

Experimental Set-Up and Data Synchronization

The data acquisition board (DAQ08-Scireq) recorded data from four sources: 1) RIPmate abdominal respiratory belt, 2) RIPmate thoracic respiratory belt, 3) flow, and 4) pressure. A double synchronization set up was used in order to synchronize the participant's respiratory data and the MIDI data from the piano. The first step was to synchronize the waverform audio file (Sound 1) with the analogue signal by using sound and pressure peaks. This was accomplished by striking a polyvinyl chloride tube which created a pressure wave detected (with a negligible resolution of 865μsec) by a pressure sensor and a microphone connected to a sound card (Digidesign Digi002). This wave created a peak in the pressure recording and a peak in the audio file. The second synchronization step was accomplished by synchronizing the MIDI data (Sound 2) and sound. This was achieved by playing a key on the piano which launched the MIDI recording and would be detected by the microphone, connected to the Digidesign Digi002 sound card, creat-

[3]From Sleepmate Technologies, Virginia, USA.

[4]From SensorMedics MicroGard Spirometry Filter. From VIASYS Healthcare, USA.

[5]Scireq Scientific Respiratory Equipment Inc., Montréal, Canada.

ing another peak in the audio file. Matlab algorhythms were subsequently coded into a Graphical User Interface to detect these three peaks (pressure, sound 1, and sound 2) and align them in time, resulting in synchronization of the system.

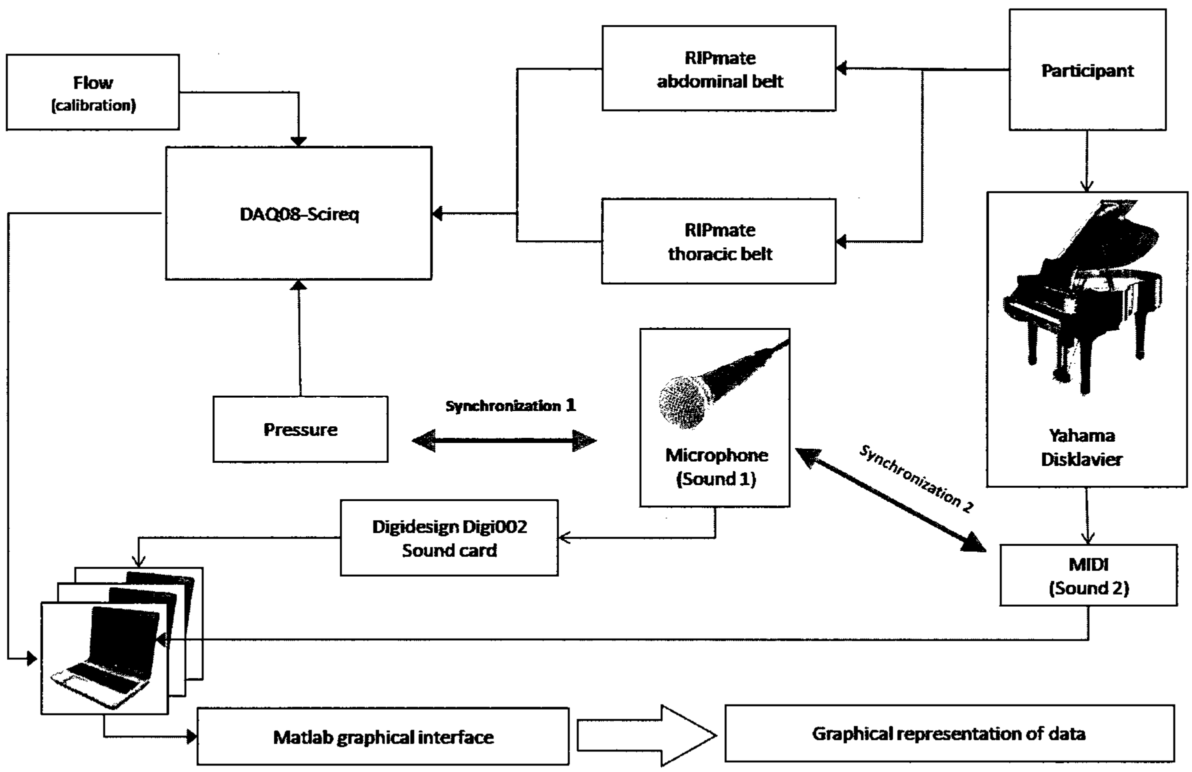

Figure 4.1: Experimental set-up illustrating the double synchronization method.

Procedure

Prior to the experiments, participants were given an information package containing the presentation letter (Appendix A), the consent form (Appendix A), and the musical scores required in preparation for the experimental session. In the letter, participants were asked to practice beforehand so they would be able to perform the scales, arpeggios, the Hanon exercise and repertoire pieces. While it did not directly divulge the purpose of the study, because of the nature of the experiment and the equipment used to collect the data, participants were aware that their breathing was being measured.

On the day of the testing session, participants came to the Piano Pedagogy Research Laboratory at the University of Ottawa at their appointed time. For demographic purposes, the participants answered a questionnaire (Appendix F) with the following information: gender, age, level of piano studies, number of years playing the piano, number of hours of practice per week, number of public performance per year, number of years since they stopped piano lessons, and familiarity with the repertoire pieces that were going to be performed.

Before starting the experiment, a two step equipment calibration procedure based on the literature (Banzett, Mahan, Garner, Brughera, & Loring, 1995; Konno & Mead, 1967; Sackner et al., 1989) was completed. The nose of each participant was plugged and they were asked to breathe in a pneumotach always keeping their hands on the piano in a natural playing position. The two calibration steps were the following:
1) Breathing at rest for 2 minutes which will be referred to as quiet breathing.
2) Vital capacity (VC): taking a breath to maximum capacity and exhaling to maximum capacity (repeated twice).
Afterwards, the participants engaged in a series of experiments that lasted in total approximately 45 minutes. Participants were asked to perform each task as they would during a normal lesson or recital. Between each experiment, breathing at rest was measured during which the participants were asked to read a pre-selected text of random facts which would serve as a distraction.

Scale (Appendix B)

Participants were asked to play repeatedly for 1 minute, 2 octaves of the C major scale ascending and descending, with the right hand, in eighth notes at three tempi: 60bpm, 120bpm, 184bpm.

Arpeggio (Appendix B)
Participants were asked to play repeatedly for 1 minute, 2 octaves of the C major arpeggio ascending and descending, with the right hand, in eighth notes at three tempi: 80bpm, 120bpm, 160bpm.

It is important to note that the metronome was on for the first 10 seconds of each task to set the tempo. For the rest of the performance, the metronome was off.

Data Acquisition

With a Graphical User Interface created in Matlab it was possible to obtain a graphical representation of the MIDI recording and of the respiration (Figure 4.2).

Piano Roll
A MIDI toolbox created by Schutte (2009) was used to visualize the MIDI data recorded by the Yamaha Disklavier. Using a piano roll format, the performance is graphically illustrated across time by squares representing each note of the musical excerpt (Figure 4.2). The position and size of each square denote the pitch played and its duration respectively. In addition, the intensity of the notes is displayed with color coding.

Respiration Curve
The RIPmate belts are sensitive to circumference changes from the thorax and abdomen but also other torso or limb movement may be detected by the sensors. Therefore, before quantitatively analyzing the respiratory patterns it was necessary to verify that patterns and peaks in the respiratory curve were in fact caused by respiratory changes and not by

a participant's abrupt movement. Since the experiment sessions were filmed, abnormal curves in the breathing pattern were verified by watching the video of the experiment session for upper body movements or arm movements.

From Matlab, the breathing curve for each participant during every activity was traced based on a 2 x thorax + 1 x abdomen equation (Banzett et al., 1995). For respiration to be graphically represented in terms of liters across time, it was first necessary to convert respiration data from voltage to liters. This was achieved by comparing the respiration flow values (in L) obtained with the pneumotach during the calibration step to the electrical signals (in V) output from the RIPmate System. A conversion factor was found between the two sets of data allowing us to represent the amplitude changes in L. Afterwards, by finding the vital capacity for each participant, the y axis of the respiration graphs was converted to percentage of vital capacity allowing for comparisons between participants.

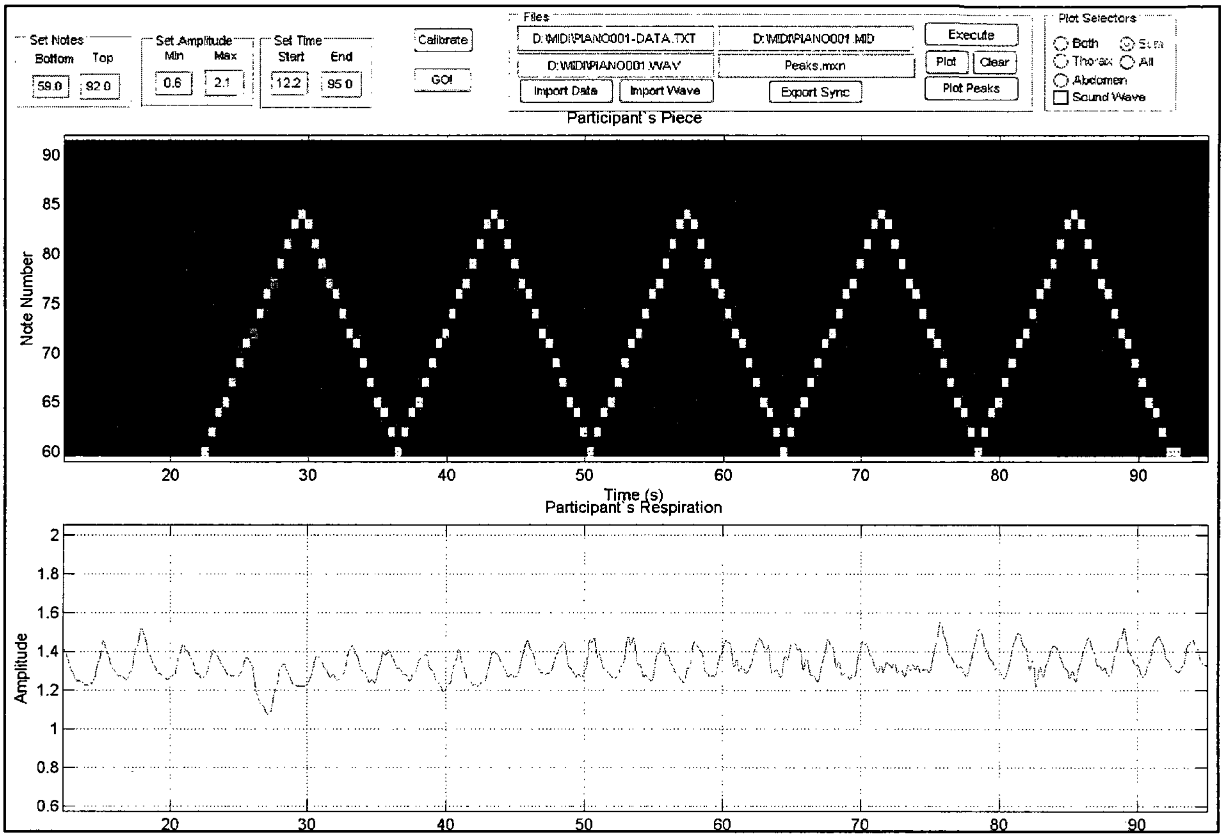

Figure 4.2: A piano roll (upper graph) showing the performance of a scale and the breathing curve (lower graph) as represented in Matlab.

4.1.4 Data Analysis

In order to study coordination, phase intervals are typically used (Ebert et al., 2000; Ebert et al., 2002; Fabre et al., 2007). This requires the measurement of the time difference between a specific point of the movement cycle and a specific point of the respiratory cycle, such as expiration or inspiration. Therefore, to determine coordination between breathing and movement, we considered the time period between a movement marker and the closest breathing marker which represents the end of expiration (Figure 4.3). This was accomplished by obtaining the time points of the end of expiration in Diamov[6],

[6]This is not a commercial product but a program created by a research laboratory. Politecnico di Milano, Department of bioengineering, Milan, Italy.

a Matlab designed program used to visualize data and to obtain minimum values within a selected window.

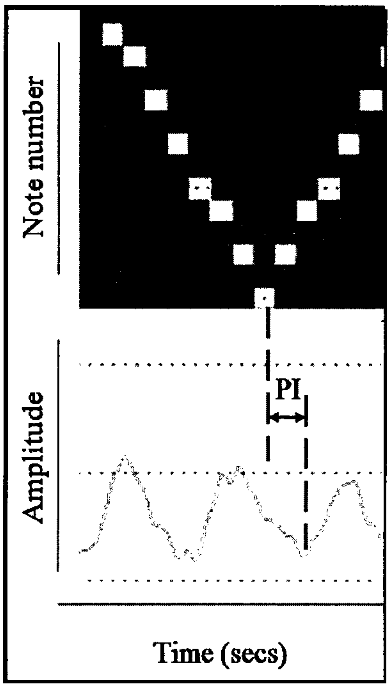

Figure 4.3: A section of piano roll (upper representation) and the breathing curve (lower graph). The phase intervals (PI) are calculated by finding the time difference between each movement marker and the closest end of expiration point on the breathing curve.

From the performance data recorded by the Disklavier, it was possible to extract the time value of each note that was pressed during the performance of the scale and arpeggio. Afterwards, the time value of each movement marker event corresponding to a specific note played was selected. Three sets of movement markers were established:

1) Pitch marker: the onset of the bottom note (middle C) and the top note (C6) of the scale/arpeggio

In this experiment, the pitch markers are based on the first and last notes of the scale. They occur at regular intervals.

2) Meter marker: the onset of every fourth notes

The meter markers are regular also. The slight accent put on every fourth note is not as obvious to perform when playing an arpeggio because of the standard fingering used.

3) Passage of the thumb marker: the onset of every note pressed by the thumb as it is tucked under the other fingers

With the standard fingering used during the performance of a scale or arpeggio, this marker occurs at irregular intervals.

Finally, as seen in Figure 4.4 and Figure 4.5 the different markers only correspond in time at the beginning of a performance of the scale or arpeggio.

Figure 4.4: Location of the different markers in the C major scale. It should be noted that the position of the passage of the thumb markers is based on the assumption that the correct fingering was used during the performance of the scale.

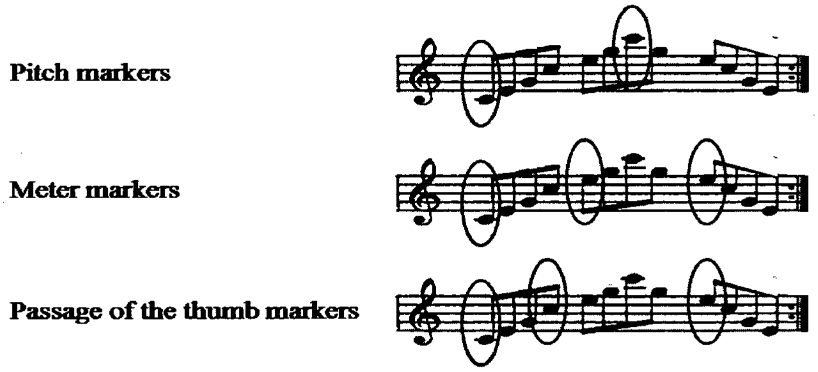

Figure 4.5: Location of the different markers in the C major arpeggio. It should be noted that the position of the passage of the thumb markers is based on the assumption that the correct fingering was used during the performance of the arpeggio.

The time interval between the different movement markers varies according to the tempi of the exercise performed and the type of marker (Table 4.2). As seen in the table, the time interval between most markers is shorter than a normal breath cycle (5sec/breath). Some of the time intervals are within the time duration of a normal breath cycle for example the second passage of the thumb marker during the performance of the arpeggio at 80bpm or the pitch markers when playing the arpeggio at 80bpm. Lastly, during the performance of the scale at 60bpm and 120bpm, the time interval of the pitch markers is bigger than a normal breath cycle.

Table 4.2: Time between the onset of the different markers at each tempo. Since the thumb is used unevenly, there are two different time intervals between the passage of the thumb markers.

Exercise	Tempo	Pitch	Meter	Passing Thumb 1	Passing Thumb 2
	60	15	4	4	9
Scales	120	7.5	2	2	4.5
	184	4.89	1.3	1.3	2.93
	80	5.25	3	21	5.25
Arpeggios	120	3.5	2	20	3.5
	160	2.625	1.5	20	2.625

4.1.5 Results

Tempo Variations

Although participants were given set tempi for the C major scale and the arpeggio, they did not always maintain the same tempo throughout their performance. The metronome was on only for the first 10 seconds of a performance.

Table 4.3: Tempo variations that occurred during the performance of the scales and arpeggios for each participant. "+" indicates and increase in tempo during the performance, "o" indicates no change in tempo, and "-" indicates a decrease in tempo.

Exercise	Tempo (bpm)	P1	P2	P3	P4	P5	P6	P7	P8
	60	o	-	-	o	-	o	o	o
Scales	120	o	-	-	o	o	o	o	o
	184	o	o	-/+	o	o	-	o	o
	80	o	o	-	-	-	o	+	-
Arpeggios	120	o	-	o	o	o	-	o	-
	160	o	o	-/+	o	o	-	+	-

Phase Relations between Breathing and Movement Markers

Different observations have been made with regards to phase relations and breathing. The phase interval plots illustrated an independent relationship between breathing and movement. The plots of pitch markers and metric markers present groups of points aligned diagonally especially at the slower speed. As the tempo increases, the time difference (phase interval) between a movement marker and the closest breathing marker decreases therefore the points gets closer to the zero.

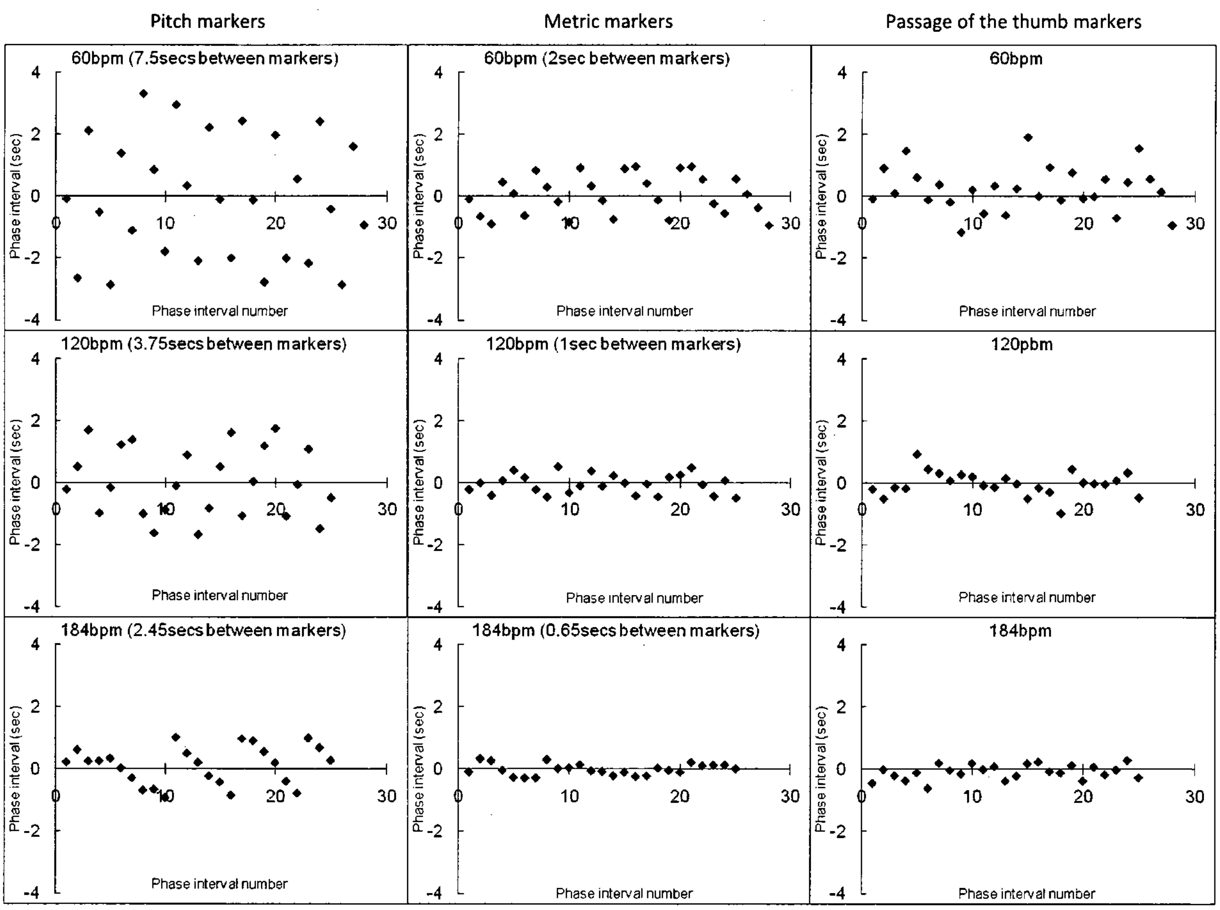

Figure 4.6: Plots of phase interval relation between onset of inspiration and onset of movement for the three markers (pitch, meter, passage of the thumb) at different tempi for one participant. Extraneous points were removed from the plots.

Markers and the Breathing Curve

Graphs showing the positioning of the different markers on the breathing curve were also plotted for further analysis. By plotting these graphical representations, it was possible to see that the pitch markers (Figure 4.7), meter markers (Figure 4.8) and passage of the thumb markers (Figure 4.9) of some participants followed a pattern. On the three graphs, the markers often corresponded to the major peaks (minimums and maximums) of the breathing pattern. This is very evident in Figure 4.7 even with the big peak that happens at around 118 sec. The pitch markers land on the minimums and maximums of the breathing curve before and after this big peak. Although the markers are not juxtaposed as precisely on the minimums and maximums of the breathing curve in Figure 4.8, a similar trend is noticed. On the third graph (Figure 4.9) it is interesting how the markers often occur on irregularities of the breathing curve.

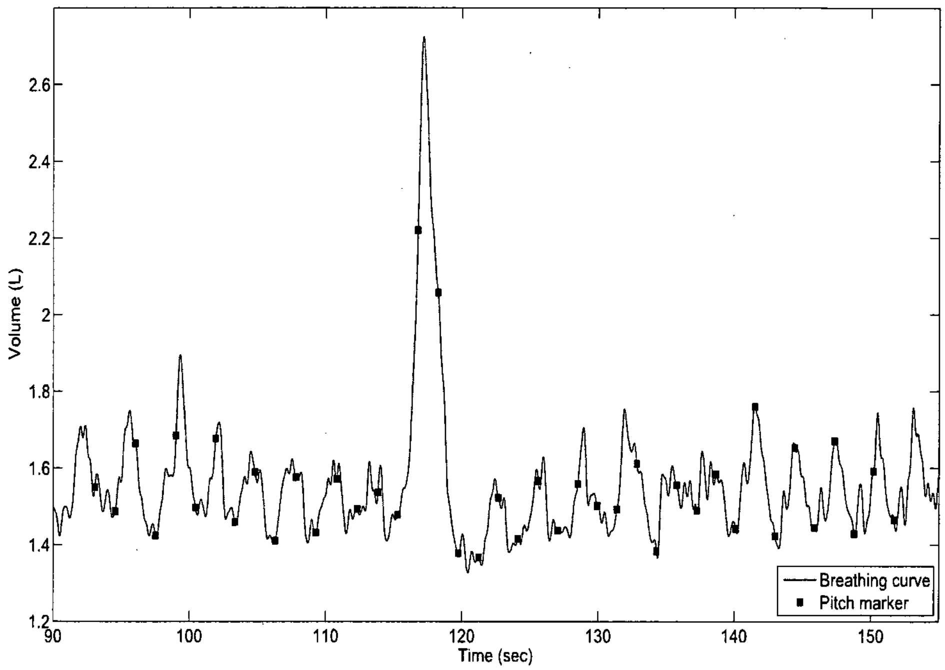

Figure 4.7: Breathing curve of a participant with juxtaposed pitch movement markers. The pitch markers occur mainly during the maximums and minimums of the breathing curve in this excerpt of the performance of the C major arpeggio at 120bpm. It should be noted that sometimes the markers fall on smaller peaks or irregularities in the breathing curve.

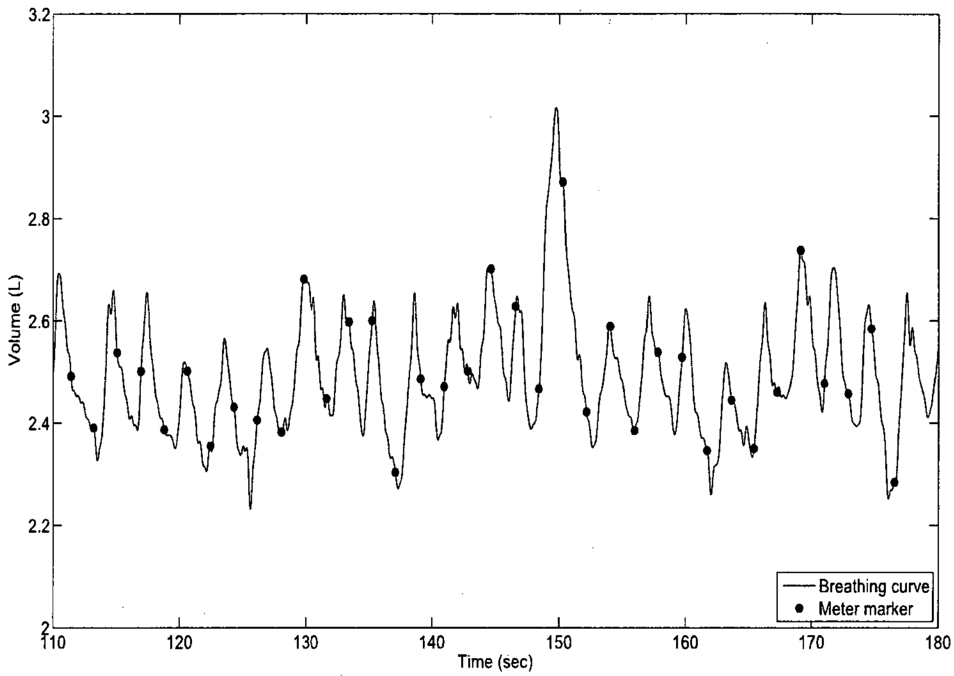

Figure 4.8: Breathing curve of a participant with juxtaposed meter movement markers. The meter markers occur mainly during the maximums and minimums of the breathing curve in this excerpt of the performance of the C major scale at 120bpm. It should be noted that sometimes the markers fall on smaller peaks in the breathing curve.

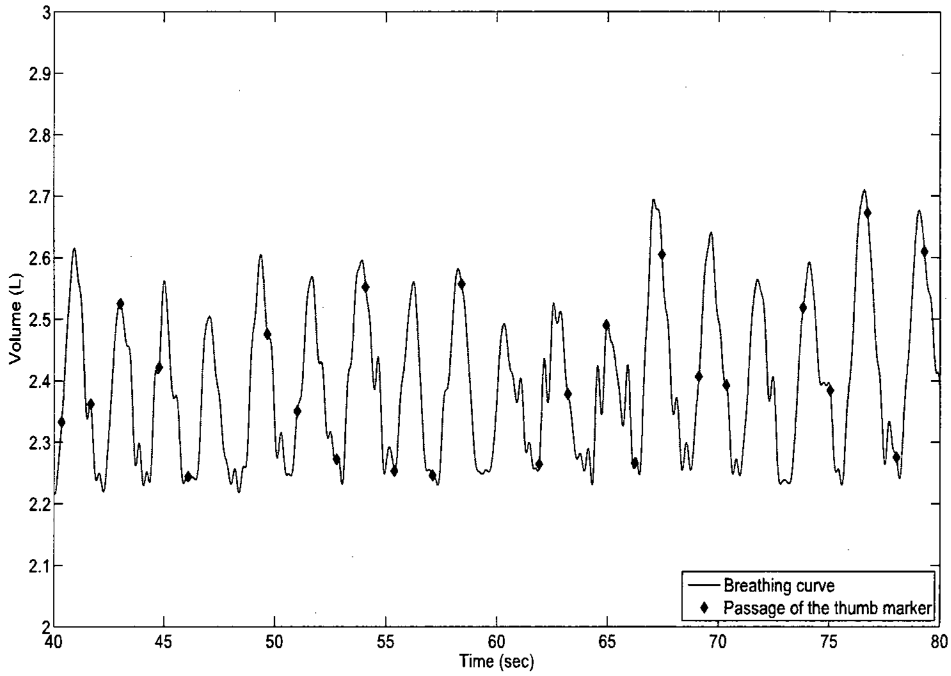

Figure 4.9: Breathing curve of a participant with juxtaposed passage of the thumb movement markers. The passage of the thumb markers occur mainly during the maximums of the breathing curve in this excerpt of the performance of the performance of the C major scale at 60bpm. It should be noted that sometimes the markers fall on smaller peaks in the breathing curve.

4.1.6 Discussion

The purpose of this paper was to investigate coordination between breathing and movement based on different markers during the performance of a scale or arpeggio. This section will discuss the results observed in the phase interval plots and breathing curve graphs of the participants during their performance.

Performance of the scale

Participants were asked to repeatedly perform the C major scale in their right hand at three different tempi for one minute. The phase interval graphs for the pitch markers of two participants displayed intriguing diagonal groupings. This pattern is examplified in the three tempi of the pitch marker graphs of Figure 4.6. For the other six participants, no recognizable patterns were noted. It was concluded that these diagonal graphical patterns are not an indication of coordination between breathing and movement. On the contrary, they are more likely indicating independence between the two elements. The scattered points shaping into a diagonal line signify that the pitch markers were progressively getting closer and further from the breathing markers. This is the normal pattern that should occur between independent rhythmic cycles that remain constant. Therefore, this contradicts the hypothesis stated earlier. Ebert and colleagues had observed coordination between forearm tracking and breathing (Ebert et al., 2000). In our experiment, the forearm flexion and extension resulting from the repetitive performance of the scale does not lead to coordination between breathing and movement as seen in Ebert and colleagues' (2000) similar study.

In our experiment the meter markers are musically identified with a slight accent intentionally performed by the pianist on every four notes. The juxtaposition of the meter markers on the breathing curve showed interesting results for some participants. For three pianists it was observed that the meter markers coincided with peaks (minimums and maximums) of the breathing curve during the performance of the scale at the first and second tempo. An example of this is shown in Figure 4.8. The other five participants showed no significant relationship between breathing and the meter markers. In a similar study on coordination between breathing and different meters, Ebert et al. (2002) observed a relationship between breathing and different time signatures. This investigation showed that a coordination occured between meter and breathing. However, this phenomenon seemed to be more common between breathing and asymmetrical meters and less common between breathing and a 4/4 meter. According to this researcher, persistent coordination between breathing and asymmetrical meters (3/4, 5/4 or 7/4) may be the result of increased mental effort by the performers. Nevertheless, Ebert and colleagues' explanation could be applicable here if participants used increased mental effort to play the scale with correctly accentuated notes. Although the results obtained from these three participants confirm the hypothesis previously stated, the study by Ebert and colleagues seemed to have found a clear and consistent relationship between meter markers and breathing in all the participants.

Analogous results were noted for the passage of the thumb markers on the plots of three other participants (Figure 4.9). The passage of the thumb markers coincided with peaks (minimums and maximums) or irregularities of the breathing curve very consistently for these pianists. This concurrence may be due to the slightly increased finger movement effort which occurs when the thumb is used after it is tucked under the other fingers. It is not uncommon for pianists to unintentionally put an accent on the note played by the thumb because of the natural rotation of the wrist. The trend noted with these three participants contradicts the hypothesis stating that the passage of the thumb markers will not be coordinated with breathing because of their irregularity. However, since this result was only observed in two pianists, there is not sufficient proof to confirm a direct relationship between breathing and passage of the thumb markers. There were no apparent patterns in the results of the other participants.

Performance of the arpeggios

After playing the scales, participants were asked to repeatedly perform the C major arpeggio with the right hand for one minute. Although the phase interval plots differ radically between participants, the breathing graphs of four participants showed that the pitch markers occurred simultaneously with the main minimums (end of inspiration) and maximums (end of inspiration) on the breathing pattern during the performance at the second tempo (Figure 4.7). In this figure, although we noted that the coordination of the markers is interrupted by an unexpected peak in the breathing curve, the concurrence of both elements resumes shortly after. These observations are in accordance with what was hypothesized. Since it is unnatural to play arpeggios with metric rhythm, if a coordination were to occur, it would be expected between breathing and pitch markers. Furthermore, this phenomena was observed at the second tempo of 120bpm (3.5 seconds between markers), an adequate time interval for concurrence to happen between breathing and the markers.

Future Studies

Certain limitations such as tempo variations and inaccurate use of accentuated notes could have influenced the results of this experiment. In the same line of research, future studies could isolate each marker while asking pianists of a specific level (ex. professionals) to perform the scales and arpeggios. Several closer tempi could be chosen and controlled with the use of a metronome. Moreover, it would be interesting to repeat this study while requiring participants to play the same exercises over several experimental sessions in order to determine if similar trends occur.

Our research belongs to a limited collection of projects on breathing and finger movements (Ebert et al., 2002) at the piano but expanding knowledge in the area could lead to more interesting questions. There are many examinations of the relationship between breathing and different finger movements (Rassler, 2000; Rassler, Bradl, & Scholle, 2000; Rassler, Ebert, Waurick, & Jaughans, 1996; Wilke et al., 1975). When analyzing the influence of breathing on movement precision, Rassler (2000) found that during late expiration, flexion movements were less precise whereas during late inspiration, extension movements lost precision. Knowing this, could late breathing influence the precision in piano playing? A similar coordination study could be used to test this while analyzing the accuracy of the performance. Lastly, coordination has also been studied between breathing and head or eye movement (Rassler & Raabe, 2003) which could be the basis for similar research with pianists. Is there a link between head movements or eye movements or torso movements and breathing during a piano performance?

4.1.7 Conclusion

Past research explored the relationship between breathing and meter (Ebert et al., 2002) but the present investigation is innovative because it is the first to examine the coordinative relationship between breathing and movement according to different pianistic movement markers. By looking at the breathing curve graphs it seemed that finger movements related to the onset of the passage of the thumb and meter markers were simultaneous with peaks in the breathing pattern during the performance of the C major scale. Similarly, pitch marker movements occurred on peaks of the breathing curve during the performance of the C major arpeggio. Although these trends were noted, results are different across participants and do not allow us to state a clear relationship between breathing and movement markers during the performance of a scale or arpeggio as was observed in similar past studies (Ebert, et al., 2000; Ebert et al., 2002). More research in the field is required to warrant a better understanding of the unconscious relationship between breathing and fast extremity movements.

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Chapter 5

Article 3

This third article approaches the study of the respiratory patterns of pianists from a qualitative angle. With a double synchronization method and peak detection in Matlab, the piano roll data and the respiratory data were aligned in time. The juxtaposed visual representation of the piano roll and the respiratory curve allowed an in-depth analysis of the breathing patterns of pianist during the execution of each musical task. Observable variations of the breathing curve were noted.

5.1 Breathing pattern changes observed while pianists performed technical exercises and repertoire pieces

5.1.1 Abstract

The breathing of pianists has become a point of interest as the field of research on the various physiological demands of being a musician is expanding. Although breathing is discussed in some piano pedagogy material, little is known on how pianists use breathing for expressive purposes. A few studies have directly investigated the respiration of pianists during the execution of different pianistic tasks such as scales, arpeggios, Hanon exercises and repertoire pieces but no study has compared the breathing of pianists across the performance of different tasks. Based on past research, the general purpose of the current project was to examine changes between the breathing patterns of pianists at rest and during various performing tasks in order to determine if respiratory patterns vary according to different musical features such as melodic complexity, meter, tempo, and phrasing. Does respiratory behaviour change as melodic complexity or tempo increase? Is breathing affected by specific musical elements such as metric changes and phrasing? In this analysis, the respiration of pianists was monitored by an inductive plethysmography system (RIPmate Respiratory Effort System) during their performance of a C major scale, a C major arpeggio, the Hanon #10 five-finger exercise, the *Minuet in G major* by C. Petzold and *Für Elise* by L. van Beethoven. Qualitative analyses of the participants' breathing curves for each performance task were conducted. Results showed that some pianists take a deep breathing before starting a performance and that often, the breathing pattern of pianists' changes while playing compared to their respiratory pattern at rest.

Keywords: respiration, breathing, breathing curves, rhythm, tempo, phrasing, respiratory pattern

5.1.2 Introduction

As research has accumulated on the various physiological aspects of being a musician, breathing has emerged as a point of interest. Although the majority of piano pedagogy material does not explain how to integrate breathing into a teaching context, the topic of respiration has been briefly addressed from a physiological and expressive standpoint (Bernstein, 1981; Mark, 2003; Sandor, 1981). In his book With Your Own Two Hands, Bernstein (1981) looks at breathing from an interpretive point of view. He believes that under certain conditions it is important to learn how to control one's breathing.

He quotes Lowen (1975): "Just as strong emotions stimulate and deepen one's breathing, the stimulation and deepening of respiration can evoke strong emotion." (p.37). Bernstein deduces that "proper" breathing would help the pianist feel the music and recommends some general breathing exercises common to singers. Mark (2003) addresses the physiological requirements of a pianist in What Every Pianist Needs to Know about the Body where he brings up the importance of breathing with the phrase. He states that singers and wind players coordinate their respiration with musical phrases whereas, pianists do not necessarily choose to follow this approach. Sandor (1981) mentions how tension caused by excessive muscular contractions in and around the respiratory system can result in a malfunction of the breathing apparatus which consequently affects various musical elements like phrasing, rubato, tempo and accentuation.

Although some work has been done on the respiratory patterns of wind players (Bouhuys, 1964; Cossette, Monaco, Aliverti, & Maclem, 2008; Cossette, Sliwinski, & Macklem, 2000; Gilbert, 1998; Kelly, 1997; Shemann, 2000) and singers (Pettersen, Bjorkoy, 2009; Smith, 2007), little is known on how pianists use breathing for expressive purposes. In the scientific literature, a few studies have directly investigated the respiration of pianists during the execution of different pianistic tasks such as scales, arpeggios, Hanon five-finger exercises and repertoire pieces (Ebert, Hefter, Binkofski, & Freund, 2002; King, 2006; Nassrallah, Comeau, Cossette, Russell, in preparation A; Nassrallah, Comeau, Cossette, Russell, in preparation B). Their individual goals were to explore the relationship between physical movement, meter, tempo, structure and breathing while performing. Results showed that the variations of the meter unconsciously affect breathing rate (Ebert et al.. 2002), that performers had a tendency to take a deep inspiration right before they started to play (King, 2006) and that there were consistencies in the timing of breaths of pianists at key phrases in a repertoire piece (King, 2006). It also became evident that respiration is unique in each performance but that the breathing of the pianist follows a certain pattern throughout the piece (King, 2006). Other than a comparison of breathing changes according to meter when playing a Hanon exercise (Ebert et al., 2002) no study has compared the breathing of pianists across the performance of different tasks. Therefore, based on past research, the general purpose of the current project was to examine changes between the breathing patterns of pianists at rest and during various performing tasks in order to determine if respiratory patterns vary according to different musical features such as melodic complexity, meter, tempo, and phrasing. Does respiratory behaviour differ as melodic complexity or tempo increase? Is breathing affected by more specific musical elements such as metric changes during the performance of a Hanon five-finger exercise and phrasing when performing repertoire pieces? Another purpose of the research was to examine whether pianists consistently took a deep breath before starting to play as was observed in the King study. It is expected that the breathing pattern of the pianists will remain regular and similar to their respiration at rest while playing the scales and arpeggios since they are melodically linear, they require a more mechanical approach and the gestures involved in their performance are repetitive. Based on Ebert's research, we anticipate breathing pattern changes when the pianists will be playing the Hanon exercises in different meters. Also, breathing should vary during the performance of the repertoire pieces. As observed in the King study, it is predicted that pianists will take a deep breath before performing a repertoire piece and use breathing to express the music. Correspondingly, participants are expected to subconsciously breathe with the phrase during these performances.

5.1.3 Methodology

In order to conduct this research, we had to establish a protocol to measure breathing during a pianist's performance while maintaining performing conditions as close to normal as possible. Three pilot studies were conducted to determine the most adequate tool for recording respiration and to establish the best procedure. The following protocol was chosen since it was deemed most adequate in terms of the duration, the pianist's comfort level and the efficiency of the data collection method. This methodology section provides information on the participants, the instrumentation, the experimental set-up, the procedure, the data acquisition and the data analysis.

Participants

Eight pianists, (7 female, 1 male; aged 18-28) whose playing level ranged from grade 8 of the Royal Conservatory of Music of Toronto to a Bachelor of Music in piano performance degree, participated in the study. These individuals took part in the experiments following the approval of the Ethics Committee of the University of Ottawa (Appendix A).

Table 5.1: Characteristics of the participants.

Participant	Gender	Level completed	# hours of practice[1]	Years playing the piano	Years of piano lessons	Years since stopped piano lessons
1	F	B. Mus.	2300	18	14	4
2	F	Gr. 9	1400	20	20	0
3	F	Gr. 8	4600	18	3	9
4	F	B mus	5400	21	17	3
5	M	Gr. 9	2900	10	10	0
6	F	B mus	5200	20	16	4
7	F	Gr. 8	2300	12	12	6
8	F	Gr. 10	3000	25	15	7

Instrumentation

Tools commonly used to measure various volumes in respiration-focused research include the following: face mask, spirometer, helium dilution method and pneumotachograph.

[1]These approximate values were calculated with the participant's estimated number of practice hours per week for the first few grades and for the later grades, with the assumptions that they practiced 6 days/week and 40 weeks/year.

Spirometry measures volumes included in the vital capacity only whereas the helium dilution method allows the measurements of all volumes included in the total lung capacity (Wanger et al., 2005). These apparatuses would not have been appropriate for this research because they are either invasive or disruptive to the performance of the pianists. In past research involving pianists, two different techniques have been used. In one study, the respiration of pianists was recorded by a thermistor placed in front of a nostril (Ebert et al., 2002). This device qualitatively gives information on the inspiratory and expiratory airflow but it does not measure volumes with accuracy. In the second study (King, 2006), they monitored pianists' respiratory patterns with a portable ergospirometer which was used to measure the timing of inspirations and of expirations during a performance. The pianists wore a ventilation mask and the breathing monitors were attached to them by a smart vest. In both cases, the respiration recording device was placed in close proximity to the face, making it seemingly uncomfortable for the pianist. It has also been shown that wearing a face mask alters the breathing pattern (Askanazi et al., 1980). Moreover, devices used in these previous studies did not allow the measurements of vital capacity required for our study. Therefore, to maintain performance conditions closest to normal and to obtain the desired data, we used a non-invasive inductive plethysmography system (RIPmate Respiratory Effort System), a technique also used in other studies monitoring respiration (Clarenbach, Senn, Brack, Kohler, & Bloch, 2005).

In order to conduct the experiment, sound, images and respiration were recorded simultaneously. The following section describes the equipment that was used.

Recording Sound and Images

Two methods were used to record sound. In accordance with past research in piano performance (Ebert et al., 2002), participants played on a Yamaha Disklavier. As explained on the Yamaha Canada Music website (2005), the 88 key sensing system of this 7'6" grand piano is made of non-contact optical fiber/grayscale shutters which can detect the key position, the keying velocity and the key releasing velocity. A non-contact digital optical system senses the pedal positions. Data obtained from these sensors during a performance are recorded by an integrated MIDI operating system which allows recording and replaying of MIDI files. Secondly, for synchronization purposes, sound was recorded in a waveform audio format with a microphone (Neumann TLM-103) connected to a Digidesign Digi002 sound card[2].

For overall visual recording of the sessions, experiments were filmed by a vertically moveable analogue video camera mounted on accordion brackets attached to the ceiling of the laboratory. The video cassettes could be viewed later for missing information during the data analysis.

Recording Respiration

The inductive plethysmography straps (RIPmate Respiratory Effort System[3]) encircled the pianist's rib cage, under the armpits, and around the abdomen, below the 12th rib. The respiratory effort sensors measured inductance changes represented by voltage output, resulting from the circumference displacements of the upper rib cage and abdomen during inspiration and expiration. The signals from the sensors were converted into digital signals by a data acquisition board (DAQ08-Scireq). Prior to gathering the data, calibration was done by simultaneously measuring the circumference displacements (RIPmate) and flow changes through a pneumotachographer (Hans Rudolf- PNPT 3830B- 400L/min) attached to a MicroGard[4]) attached to a Microgard filter. Both were connected to the DAQ08-Scireq[5].

[2]Sound card model Digi 002. From Digidesign, a division of Avid Technology Inc., USA.
[3]From Sleepmate Technologies, Virginia, USA.
[4]From SensorMedics MicroGard Spirometry Filter. From VIASYS Healthcare, USA.
[5]Scireq Scientific Respiratory Equipment Inc., Montréal, Canada.

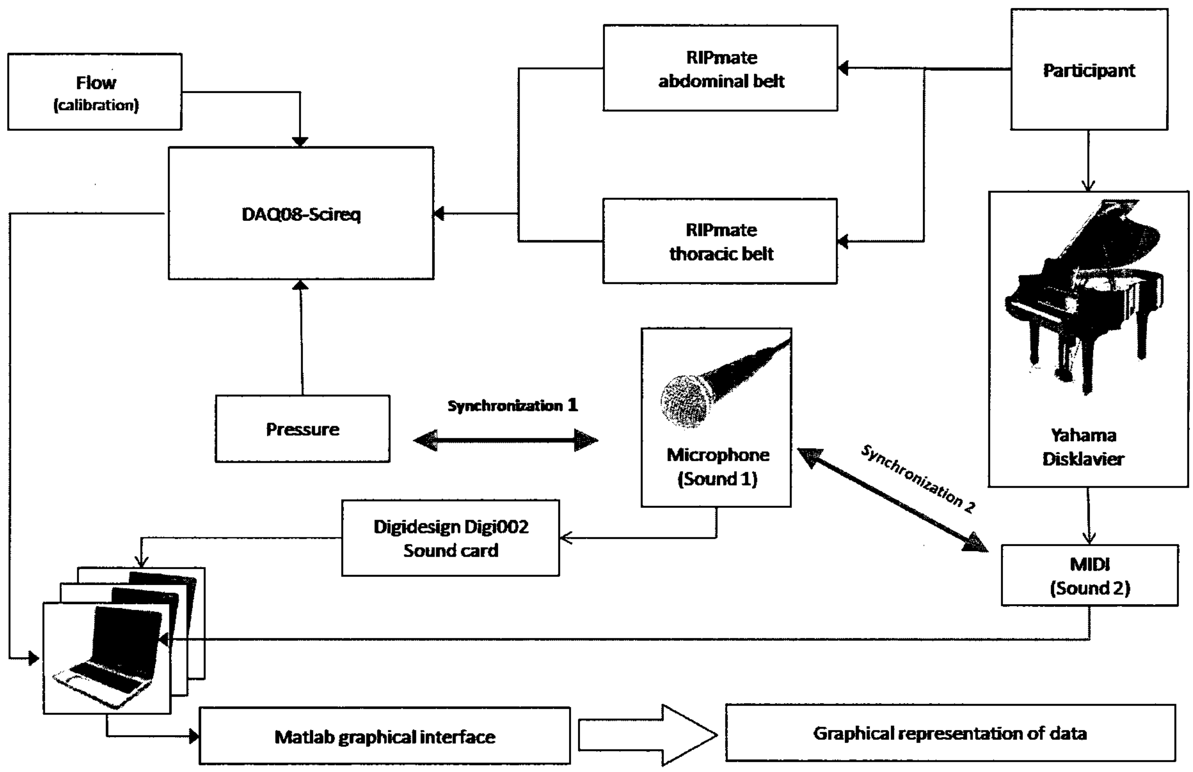

Figure 5.1: Experimental set-up illustrating the double synchronization method.

Experimental Set-Up and Data Synchronization

The data acquisition board (DAQ08-Scireq) recorded data from four sources: 1) RIPmate abdominal respiratory belt, 2) RIPmate thoracic respiratory belt, 3) flow, and 4) pressure. A double synchronization set up was used in order to synchronize the participant's respiratory data and the MIDI data from the piano. The first step was to synchronize the waverform audio file (Sound 1) with the analogue signal by using sound and pressure peaks. This was accomplished by striking a polyvinyl chloride tube which created a pressure wave detected (with a negligible resolution of 865μsec) by a pressure sensor and a microphone connected to a sound card (Digidesign Digi002). This wave created a peak in the pressure recording and a peak in the audio file. The second synchronization step was accomplished by synchronizing the MIDI data (Sound 2) and sound. This was achieved by playing a key on the piano which launched the MIDI recording and would be detected by the microphone, connected to the Digidesign Digi002 sound card, creating another peak in the audio file. Matlab algorhythms were subsequently coded into a Graphical User Interface to detect these three peaks (pressure, sound 1, and sound 2) and align them in time, resulting in synchronization of the system.

Procedure

Prior to the experiments, participants were given an information package containing the presentation letter (Appendix A), the consent form (Appendix A), and the musical scores required in preparation for the experimental session. In the letter, participants were asked to practice beforehand so they would be able to perform the scales, arpeggios, the Hanon exercise and repertoire pieces. While it did not directly divulge the purpose of the study, because of the nature of the experiment and the equipment used to collect the data, participants were aware that their breathing was being measured.

On the day of the testing session, participants came to the Piano Pedagogy Research Laboratory at the University of Ottawa at their appointed time. For demographic purposes, the participants answered a questionnaire (Appendix F) with the following information: gender, age, level of piano studies, number of years playing the piano, number of hours of practice per week, number of public performance per year, number of years since they stopped piano lessons, and familiarity with the repertoire pieces that were going to be performed.

Before starting the experiment, a two step equipment calibration procedure based on the literature (Banzett, Mahan, Garner, Brughera, & Loring, 1995; Konno & Mead, 1967; Sackner et al., 1989) was completed. The nose of each participant was plugged and they were asked to breathe in a pneumotach always keeping their hands on the piano in a natural playing position. The two calibration steps were the following:

1) Breathing at rest for 2 minutes which will be referred to as quiet breathing.

2) Vital capacity (VC): taking a breath to maximum capacity and exhaling to maximum capacity (repeated twice).

Afterwards, the participants engaged in a series of experiments that lasted in total approximately 45 minutes. Participants were asked to perform each task as they would during a normal lesson or recital. Between each experiment, breathing at rest was measured during which the participants were asked to read a pre-selected text of random facts which would serve as a distraction.

Scale (Appendix B)

Participants were asked to play repeatedly for 1 minute, 2 octaves of the C major scale ascending and descending, with the right hand, in eighth notes at three tempi: 60bpm, 120bpm, 184bpm.

Arpeggio (Appendix B)

Participants were asked to play repeatedly for 1 minute, 2 octaves of the C major arpeggio ascending and descending, with the right hand, in eighth notes at three tempi: 80bpm, 120bpm, 160bpm.

Five Finger Exercise (Appendix C)

In order to give them time to practice, approximately one week before the experiment participants were given the Hanon #10 five-finger exercise (Berlin, 1945) with no meter indication. This exercise number was chosen because of its adequate difficulty and melodic pattern. Furthermore, the first Hanon exercises were avoided since they are commonly encountered by pianists. On the day of the experiment, participants were asked to play this same exercise transcribed in five different meters 4/4, 3/4, 6/4, 5/4, 7/4 (Figure 5.2). Since the pianists were all advanced, it was expected that they would

Figure 5.2: Excerpt of the Hanon #10 five-finger exercise transcribed in five different meters.

play the exercise shifting the accent according to the meter. Every participant played the exercises in the same order (4/4, 3/4, 6/4, 5/4, 7/4) at a tempo of 168bpm (per quarter note). The data obtained from this part of the experiment was not analyzed or discussed in this article.

Minuet in G major by C. Petzold (Appendix D)

Participants were given the *Minuet in G major* by C. Petzold (Palmer, 1992), a grade 3 repertoire piece according to the Royal Conservatory of Music of Toronto, approximately one week before the experiment session which gave them time to practice if they were not already familiar with it. They were asked to perform the first 16 measures of the piece with repeats - the first time without ornamentation and the second time with ornamentation. This was done at three different tempi: 80bpm, 120bpm, 160bpm.

Für Elise by L. van Beethoven (Appendix E)
Participants were given *Für Elise* by L. van Beethoven (Hinson, 1986), a grade 7 repertoire piece according to the Royal Conservatory of Music, approximately one week before the experiment session which gave them time to practice if they were not already familiar with it. They were asked to perform the 22 measure theme with repeats. This was done at three different tempi: 100bpm, 144bpm, 184bpm.

It is important to note that the metronome was on for the first 10 seconds of each task to set the tempo. For the rest of the performance, the metronome was off.

Data Acquisition

With a Graphical User Interface created in Matlab it was possible to obtain a graphical representation of the MIDI recording and of the respiration (Figure 5.3).

Piano Roll
A MIDI toolbox created by Schutte (2009) was used to visualize the MIDI data recorded by the Yamaha Disklavier. Using a piano roll format, the performance is graphically illustrated across time by squares representing each note of the musical excerpt (Figure 5.3). The position and size of each square denote the pitch played and its duration respectively. In addition, the intensity of the notes is displayed with color coding.

Respiration Curve
The RIPmate belts are sensitive to circumference changes from the thorax and abdomen but also other torso or limb movement may be detected by the sensors. Therefore, before quantitatively analyzing the respiratory patterns it was necessary to verify that patterns and peaks in the respiratory curve were in fact caused by respiratory changes and not by a participant's abrupt movement. Since the experiment sessions were filmed, abnormal

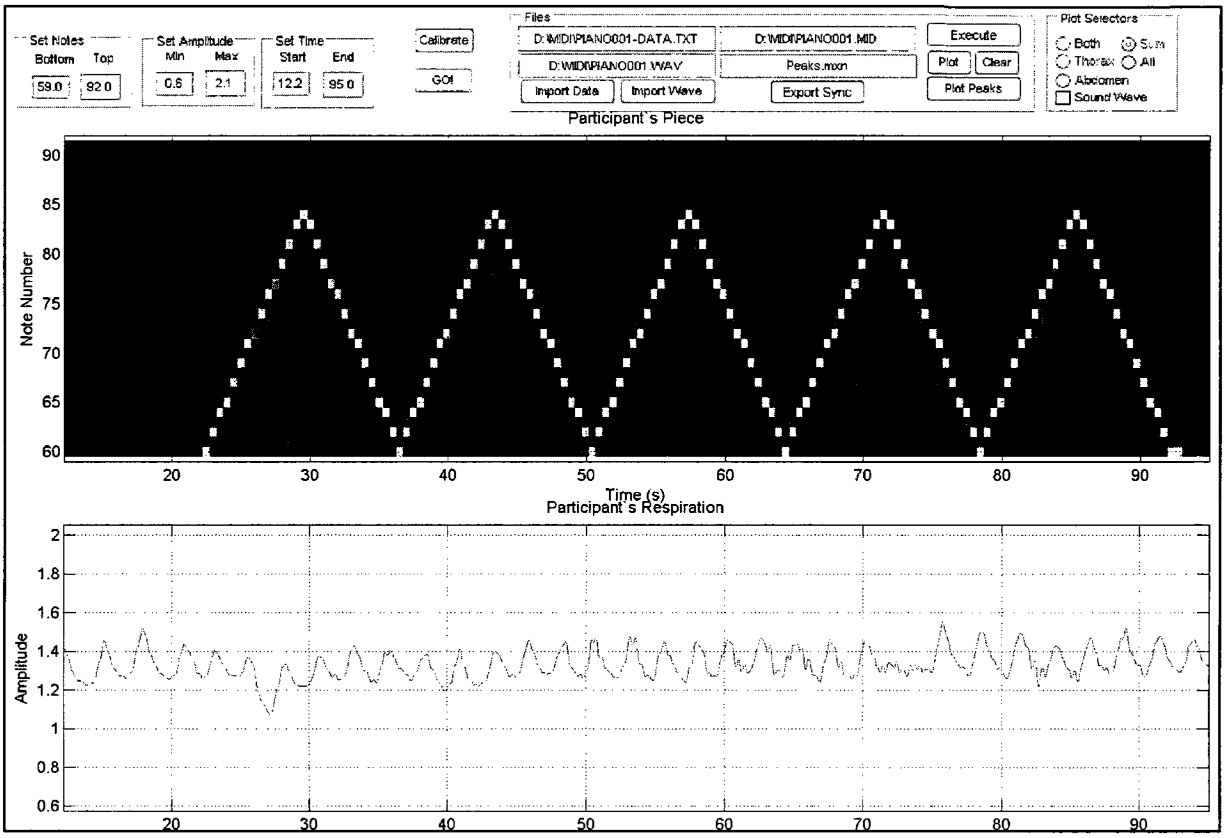

Figure 5.3: A piano roll (upper graph) showing the performance of a scale and the breathing curve (lower graph) as represented in Matlab.

curves in the breathing pattern were verified by watching the video of the experiment session for upper body movements or arm movements.

From Matlab, the breathing curve for each participant during every activity was traced based on a 2 x thorax + 1 x abdomen equation (Banzett et al., 1995). For respiration to be graphically represented in terms of liters across time, it was first necessary to convert respiration data from voltage to liters. This was achieved by comparing the respiration flow values (in L) obtained with the pneumotach during the calibration step to the electrical signals (in V) output from the RIPmate System. A conversion factor was found between the two sets of data allowing us to represent the amplitude changes in L. Afterwards, by finding the vital capacity for each participant, the y axis of the respiration graphs was converted to percentage of vital capacity allowing for comparisons between participants.

5.1.4 Data Analysis

Qualitative analyses of the participants' breathing curves for each performance task were conducted. Each participant's reference breathing pattern was established from the tracings of breathing at rest. Variations of the breathing pattern during the performance away from the reference pattern were of interest. Asymmetry, changes in the sinusoidal shape and the presence of other irregularities, such as peaks of different sizes, were observed and noted in parallel with the exercise or piece performed. The timing of these irregularities was noted and compared to the musical performance (piano roll) in order to determine if they are associated to a specific musical element (Figure 5.4).

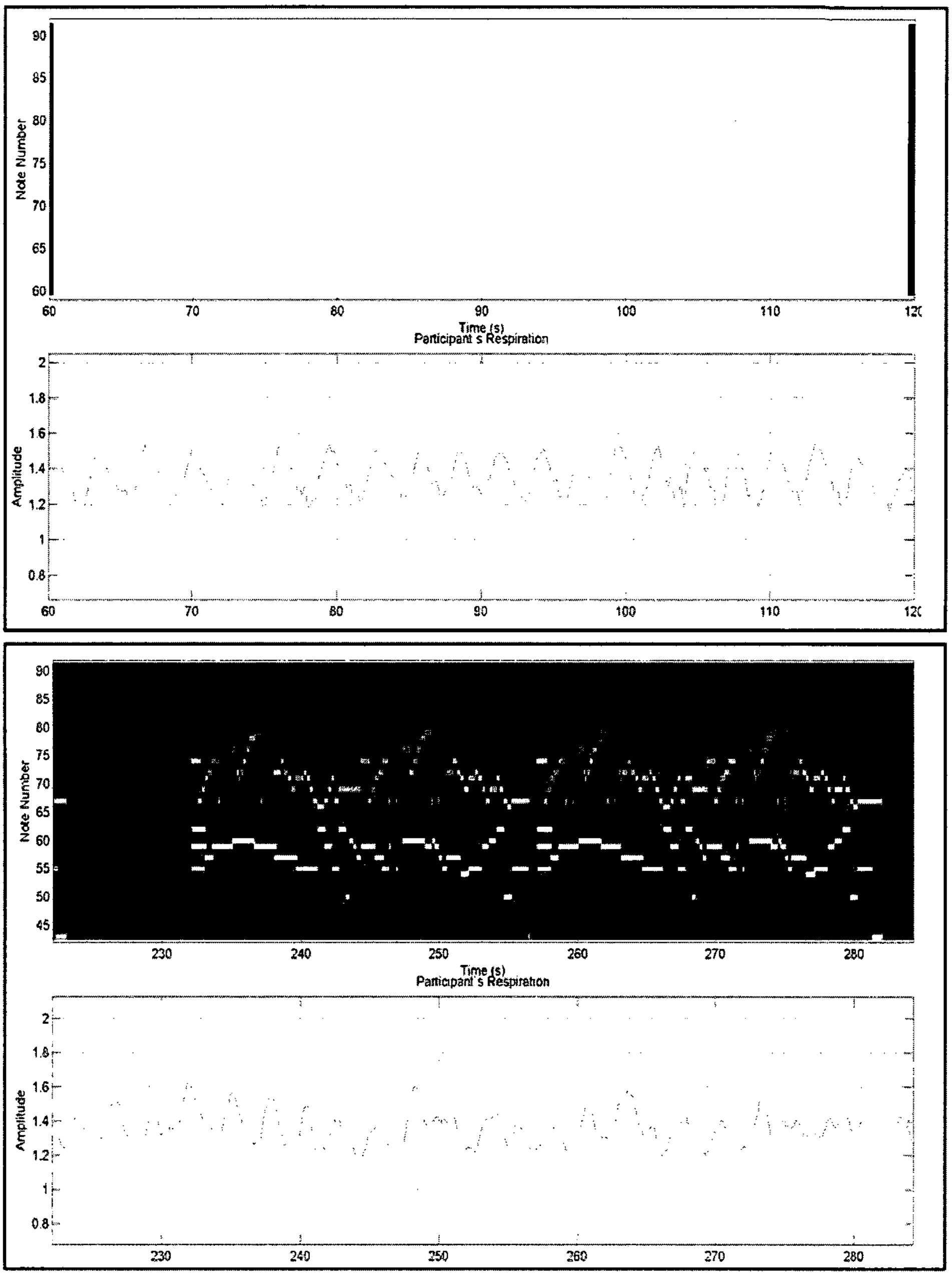

Figure 5.4: The upper graph shows breathing at rest. The lower graph displays the breathing curve during a performance of the *Minuet in G major.* This figure is an example of observable differences between breathing at rest and during a performance of one participant.

5.1.5 Results

In this section, results of how often participants breathed at the beginning of their performance are illustrated. Additionally, comparisons of the respiratory patterns at rest and during each performance are presented.

Breathing at the beginning of a performance

The respiratory patterns of each participant were analyzed in order to determine if the individual's breathing pattern changed at the beginning of their performance or if they took a deep breath before starting to play. When this behaviour was observed, the breathing curve changed significantly as seen in Figure 5.5.

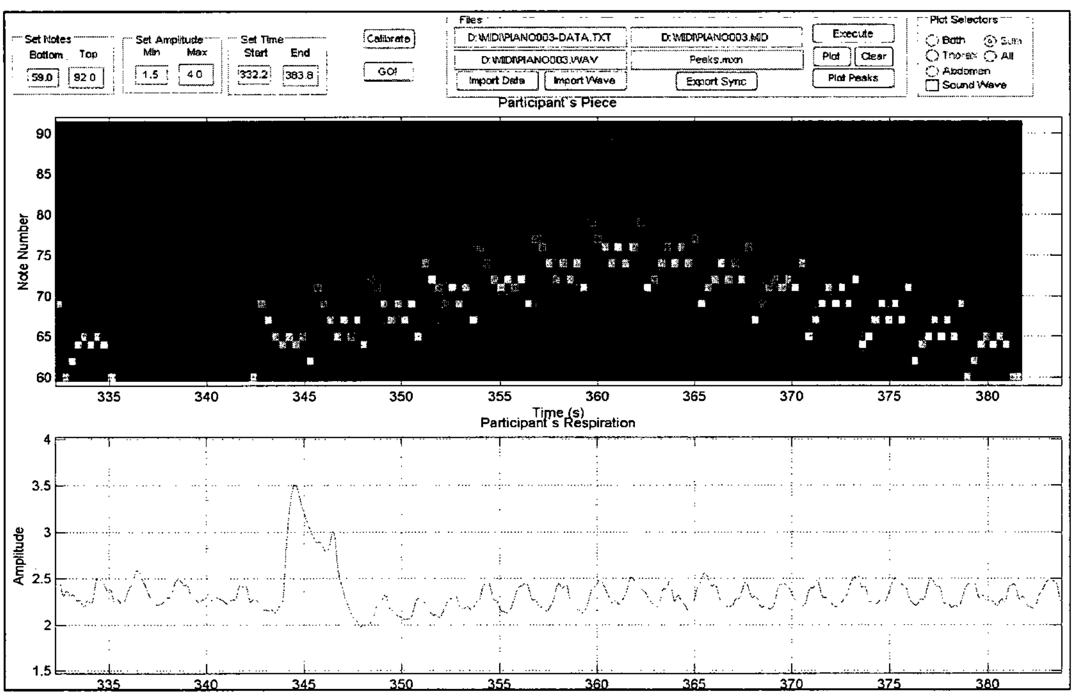

Figure 5.5: The piano roll (upper graph) illustrating the performance of the Hanon five-finger exercise in 7/4 and the breathing curve (lower graph). The breathing pattern of this performer changed as the pianist started to play.

The following table indicates every time a participant took a deep breath before starting their performance of an element. Out of a possible 136 events, participants started their performance with a deep breath 57 times which is less than half the maximum amount.

Table 5.2: Occurrence of a deeper breath or expiration on the breathing curve of the pianists at the beginning of the performance of a task.

Part.	Scales			Arpeggios			Hanon Exercise					*Minuet*			*Für Elise*			**Total**
	60	120	184	80	120	160	4/4	3/4	6/4	5/4	7/4	80	120	160	100	144	184	
1	x		x		x		x	x	x	x	x							7
2		x	x	x	x	x	x	x	x	x	x		x	x		x	x	15
3							x	x	x	x	x							5
4		x		x												x		3
5	x			x			x					x	x					5
6		x	x		x	x	x		x	x	x	x						9
7			x			x		x	x	x	x		x	x			x	9
8		x						x			x					x		4
Total	2	4	4	3	3	3	5	5	5	5	6	2	3	2	0	3	2	57/136

Breathing patterns at rest and during a performance

The respiratory patterns of each participant were examined for noticeable changes between their breathing curve at rest and during the various performances (Figure 5.4 and Figure 5.6). In circumstances where such differences were observed, breathing pattern changes across the performance of the exercises or pieces at different tempi (or meter) were also investigated. Additionally, specific areas in the repertoire pieces were analyzed to determine if breathing was affected by phrasing. One participant's breathing seemed to follow the phrasing in the music (Figure 5.7).

Participants were asked to perform the repertoire pieces with repeats. This allowed us to compare the breathing curve during the first performance of the piece to the breathing curve during the second performance of the piece. If breathing is related to the performance, these two sequences of the breathing pattern should appear very similar. An examination of the graphs in such a manner showed that the breathing pattern of the pianists was different even during repeated segments of a repertoire piece (Figure 5.6).

The following table indicates if a participant's breathing curve changed between the resting condition and the performance condition of each task played at a different tempo or meter. The breathing curve of most of the participants changed during their performance of the scale, the arpeggio, the minuet and *Für Elise* but it did not change when playing the Hanon exercise.

Table 5.3: Presences of changes between the breathing pattern at rest and the breathing pattern during the performance of each task played at a different tempo or meter. A mark in column A represents a difference seen between the breathing pattern at rest and during the performance (at the first tempo for the scale, the arpeggio, the minuet and *Für Elise*). A mark in column B indicates a difference also seen between the breathing pattern of the different performances as tempo increases.

Part.	Scales			Arpeggios			Hanon		*Minuet*			*Für Elise*		
	None	A	B	None	A	B	None	A	None	A	B	None	A	B
1		x			x	x	x			x	x		x	x
2	x				x		x		x				x	x
3		x	x		x	x		x		x	x		x	
4		x	x		x	x		x		x			x	x
5		x	x		x	x	x			x			x	
6	x			x			x			x	x		x	x
7		x	x		x		x		x				x	x
8		x	x		x	x	x			x	x		x	x
Total	2	6	5	1	7	5	6	2	2	6	4	0	8	6

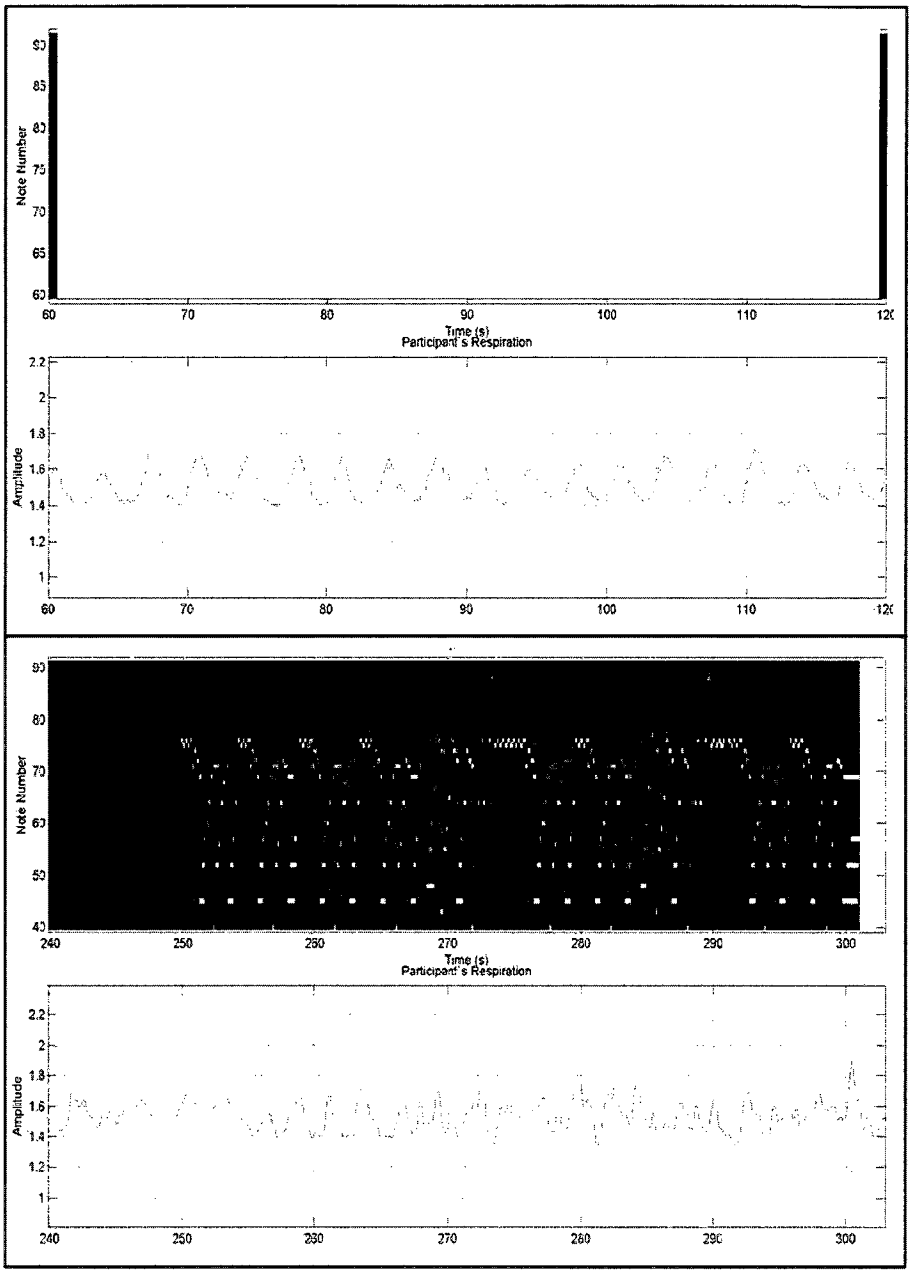

Figure 5.6: A participant's breathing at rest (upper graph) and during the performance of *Für Elise* at the fastest tempo (bottom graph). This figure displays an example of observable differences between breathing at rest and during a performance. Notice that when the piece is repeated, the breathing curve is different.

5.1.6 Discussion

The breathing patterns of pianists have been investigated during the performance of various pianistic tasks in past research (Ebert et al., 2002; King, 2006; Nassrallah et al., in preparation A; Nassrallah et al., in preparation B). Similarly, this study examined changes in the breathing patterns of pianists during the performance of different technical exercises and repertoire pieces with an added focus on how melodic complexity, meter, tempo and phrasing affected respiration. Changes in the breathing pattern at the beginning of a performance and during the different performances were qualitatively noted.

Breathing at the beginning of a performance

From bowing their heads to closing their eyes (Van Zile, 1988) each pianist has his/her own habits to gain concentration or mentally prepare right before starting a performance. Taking a deep inspiration before starting to play has also been noted as a gesture common to many pianists (King, 2006). In our study, we noted the number of times a participant took a deep breath before performing. Results ranged from 3 to 9 times on the 17 times participants were asked to play, with the exception of one pianist, who took a deep breath 15 times out of the 17 times. These values are quite low and contradict King's study (2006) where all performances were initiated with a preparatory breath. However, it is important to note that her study involved only 3 pianists. In addition, two of these musicians were professionals that had over forty years of experience in solo and ensemble performances. Noteworthy, in our experiment, the pianist who took a deep breath almost every time at the beginning of a performance (15 times out of 17) is also a singer. Therefore, this habit might be due to that musician's background as a vocalist. In summary, it seems that the results for this variable are not homogenous amongst participants. However, by grouping and adding the different exercises and repertoire pieces performed, the one consistent observation is that individuals noticeably were more likely to take a deep breath when they had to play the Hanon exercise as seen in Figure 5.5. Since participants were given the Hanon score without a meter to practice, one could hypothesize that the preparatory breath occurred because of the unexpected change of meter the pianists were faced with.

Breathing patterns at rest and during the performances

The various pianistic tasks that can be performed at the piano require a balance of technical and expressive proficiency. There are studies on the breathing of pianists during the performance of different exercises and pieces (King, 2006; Ebert et al., 2002; Nassrallah et al., in preparation A; Nassrallah et al., in preparation B) but the question investigated in this paper is whether or not specific components such as melodic complexity, meter, tempo and phrasing of the musical task performed had an effect on the breathing pattern. To accomplish this goal, participants were asked to play the C major scales, the C major arpeggios, the Hanon #10 exercise, the *Minuet in G major* by Petzold and *Für Elise* by Beethoven.

The scales, arpeggios and Hanon exercise can be grouped as technical pianistic tasks. The scales and arpeggios were played repeatedly for a minute. They have a simple melodic line and are limited in the way they can be musically interpreted. During their performance, the breathing pattern of the pianists was expected to remain regular and similar to the one at rest since breathing would not be used as a way to express the music. In contrast to the hypothesis presented, results showed that in most cases, the breathing pattern during the performance was different than at rest and as speed increased, the breathing curve of the pianist changed. Loss of symmetry and irregularity in the breathing pattern were commonly observed. For one participant, the increased speed caused sporadic large breaths. Anxiety may have been the cause of these changes. As for the Hanon #10 exercise, this five-finger piece is constructed of repetitive sequences. Although it remains a technical task, it has a slightly more defined melody than the scales and arpeggios. Furthermore, for the purpose of the experimentation, the exercise had been transcribed in 5 different meters, indicating to the pianists that they should shift the accentuated note according to the time signature. It is worthy to note, in six of the eight participants, there seemed to be no change between the breathing curve at rest and the breathing curve during the performance which concurs with what was expected. One explanation for these results could be that the pianists were not challenged while playing the Hanon exercise at the tempo chosen and they might have found it boring. However, since it seemed that participants did not put an accent on the first note of a bar, according to the experimenter's perception, it is hard to deduce anything on the effect of meter on breathing in this study.

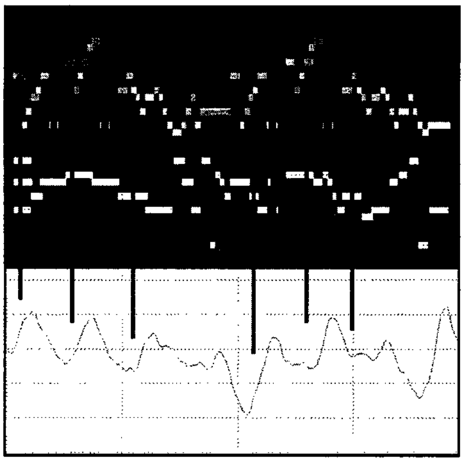

Figure 5.7: The piano roll (upper graph) illustrating the performance of the *Minuet in G major* by Petzold and the breathing curve (lower graph). Vertical lines indicate where the breathing pattern seems to follow the phrasing in the music.

The other group of performed elements was the repertoire pieces; the *Minuet in G major* by Petzold and *Für Elise*. The breathing pattern of most participants was different during their performance of these pieces compared to rest (Figure 5.6). Furthermore, as seen with the scales and arpeggios, the participants' breathing pattern lost symmetry and regularity as the speed increased. This phenomenon seemed to be more common during the performance of *Für Elise* where the breathing pattern of six out of eight participants changed as speed increased. In King's study (2006), there was evidence that the performer breathed similarly during a musical segment that is repeated. According to our results, the breathing pattern of pianists was not consistent even during repeated segments (Figure 5.6).

For one participant, the breathing curve showed irregularities when the pianist had to perform the ornaments in the minuet. Anxiety or concentration could be the cause of these changes in this individual's breathing pattern. This can be associated to observations made by some piano pedagogues. From their pedagogical points of view as teachers, certain authors discuss common breathing problems that pianists face, such as tightening the abdominal wall, tightening the throat muscles, expanding the chest forward, tensing up the diaphragm, heavy breathing and breath holding (Mark, 2003; Sandor, 1981). Also, in a study on cellists, it was apparent that players held their breath during a technically difficult passage (Igarashi, Ozaki & Furukawa, 2002). More research would be required in order to determine if the variations seen on the breathing pattern of this pianist during the execution of the ornaments are caused by such a physical reaction.

On another participant's breathing curve, it is noted that the pianist was breathing with the phrasing in the music (Figure 5.7). Similarly, in a study on breathing and violinists (Stadler & Szende, 1965a), researchers found that performers took a deeper respiration during some of the musical pauses which indicated the use of breathing as a tool to express music. The performers also had the tendency to play one musical structure as one breathing phrase. Since the *Minuet in G major* by Petzold and *Für Elise* by Beethoven are more melodic than the previous exercises, it was expected that breathing would be used for expressive purposes as seen in the literature. Hence, it was hypothesized that the breathing of the participants would follow the phrasing in the music. Nonetheless, this observation was noted only with one participant (Figure 5.7) and cannot be confirmed with the results of this experiment.

Limitations and Future Considerations

Certain limitations and suggestions should be considered for future studies on the breathing patterns of pianists. The small sample size and lack of homogeneity amongst the participants are factors that caused difficulties during the analysis of the results. Selecting individuals with a more similar musical background would eliminate certain factors that may have affected the results such as anxiety, or uneasiness with the tasks asked. According to Ericsson, Krampe, & Tersch-Römer (1993), 10000 hours of practice or more are needed for a pianist to become a professional performer on their instrument. This value is based on an estimate number of hours of practice per week. The study reinforces the fact that a common determinant in attaining a certain level of expertise in a particular task is the result of intense practice starting at a young age. With participants who mastered their instrument to such a level, the results obtained from testing professional pianists might be more similar. Likewise, regarding future studies, one might consider investigating the effects of musical interpretation on breathing more closely by asking participants to perform varied repertoire pieces from different time periods. Also, future research could investigate the effects of executing certain musical articulations like staccatos. Certain pedagogues (Sandor, 1981) believe that the diaphragm can participate in the execution of such elements.

Conclusion

A well-rounded pianist should be proficient from a technical and expressive standpoint in order to meet the requirements of the various pianistic exercises or pieces performed. Scales, arpeggios, technical finger exercises and repertoire pieces are different musically and involve different musical features. Based on this study, the use of breathing as an expressive tool seems to be a factor that depends on the musician since the breathing of each pianist is different. However, changes in the breathing pattern during resting conditions and performing conditions were clearly identified warranting the need for more research on the topic in order to integrate breathing in a pedagogical context.

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Chapter 6

General Discussion

The field of performing arts medicine is gaining popularity as people increase their awareness on the health problems emerging from the daily practising habits of musicians. Amongst the various physiological demands of being a pianist, breathing has emerged as an important topic and point of interest. Since little is known on the breathing pattern of pianists, the goal of this thesis was to explore the respiration of these instrumentalists from an expressive and physiological context. Therefore, the general purpose of the three articles presented, was to expand the knowledge on the breathing pattern of pianists by analyzing it during their performance of different technical exercises and repertoire pieces. Eight pianists participated in the study and played the C major scale, the C major arpeggio, the *Hanon #10* exercise, the *Minuet in G major* by C. Petzold, and *Für Elise* by L. van Beethoven on a Yamaha Disklavier. During each performance, their breathing was recorded by an inductive plethysmography system (RIPmate Respiratory Effort System). This monitoring device was chosen since it was non-invasive and maintained performance conditions closest to normal. With the data collected, different analyses were conducted in order to examine various aspects of their breathing pattern. The following discussion will reiterate the findings of each article (Table 6.1), present the limitations of this study, introduce the knowledge implications, suggest considerations for future projects and conclude this thesis.

Table 6.1: Summary of the results obtained for each experiment.

	Research Goals	Analysis	Results
Article 1	To investigate the effect of performing various exercises and pieces on the breathing rate and functional residual capacity of pianists.	Pooled data: Non-parametric statistical tests - Friedman test - Wilcoxon rank test Individual data: Line graphs with error bars	Breathing rate: - was significantly faster during a performance compared to rest. - increased from the performance of the scales, arpeggios and minuet at a slower speed to the performance of these exercises at a faster speed. FRC volume: - increased during the performance of the scales. - showed no statistically significant increase from the resting condition to the performing of the other exercises.
Article 2	To determine whether coordination develops between breathing and finger movements made while performing a scale and arpeggio. Finger movement will be defined according to three markers: meter, pitch, passage of the thumb.	Phase interval plots: - Time difference between a movement marker and the closest breathing marker representing the end of expiration. - Three markers: pitch, meter, passage of the thumb Graphs of the different markers directly placed on the breathing curve.	Coordination: - No evident indication of coordination between breathing and the movement markers. Juxtaposition of markers and breathing pattern: - Movement markers often coincided with major breathing peaks.
Article 3	To examine changes between the breathing patterns of pianists at rest and during various performing tasks while also analyzing the effects of specific musical features such as melodic complexity, meter, tempo and phrasing on respiration.	Qualitative observations of the breathing curve during a performance by comparing it to the tracings of the breathing at rest: - loss of symmetry - changes in the sinusoidal shape - presence of other irregularities - a big breath taken at the beginning of the performance	- Participants did not consistently take a deep breath at the beginning of a performance. - Breathing pattern changed as tempo increased - The breathing pattern of the pianists was different even during repeated segments of a piece.

6.1 Summary of findings

Each article examined a different aspect of breathing during piano performances. The results obtained will be described in the following section.

6.1.1 Article 1

The first article is entitled *Breathing rate and functional residual capacity of pianists during a performance.* As observed in similar research from the field of music (Ebert et al., 2002) and kinesiology (Ebert et al., 2000; Wilke et al., 1975), pooled results showed that breathing rate increased significantly when the pianists were performing, compared to breathing rate at rest. However, pooled results surprisingly did not confirm a significant increase of breathing rate during the performance of the exercises across different tempi, even though the speeds at which the pianists played were purposely chosen to force extreme performance conditions - from very slow to very fast. These results concur with King (2006) who stated that it is still not possible to conclude a causal effect relationship between increasing tempo and increasing breathing rate. The increase of breathing from the resting condition to the performing condition is unclear. It may not necessarily be due to changes in carbon dioxide levels that normally result in a higher breathing rate (Ebert et al., 2002). In a study on violinists, the increased respiratory rate noted was not associated to oxygen inhalation but rather attributed to a pattern of breathing peculiar to violin playing (Stadler & Szende, 1965a).

With regards to functional residual capacity, results showed no significant difference between FRC at rest and during the performance. In another study on violinists, *Violin playing and respiration: Oxygen consumption and respiratory function during violin playing* (Stadler & Szende, 1965b), results showed that oxygen consumption always increased during playing, especially when the subject made a mistake during the performance. This indicated that psychic conditions, such as embarrassment, had an effect on oxygen consumption. Knowing this, similar tests could be conducted on pianists to determine if analogous results emerge.

6.1.2 Article 2

The second article was *Analysis of coordination between breathing and different movement markers in pianists performing a C major scale and arpeggio.* Based on past research (Ebert et al., 2000; Ebert et al., 2002), the purpose of this article was to explore whether coordination develops between breathing and finger movements when targeting three types of specific finger movement markers: 1) metric, the typical four note division of a scale or arpeggio, 2) pitch, the top and bottom note of each exercise and 3) passage of the thumb, the notes pressed by the thumb as it is tucked under the other fingers. Phase interval plots illustrated independence between breathing and movement during the performance of the scales and arpeggios. Nevertheless, the juxtaposition of the different types of markers directly on the breathing curve provided interesting results. On the graphs of certain participants, it was noticed that the metric markers and the passage of the thumb markers occurred on the maximum and minimum peaks of their breathing pattern during the performance of the scale. Similar results were gathered with pitch makers during the performance of the arpeggio. Although these observations are interesting, they were not consistently noted in all participants. In Ebert and colleagues' study (2002), a clearer coordination relationship was found between breathing and the metric finger movement marker event. In contrast the results of our study did not yield such a definite relationship. Furthermore, Ebert and colleagues (2000) had observed coordination between forearm tracking and breathing. In our experiment, the forearm flexion and extension resulting from the repetitive performance of the scale did not lead to coordination between breathing and movement as seen in their similar study.

This article belongs to a limited collection of projects on breathing and finger movements (Ebert et al., 2002) at the piano but expanding knowledge in the area could lead to more interesting questions. There are many examinations of the relationship between breathing and different finger movements (Rassler, 2000; Rassler, Bradl, & Scholle, 2000; Rassler, Ebert, Waurick, & Jaughans, 1996; Wilke et al., 1975). When analyzing the influence of breathing on movement precision, Rassler (2000) found that during late expiration, flexion movements were less precise whereas during late inspiration, extension movements lost precision. A similar coordination study could be used to test if late breathing influences finger precision during a performance. Also, coordination has been studied between breathing and head or eye movement (Rassler & Raabe, 2003). This could be the basis for similar research with pianists.

6.1.3 Article 3

The purpose of the third article, *Breathing pattern changes observed while pianists performed technical exercises and repertoire pieces*, was to establish if respiratory patterns vary according to different musical features such as melodic complexity, meter, tempo, and phrasing. In contrast to King's (2006) study, where all performances were initiated with a preparatory breath, participants did not always take a deep breath before starting to play. Qualitative analyses showed that in most cases, the breathing pattern during the performance of the scale and arpeggio was different than at rest and that as speed increased, the breathing curve of the pianist changed. Loss of symmetry and irregularity in the breathing pattern were commonly observed. The breathing pattern of most participants was also different during their performance of the repertoire pieces compared to rest. Loss of symmetry and regularity of the breathing curve as the tempi increased seemed to be more common during the performance of *Für Elise*. The breathing of only one participant followed the phrasing in the music. Similarly, in a study on breathing and violinists (Stadler & Szende, 1965a), researchers found that performers took a deeper respiration during some of the musical pauses which indicated the use of breathing as a tool to express music. The performers also had the tendency to play one musical structure as one breathing phrase. These researchers concluded that when playing the violin, performers adopted a respiratory pattern that matched motion and consequently matched the composition. Likewise, since the *Minuet in G major* by Petzold and *Für Elise* by Beethoven are more melodic than the previous exercises, it was expected that breathing would be used for expressive purposes as seen in the literature. Nonetheless, this observation was noted only with one participant and cannot be confirmed with the results of this experiment.

6.2 Limitations

Certain experimental limitations originating from the recruited participants and the methodology may have affected the outcome of the experiment. Although the 8 pianists who participated in the study seemed to be at a similar level, they later proved to be from diverse musical backgrounds. Consequently, the small sample size and the heterogeneity of the individuals who participated are, in our opinion, the most important limitations of this study and factors that caused difficulties in the interpretation of the results. Ideally, the performing history, the number of years of piano lessons, the total number of practice hours and the current musical involvement should be as consistent as possible amongst participants. Selecting individuals with a more similar musical background would eliminate certain factors that may have affected the results such as anxiety, or uneasiness with the tasks that were required. Secondly, the execution of the Hanon exercise was not successful. The analysis of the results stemming from this stimulus was based on the pianists' interpretation of the meter changes. During the performance of the Hanon exercise, it was expected that participants would intuitively place accentuated notes on the first note of every bar which would vary according to the meter. Since the individuals did not perform the task as expected, it is not possible to draw any conclusions from the data of that exercise. Thirdly, some participants did not maintain their tempo consistent while performing. The slight tempo inconsistencies were an added variable that made the results harder to interpret. Finally, although participants were not directly told about the purpose of the study, because of the nature of the experiment and the instruments used to collect the data, the individuals were aware that their breathing was being measured.

6.3 Knowledge Implications

The following section will explain how this study contributes to the scientific literature as well as how the acquired knowledge on this topic may be integrated in a pedagogical context.

6.3.1 Contributions to the literature

Other than observations noted in piano pedagogy material, only two studies have directly explored the respiration of pianists. King (2006) examined the relationship between pianists' respiration and meter, tempo, structure and physical movement during a performance. She determined that although a specific tempo to breathing rate relationship was not found, there appeared to be a consistent ratio between these two elements for each pianist. Also, performers had a tendency to take a deep inspiration right before they started to play and there were consistencies in the timing of breaths of pianists at key phrases in a repertoire piece. Finally, it became evident that respiration is unique in each performance but that the breathing of the pianist follows a certain pattern throughout the piece. In the other study on this topic, Ebert et al. (2002) addressed the relationship between breathing and piano playing by researching the coordination between breathing and mental groupings of piano finger movements during the performance of a Hanon exercise transcribed in five different meters. They concluded that coordination occurred between breathing and finger movement and changed according to meter - more frequently in 7/4 meter and less frequently with a 4/4 meter. Therefore, variations of the meter unconsciously affect breathing rate. They also observed that the breathing rate of pianists during a performance was significantly higher than their breathing rate at rest.

The first study by King (2006) was very broad and lacked the control of several factors whereas the second study by Ebert and colleagues (2002) was restricted and did not fully mimic natural performance conditions. Pertinently, the present investigation has attempted to isolate several elements in a piano performance in order to determine how each one affects breathing while controlling for some variability and maintaining performing conditions as close to normal as possible. As previously observed in Ebert and colleagues' study (2006), the breathing rate of a pianist increases from the resting state to the performing state. However, changes of tempo did not seem to cause significant fluctuations in breathing rate. As breathing rate changed between the resting and performing conditions, the breathing curve seemed to change by loosing symmetry and regularity in most cases as well. As noticed by King (2006), each performer demonstrated unique breathing tendencies. For some pianists phrases and ornamentation had an effect on their breathing pattern. Moreover, the results of other participants displayed a relationship between the repetitious movements done during the performance of a scale or arpeggio and the breathing pattern. Nevertheless, it was apparent that some pianist's breathing was completely independent from their performance.

6.3.2 Practical applications

This section will illustrate how the methodology and findings of this thesis will be beneficial to piano teachers and researchers in the field of piano pedagogy.

Piano Teaching

Unlike the breathing exercises and techniques discussed during a wind player or singer's music lesson, respiration is not commonly addressed during a piano lesson. As research is being done on this topic and links are drawn between breathing and certain musical elements, questions emerge on how to integrate breathing in the pianist's learning process. Even though this thesis contributes to the knowledge advancement in this area, it is evident that more research needs to be conducted on the topic to fully understand how to use breathing as a pedagogical tool. Based on the results of this experiment, for some pianists it is clear that breathing and performing are non-related, however, for others there is a visible relationship between their respiration and their performance. The increased breathing rate during a performance compared to rest exemplifies this statement. Knowing this, piano teachers should treat performing as a sport and encourage the practice of breathing exercises before a performance.

Research in Piano Pedagogy

This thesis contributes to the field of research in piano pedagogy by establishing a new methodology to measure the respiration of pianists during a performance. Before choosing to use respiratory transducer straps to collect data for this experiment, several alternative devices were considered based on the two previous studies in this field. Ebert and colleagues (2002) recorded respiration with a thermistor placed in front of a nostril. King (2006) monitored pianists' respiratory patterns with a portable ergospirometer. These devices were not selected for this research for several reasons. Firstly, they seemed invasive or disruptive to the performance of the pianists. Secondly, it has been shown that wearing a face mask alters the breathing pattern (Askanazi et al., 1980). Finally, devices used in these studies did not allow the measurements of all the respiratory parameters required for our study. Throughout the experimental process, we discovered advantages and disadvantages of using respiratory transducer straps to measure the respiration of the pianists. When asked, participants attested to the fact that these belts were comfortable to wear and did not disrupt or modify their performance in any way. Additionally, the respiratory belt system proved to be very sensitive in its detection of abdominal and thoracic circumference changes. With regard to the instrumental set-up, several trials were executed to determine the most accurate way of synchronizing the breathing curve to the pianist's performance. A double synchronization technique was established. This set up was used in order to synchronize the participant's respiratory data and the MIDI data from the piano. The development of this efficient methodology required several trials and pilot studies and is deemed a significant contribution to research in the field in piano pedagogy.

6.4 Future research

The limitations and results of this experiment have raised several other questions and warrant more research to further understand the breathing of pianists. Other than research directions that have already been proposed in this discussion, this section will recommend directions and suggestions for future research on the topic.

In this study, the participants were asked to play a C major scale, a C major arpeggio, the *Hanon #10* exercise, the *Minuet in G major* by Petzold and *Für Elise* by Beethoven. Certain pedagogues (Sandor, 1981) believe that the diaphragm can participate in the execution of staccatos. Accordingly, for the technical exercises, it would be interesting to repeat the experiment while asking the performers to play with different musical articulations. Do staccatos, accentuated notes, or dynamics affect the breathing pattern? As to the repertoire pieces, one might consider investigating the effects of musical interpretation on breathing more closely by asking participants to perform varied repertoire pieces from different time periods. Repertoire from other eras, such as the Romantic period or 20th century music, introduce additional musical elements that may require breathing for expressive purposes.

During this experiment, participants were asked to perform the scale, arpeggio and pieces at three different tempi. The speeds at which the pianists played were intentionally chosen because of the extreme performance conditions - from very slow to very fast. Since in some cases, changes in the breathing pattern were observed, it would be interesting to repeat this exercise while playing at closer tempi. In addition, since pianists did not always maintain a constant tempo, the use of the metronome should be considered.

Finally, the level of the individuals who participated in this study ranged from grade 8 of the Royal Conservatory of Music of Toronto to a Bachelor of music in piano performance degree. According to Ericsson, Krampe, & Tersch-Römer (1993), 10000 hours of practice or more are needed for a pianist to become a professional performer on their instrument. This value is based on an estimate number of hours of practice per week. The study reinforces the fact that a common determinant in attaining a certain level of expertise in a particular task is the result of intense practice starting at a young age. Therefore, it would be interesting for future studies to explore the breathing patterns of professional pianists to determine if a more consistent trend is present.

6.5 Conclusion

The presented research is a very important step towards analysing the breathing pattern of pianists. Even though our findings did not yield consistent results throughout all participants, it is clear that performing affects the breathing of these individuals. The results of this study are expected to stimulate the exploration of respiration in these musicians and will serve as a basis for future studies in the field of piano pedagogy.

Chapter 7

Contribution of the Authors

The following appendix will describe the contribution of the three authors (Dr. Gilles Comeau, Dr. Isabelle Cossette, Dr. Donald Russell) named on the journal articles included in this thesis.

Dr. Comeau and I played an important role in the elaboration and completion of this master's thesis and of the journal articles. This research project was conceived as a part of the health issues research area in the Piano Pedagogy Research Laboratory bridging the gap between scientific research and musical practice. This topic was decided with discussion between Dr. Comeau, my supervisor, Dr. Cossette, my co-supervisor, and myself. Subsequently, my experience in teaching piano and my background in science, were combined with Dr. Comeau's expertise in piano pedagogy and Dr. Cossette's research interest on the breathing of musicians. This study was conducted within the multi disciplinary projects underway in Dr. Gilles Comeau's laboratory, a state-of-the-art research facility that specializes in the interdisciplinary study of piano learning and piano teaching.

Regarding methodology, Dr. Cossette's knowledge in this field of research was significant for the conceptualisation of the instrumental set-up. More specifically, the equipment from her research laboratory at McGill University was invaluable for the realisation of this study. Dr. Russell was also very involved during the development of the methodology by providing suggestions and technical assistance. Under Dr. Comeau's guidance, I obtained ethical approval to test human participants from the Ethics Committee of the University of Ottawa. Dr. Comeau, Dr. Cossette and I developed a suitable protocol to follow at each experimental session.

With regards to data collection, I was in charge of recruiting the participants, arranging their appointed experimental sessions and leading the experiments with the help of a technician at the Piano Pedagogy Research Laboratory. In terms of data management, I was responsible for the data entry and conducted the required analyses under the recommendations of Dr. Comeau, Dr. Cossette and Dr. Russell. As for data interpretation, Dr. Russell frequently met with me to discuss the results and provide guidance.

Finally, while writing the thesis and the journal articles I was responsible for producing numerous drafts of the final product. Each draft was firstly reviewed by Dr. Comeau. Dr. Cossette also contributed to the corrections of the drafts. Both returned them to me for improvements. It should be mentioned that Dr. Russell was involved in a revision of the journal articles. The final articles presented in this thesis: 1) *Breathing rate and functional residual capacity of pianists during a performance*, 2) *Analysis of coordination between breathing and different movement markers in pianists performing a C major scale and arpeggio*, and 3) *Breathing pattern changes observed while pianists performed technical exercises and repertoire pieces* are in preparation for submission in journals.

Appendix A

Ethics Documents

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Flora Nassrallah, M.Sc. (Cand.)
School of Human Kinetics,
University of Ottawa
Ottawa, ON

Dear pianist,

My name is Flora Nassrallah and I am presently involved in a research study conducted under the auspices of the University of Ottawa examining the somatic aspects of piano playing. The results of this study will form the basis of my Master's thesis at the University of Ottawa under the direction of Dr. Gilles Comeau in the School of Music.

As a piano student of grade 8 or higher of the RCM and between the ages of 18 and 30, your participation would be a great help and I invite you to participate.

What you will be asked to do: Your participation to this project will consist of attending a short session at the Piano Pedagogy Research Laboratory at the University of Ottawa during which you will be asked to perform the following tasks:

- 1) C major scale (right hand): ♩ = 60, ♩ = 120, ♩ = 180
- 2) C major arpeggio (right hand): ♩ = 80, ♩ = 120, ♩ = 160
- 3) Hanon finger exercise (right hand): ♩ = 170
- 4) Measures 1-16 (with repeats) of the Minuet in G major by J. S. Bach
  - The first time without the ornamentations
  - The repeat with the ornamentations

  Performed at the following metronome speeds:
  ♩ = 80, ♩ = 120, ♩ = 160
- 5) Measures 1-22 (with repeats) of Für Elise by L. Beethoven
  Performed at the following metronome speeds: ♪= 100, ♪= 140, ♪= 180

Before performing the exercises, we will do a calibration of the tools used. During these exercises, movement of the torso and respiration will be measured by a non-invasive elastic belt placed around the pianist's chest and abdomen.

Where the study will be carried out: The study will take place at the Piano Pedagogy Research Laboratory, located in the Pérez building, 50 University, at the University of Ottawa.

Voluntary participation and anonymity: Your involvement in this study is voluntary, and at anytime you may choose not to participate. ***Additionally, at all times you will remain anonymous.*** The results of this study may be published but your name will not appear on any of the documentation from the project. Your participation will bear no cost to you other than the time it takes to come to the

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Piano Pedagogy Research Laboratory and performing the different tasks. Findings from this project will contribute to our knowledge on the somatic effects during a piano performance. No risks to participants beyond those experienced in everyday life are anticipated.

If you would like to participate in this project please contact Flora Nassrallah at If you have any questions about this research project, please feel free to contact.

Thank you for your time and consideration.

Sincerely,

Flora Nassrallah

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Pianists Consent Form

Project Title: The somatic aspects of novice, advanced and professional pianists while executing four performing tasks

Flora Nassrallah, M.Sc. (Cand.) and Professor Gilles Comeau
School of Human Kinetics, University of Ottawa, Ottawa, ON

Invitation to participate: I am invited to participate in the research project mentioned above conducted by Flora Nassrallah.

Purpose of the study: This study will examine the somatic aspects of piano playing by focussing on torso movement and respiration.

Participation: My participation consists of attending a one hour session at the Piano Pedagogy Research Laboratory during which I will be asked to perform the following tasks:

- 1) C major scale (right hand): ♩ = 60, ♩ = 120, ♩ = 180
- 2) C major arpeggio (right hand): ♩ = 80, ♩ = 120, ♩ = 160
- 3) Hanon finger exercise (right hand): ♩ = 170
- 4) Measures 1-16 (with repeats) of the Minuet in G major by J. S. Bach
  - The first time without the ornamentations
  - The repeat with the ornamentations

  Performed at the following metronome speeds:
  ♩ = 80, ♩ = 120, ♩ = 160
- 5) Measures 1-22 (with repeats) of Für Elise by L. Beethoven
  Performed at the following metronome speeds: ♪= 100, ♪= 140, ♪= 180

The session has been scheduled for ______________________________
(location, date, and time of session)

Risks: My participation in this study involves the performance of various exercises at the piano and the performance of a piano piece. My performance will be taped by video camera. Additionally, the performance will be recorded and saved as MIDI data, a standard system for recording and transferring musical information from the piano to a computer which makes possible the graphic representation of a musical performance. My torso movement, and respiration during the performance of the different tasks will be measured by a non-invasive elastic belt that will encircle my chest and abdomen.

Benefits: My participation in this study will help provide reliable information on the effects of torso movement, and breathing during a piano performance.

Confidentiality and anonymity: I have received assurance from the researcher that my performances will remain strictly anonymous. I understand that the performance will be used only for the purpose of this research project and that my confidentiality will be protected by removing my name from all documentation. The results of the study may be published, but my name will not be linked to results in publications that are released from the project.

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Conservation of data: The information collected will consist of audio and video recordings, MIDI data and physiological measurements. This data will be conserved in a secure manner at the Piano Pedagogy Research Laboratory for five years and will be available only to the researchers directly involved in this project.

Voluntary Participation: I am under no obligation to participate and if I choose to participate, I can withdraw from the study at any time. If I choose to withdraw, all data gathered until the time of withdrawal will be discarded and will not be used for the purpose of this project.

Acceptation: I, ______________________________, agree to participate in this study conducted by Flora Nassrallah of the School of Human Kinetics at the University of Ottawa, whose research is under the supervision of Dr. Gilles Comeau.

For any additional information concerning this study, I may communicate with the researcher or her supervisor.

For any information regarding the ethical aspects of this research, I may contact the Protocol Officer for Ethics, University of Ottawa, Tabaret Hall, 550, Cumberland Street, room 159, Ottawa, ON K1N 6N5.
Tel.: (613) 562-5841
Email: ethics@uottawa.ca

There are two copies of the consent, one which I may keep.

Signature of the participant:	Date:
____________________	____________________
Signature of the researcher:	Date:
____________________	____________________

Name of the researcher:	Flora Nassrallah
Institution, Faculty, Department:	University of Ottawa, Faculty of Health Sciences, School of Human Kinetics
Telephone number:	
Email address:	
Name of the supervisor:	Gilles Comeau
Institution, Faculty, Department:	University of Ottawa, Faculty of Arts, School of Music
Telephone number:	
Email address:	

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Flora Nassrallah, M.Sc. (Cand.)
École de l'activité physique,
Université d'Ottawa
Ottawa, ON

Cher(e) pianiste,

Je m'appelle Flora Nassrallah et je suis présentement impliquée dans un projet de recherche qui se déroule à l'Université d'Ottawa. Ce projet de recherche examine les aspects somatiques de la performance au piano. Les résultats de ce projet de recherche formeront la base pour ma thèse de maîtrise à l'Université d'Ottawa sous la direction du professeur Gilles Comeau de l'École de musique.

En tant qu'étudiant(e) de piano du grade 8 ou plus (Conservatoire de musique de Toronto) et entre l'âge de 18 et 30 ans, votre participation à ce projet nous serait d'une aide inestimable, et je vous invite donc à participer.

Que devrez-vous faire : Essentiellement, votre participation à ce projet comporterait une courte session au Laboratoire de recherche en pédagogie du piano à l'Université d'Ottawa, durant laquelle nous vous demanderons de faire les tâches suivantes :

- 1) Gamme de Do majeur (main droite) : ♩ = 60, ♩ = 120, ♩ = 180
- 2) Arpège de Do majeur (main droite) : ♩ = 80, ♩ = 120, ♩ = 160
- 3) Exercice Hanon (main droite) : ♩ = 170
- 4) Minuet en sol majeur de J. S. Bach, les mesures 1-16 (avec répétitions)
    - La première fois sans l'ornementation
    - La répétition avec l'ornementation

  Aux vitesses suivantes : ♩ = 80, ♩ = 120, ♩ = 160
- 5) Für Elise de L. van Beethoven, les mesures 1-22 (avec répétitions)
  Aux vitesses suivantes : ♪= 100, ♪= 140, ♪= 180

Avec de commencer, il y aura une courte session de calibrage des appareils utilisés. Durant les exercices, le mouvement du torse, et la respiration seront mesurés à l'aide d'une bande élastique placée autour de la partie supérieure du tronc du pianiste et autour de l'abdomen.

Où aura lieu cette session : Cette session aura lieu au Laboratoire de recherche en pédagogie du piano, situé dans le pavillon Pérez, au 50 rue Université, à l'Université d'Ottawa.

Participation volontaire et anonyme : Votre participation à cette recherche est à titre volontaire et vous pouvez vous retirer à n'importe quel moment. ***Votre contribution à ce projet sera en tout temps anonyme.*** Les résultats de cette étude pourraient être publiés, cependant, votre nom sera exclu de toute documentation

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reliée à ce projet. Votre temps, ainsi que votre déplacement au Laboratoire de recherche en pédagogie du piano seront les seuls coûts que vous aurez à défrayer. Les découvertes découlant de ce projet vont accroître les connaissances sur les effets somatiques pendant une performance au piano. Il n'y aura aucun risque pour les participants autre que ceux qui font partie de la vie de tous les jours.

Si vous voulez participer à ce projet, veuillez contacter Flora Nassrallah au N'hésitez pas de me contacter si vous avez des questions sur ce projet.

Merci de votre temps et de votre considération.

Sincèrement,

Flora Nassrallah

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Formulaire de consentement pour pianiste

Titre du projet : Les aspects somatiques de pianistes novices, avancés et professionnels durant l'exécution de quatre tâches pianistiques

Flora Nassrallah, M.Sc. (Cand.) et Professeur Gilles Comeau
École de l'activité physique, Université d'Ottawa, Ottawa, ON

Invitation : Je suis invité à participer au projet de recherche mentionné ci-dessus. Ce projet est mené par Flora Nassrallah et par le Professeur Gilles Comeau.

But de l'étude : Ce projet a pour but d'examiner les aspects somatiques des pianistes en ciblant le mouvement du torse et la respiration.

Participation : Ma participation consistera d'une session d'une heure au Laboratoire de recherche en pédagogie du piano durant laquelle on me demandera de faire les tâches suivantes :

- 1) Gamme de Do majeur (main droite) : ♩ = 60, ♩ = 120, ♩ = 180
- 2) Arpège de Do majeur (main droite) : ♩ = 80, ♩ = 120, ♩ = 160
- 3) Exercice Hanon (main droite) : ♩ = 170
- 4) Minuet en sol majeur de J. S. Bach, les mesures 1-16 (avec répétitions)
  - La première fois sans l'ornementation
  - La répétition avec l'ornementation

  Aux vitesses suivantes : ♩ = 80, ♩ = 120, ♩ = 160
- 5) Für Elise de L. van Beethoven, les mesures 1-22 (avec répétitions)
  Aux vitesses suivantes : ♪= 100, ♪= 140, ♪= 180

La session aura lieu ____
(endroit, date, et heure de la session)

Risques : Ma participation à cette étude comportera la performance de différents exercices au piano ainsi que la performance d'une pièce de répertoire. Ma performance sera filmée par une caméra vidéo. De plus, ma performance sera enregistrée et convertie en information MIDI, une forme standard d'enregistrer et de transférer l'information musicale d'un piano à un ordinateur qui rend possible la production d'un graphique représentant une performance musicale. Le mouvement de mon torse, mon rythme cardiaque et ma respiration durant la performance des différentes tâches seront mesurés par un appareil non invasif entourant la partie supérieure du tronc et l'abdomen à l'aide d'une bande élastique.

Bénéfices : Ma participation à cette étude contribuera au développement des connaissances sur les effets du mouvement du torse et de la respiration durant une performance au piano.

Confidentialité et anonymat : J'ai l'assurance du chercheur que ma performance demeurera strictement confidentielle. Je m'attends à ce que les résultats soient utilisés uniquement pour ce projet et que pour le respect de la confidentialité, mon nom soit omit de toutes documentations. Les résultats de cette recherche peuvent être publiés mais mon

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nom ne sera aucunement relié aux résultats émis dans ces publications.

Conservation des données : Les données recueillies comprendront les mesures physiologiques, des enregistrements audios et l'information MIDI. Ces données seront conservées d'une façon surveillée au Laboratoire de recherche en pédagogie du piano pour cinq ans et seront uniquement accessibles aux chercheurs directement impliqués dans ce projet.

Participation volontaire : Ma participation à cette recherche est complètement volontaire et je suis libre de me retirer du projet en tout temps sans subir de conséquences négatives. Si je choisis de me retirer, les données recueillies jusqu'à ce point seront détruites et ne seront pas utilisées pour le projet.

Acceptation : Je, ______________________________, accepte de participer à cette étude menée par Flora Nassrallah, de l'École de l'activité physique à l'Université d'Ottawa, la recherche étant supervisée par Professeur Gilles Comeau.

Pour tous autres renseignements concernant cette étude, je peux communiquer avec le chercheur ou son superviseur.

Pour toutes informations sur l'aspect éthique de cette recherche, je peux m'adresser au Responsable de l'éthique en recherche, Université d'Ottawa, Pavillon Tabaret, 550, rue Cumberland, salle 159, Ottawa, ON K1N 6N5
Tél. : 613-562-5841
Courriel : ethics@uottawa.ca

Il y a deux copies du formulaire de consentement. Je peux garder une des copies.

Signature du participant: ____________________ Date: ____________________

Signature du chercheur: ____________________ Date: ____________________

Nom du chercheur: Flora Nassrallah
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Ethics Approval Notice

Social Science and Humanities REB

Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

First Name	Last Name	Affiliation	Role
Gilles	Comeau	Arts / Music	Supervisor
Flora	Nassrallah	Health Sciences / Human Kinetics	Student Researcher

File Number: 11-08-07

Type of Project: Master's Thesis

Title: The Somatic Aspects of Novice, Advanced and Professional Pianists while Executing Four Performing Tasks

Approval Date (mm/dd/yyyy)	Expiry Date (mm/dd/yyyy)	Approval Type
03/17/2009	03/16/2010	Ia

(Ia: Approval, Ib: Approval for initial stage only)

Special Conditions / Comments:
N/A

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This is to confirm that the University of Ottawa Research Ethics Board identified above, which operates in accordance with the Tri-Council Policy Statement and other applicable laws and regulations in Ontario, has examined and approved the application for ethical approval for the above named research project as of the Ethics Approval Date indicated for the period above and subject to the conditions listed the section above entitled "Special Conditions / Comments".

During the course of the study the protocol may not be modified without prior written approval from the REB except when necessary to remove subjects from immediate endangerment or when the modification(s) pertain to only administrative or logistical components of the study (e.g. change of telephone number). Investigators must also promptly alert the REB of any changes which increase the risk to participant(s), any changes which considerably affect the conduct of the project, all unanticipated and harmful events that occur, and new information that may negatively affect the conduct of the project and safety of the participant(s). Modifications to the project, information/consent documentation, and/or recruitment documentation, should be submitted to this office for approval using the "Modification to research project" form available at: http://www.rges.uottawa.ca/ethics/application_dwn.asp

Please submit an annual status report to the Protocol Officer 4 weeks before the above-referenced expiry date to either close the file or request a renewal of ethics approval. This document can be found at: http://www.rges.uottawa.ca/ethics/application_dwn.asp

If you have any questions, please do not hesitate to contact the Ethics Office at extension 5841 or by e-mail at: ethics@uOttawa.ca.

Signature:

Leslie-Anne Barber
Protocol Officer for Ethics in Research
For Peter Beyer, Past-president of the Social Sciences and Humanities REB

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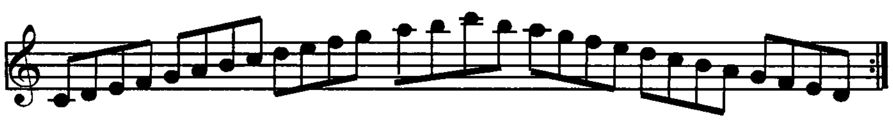
Appendix B

C Major Scale and C Major Arpeggio

C major scale



C major arpeggio

Appendix C

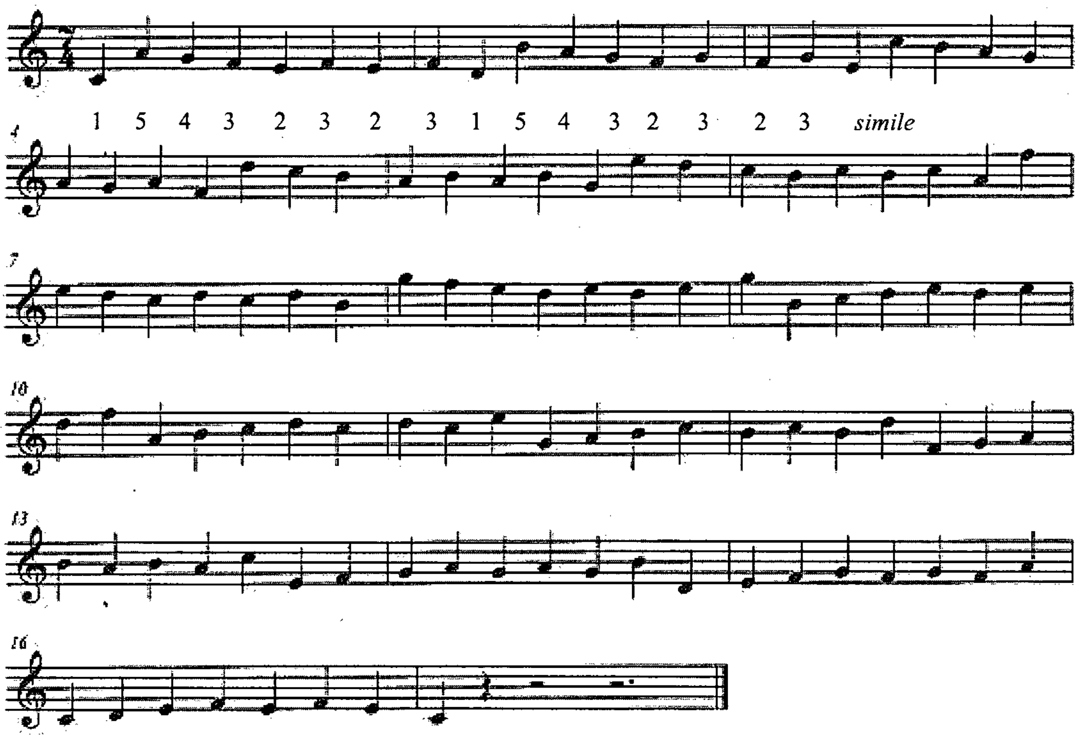
Hanon #10 Exercise


1 5 4 3 2 3 2 3 1 5 4 3 2 3 2 3 simile
6
11
16
21
26


1 5 4 3 2 3 2 3 1 5 4 3 2 3 2
3 simile


1 5 4 3 2 3 2 3 1 5 4 3 2 3 2 3 *simile*
5
9
13
17


1 5 4 3 2 3 2 3 1 5 4 3 2 3 2 3 *simile*
5
9
13
17
21

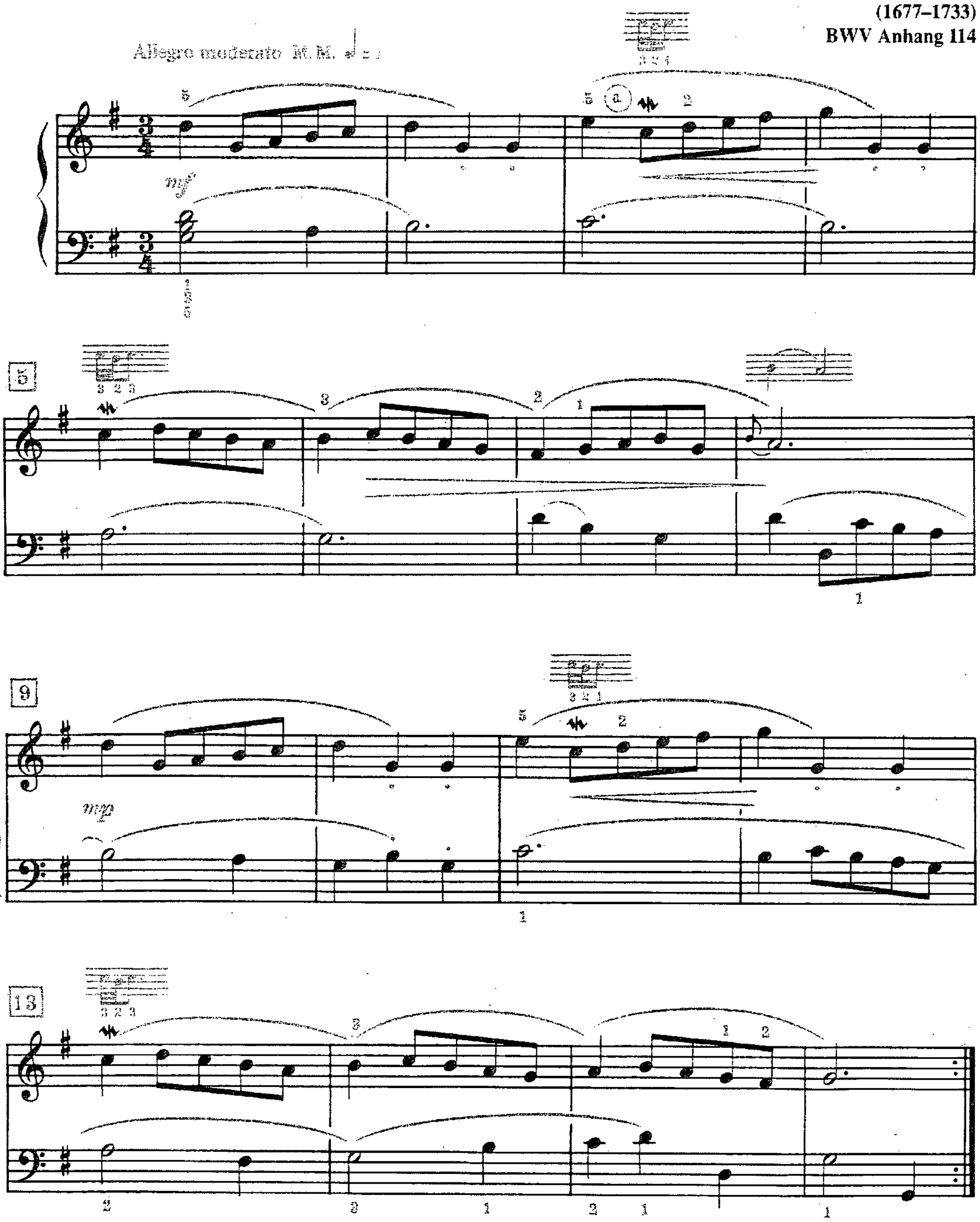

1 5 4 3 2 3 2 3 1 5 4 3 2 3 2 3 simile
4
7
10
13
16

Appendix D

Minuet in G major by C. Petzold

MENUET

Attr. to Christian Pezold (Petzold)
(1677–1733)
BWV Anhang 114



Appendix E

Für Elise by L. van Beethoven

FÜR ELISE

1810

WoO 59

Appendix F

Demographic Questionnaire

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Canada's university

Laboratoire de recherche
en pédagogie du piano
Piano Pedagogy
Research Laboratory

Questionnaire

Before we begin the experiment, please take the time to fill out this short questionnaire. Thank you for your cooperation.

Gender: M F

Date of birth: _____ / _____
mm yy

Academic status: High school student ☐

Undergraduate student ☐

BMus - Piano YES NO

If YES - Year: ____________

Graduate student ☐

MMus - Piano Performance YES NO

If YES - Year: ____________

Number of years playing the piano: ______________

Number of years enrolled in piano lessons: ______________

Piano level reached (ex. the last Royal Conservatory of Music examination): ______

Number of hours of practise per week: ______________

Approximate number of public performances per year: ______________

Have you ever performed Für Elise? NO ☐ YES ☐
If NO - Approximately how long did you spend practising this piece?
< 30min ~ 1 hour ~ 2 hours ~ 3 hours > 3 hours

Have you ever performed the Minuet? NO ☐ YES ☐
If NO - Approximately how long did you spend practising this piece?
< 30min ~ 1 hour ~ 2 hours > 2 hours

uOttawa

Laboratoire de recherche en pédagogie du piano

Piano Pedagogy Research Laboratory

Questionnaire

Avant de commencer l'expérimentation, veuillez prendre le temps de remplir ce court questionnaire. Merci de votre coopération.

Sexe: M F

Date de naissance: _____ / _____
mm aa

Statut académique: Étudiant(e) du secondaire ☐

Étudiant(e) du premier cycle ☐

BMus - Piano YES NO

Si OUI - Année: _____________

Étudiant(e) du 2e cycle ☐

MMus – Performance au piano YES NO

Si OUI - Année: _____________

Nombre d'années d'étude de piano: _______________

Nombre d'années de cours de piano: ________________

Niveau de piano atteint (ex. le niveau du dernier examen du Conservatoire de musique de Toronto): _________________

Nombre d'heures de pratique par semaine: _______________

Nombre approximatif de performances publiques par année: _______________

Avez-vous déjà joué Für Elise? OUI ☐ NON ☐
Si NON - Approximativement combien de temps avez-vous pratiqué cette pièce? < 30 min ~ 1 heure ~ 2 heures ~ 3 heures > 3 heures

Avez-vous déjà joué le Menuet? OUI ☐ NON ☐
Si NON - Approximativement combien de temps avez-vous pratiqué cette pièce? < 30 min ~ 1 heure ~ 2 heures > 2 heures

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