

Investigating the cross-modal relationship between music and motion in an improvised music production context

**By:**

Shen Li

A dissertation submitted in partial fulfilment of the requirements for the degree of

Master of Music

The University of Sheffield

Faculty of Arts and Humanity

Department of Music

Sep. 2015

**Abstract**

When responding to music, humans move their bodies with various motional patterns varying in speed, spatial dimensions and continuity. This cross-modal association has been widely examined by motion-induction studies; however, it is less studied in a music-production context. This research examined the transformation from the visualized motion patterns into musical characteristics of performed sounds in a creative production environment. Pianists were required to play expressively on either a single tone or a sequence of musical tones several times after watching different video stimuli. The results revealed that perceived speed in visual stimuli had an impact on performance tempo; walking distance (increasing/decreasing) from the camera influenced performance volume; and movement continuity affected performance articulation. This is consistent with previous findings on music-motion analogies. This research also revealed several potential correspondence patterns: Visualized motional height had an impact on musical articulation (higher/staccato, lower/legato), and motional speed may influence musical loudness (faster/louder, slower/softer). This research implied that expressive performance intention of pianists is associated with specific movement patterns.

***Keywords***: cross-modal mapping, motion-music association, embodied cognition, musical production, expressive performance.

**Acknowledgement**

Firstly, I would like to express my sincere appreciation to my supervisor Dr. Renee Timmers who has supported me and supervised my research project for such a long period. Dr. Timmers has motivated me by being patient, sharing her knowledge and providing continuous encouragement. Her guidance, feedback and assistance has led me to complete this project. Furthermore, I have presented my research at an international conference, which was very beneficial.

I also want to thank to my colleagues in the Department of Music, who have helped me to recruit participants and given me helpful and professional comments. I also would like to thank all the pianists who participated in my experiment, who were patient and enthusiastic.

Last but not least, I would like to thank my parents who have supported me spiritually throughout writing this dissertation and during my life.

CONTENTS

[**1. Introduction** 6](#_Toc450406743)

[**2. Literature Review** 9](#_Toc450406744)

[**2.1 Embodied metaphors related to music and motion** 9](#_Toc450406745)

[**2.2 Rational Explanation from Cross-modal Correspondence Domains** 11](#_Toc450406746)

[**2.2.1 General introduction.** 11](#_Toc450406747)

[**2.3 Theoretical Explanation of Music-Motion Association Mechanisms** 13](#_Toc450406748)

[**2.3.1 Three models proposed by Palmer.** 13](#_Toc450406749)

[**2.3.2 Neurobiological perspectives.** 15](#_Toc450406750)

[**2.3.3 Action-perception coupling.** 15](#_Toc450406751)

[**2.4 Significance in Musical Meaning** 17](#_Toc450406752)

[**2.4.1 Two psychological perspectives.** 17](#_Toc450406753)

[**2.5 Examination of the Motion-Music Connection in a Motion Production Context** 19](#_Toc450406754)

[**2.5.1 Synchronization with music.** 19](#_Toc450406755)

[**2.5.2 Music-induced gestures.** 21](#_Toc450406756)

[**2.5.3 Analogies between motion features and musical attributes.** 22](#_Toc450406757)

[**2*.5.3.1 Musical tempo & motion speed.*** 22](#_Toc450406758)

[**2*.5.3.2 Musical volume & physical distance.*** 23](#_Toc450406759)

[**2*.5.3.3 Musical articulation & motion continuity.*** 24](#_Toc450406760)

[***2.5.3.4 Musical pitch & spatial location.*** 25](#_Toc450406761)

[**2.6 Examination of the Motion-Music Connection in a Music Production Context** 25](#_Toc450406762)

[**2.6.1 Motion and musical expressiveness.** 26](#_Toc450406763)

[**2.6.2 Communicative aspects of gestures in music production.** 27](#_Toc450406764)

[***Perspective from listeners.*** 27](#_Toc450406765)

[***Perspective from cooperative performance.*** 28](#_Toc450406766)

[**2.7 Interim Summary** 29](#_Toc450406767)

[**2.8 Research Gaps** 30](#_Toc450406768)

[**2.9 Research Aims** 31](#_Toc450406769)

[**3. Methodology** 33](#_Toc450406770)

[**3.1 Research Design** 33](#_Toc450406771)

[**3.1.1 Motional features.** 33](#_Toc450406772)

[**3.1.2 Examination of musical features.** 35](#_Toc450406773)

[**3.1.3 Dependent variables and independent variables.** 36](#_Toc450406774)

[**3.2 Participants** 36](#_Toc450406775)

[**3.3 Materials** 37](#_Toc450406776)

[**3.3.1 Videos.** 37](#_Toc450406777)

[**3.3.2 Musical score.** 39](#_Toc450406778)

[**3.4 Procedure** 40](#_Toc450406779)

[**3.5 Data Analysis** 41](#_Toc450406780)

[**3.5.1 Background.** 41](#_Toc450406781)

[**3.5.2 Cross-modal relationshipexamination.** 42](#_Toc450406829)

[**4. Research Results** 44](#_Toc450406830)

[**4.1 Tapping Session Analysis** 44](#_Toc450406831)

[**4.1.1 Tapping speed.** 44](#_Toc450406832)

[**4.1.2 Tapping volume.** 44](#_Toc450406833)

[**4.1.3 Tapping articulation.** 45](#_Toc450406834)

[**4.1.4 Examination of crossed pairs of mapping.** 46](#_Toc450406835)

[**4.2 Melody Session Analysis** 49](#_Toc450406836)

[**4.2.1 Playing tempo.** 49](#_Toc450406837)

[**4.2.2 Musical volume.** 49](#_Toc450406838)

[**4.2.3 Musical articulation.** 49](#_Toc450406839)

[**4.2.4 Crossed-paired connection.** 50](#_Toc450406840)

[**4.3 Overall Results in Two Performance Sessions** 54](#_Toc450406841)

[**5. Discussion** 55](#_Toc450406842)

[**5.1 Connections between Motional Feature and Musical Feature** 55](#_Toc450406843)

[**5.1.1 Mapping of motional feature onto musical tempo.** 55](#_Toc450406844)

[**5.1.2 Mapping of motional feature onto *musical volume.*** 57](#_Toc450406845)

[**5.1.3 Mapping of motional feature onto musical articulation.** 58](#_Toc450406846)

[**5.1.4 Comparisons between tapping session and melody session.** 60](#_Toc450406847)

[**5.2 Embodied Perspective on Musical Expression** 62](#_Toc450406848)

[**5.3 Significance for Musical Pedagogy and Musical Technology Development** 63](#_Toc450406849)

[**5.3.1 Expressive musical performance.** 63](#_Toc450406850)

[**5.3.2 Perception of musical attributes.** 64](#_Toc450406851)

[**5.3.3 Musical techniques.** 65](#_Toc450406852)

[**5.4 Limitations and Future Research** 66](#_Toc450406853)

[**6. Conclusion** 69](#_Toc450406854)

[**References** 70](#_Toc450406855)

APPENDIX 1: Participant Information Sheet ………………………………………………….…….75

APPENDIX 2: Background Musical Information………………………………………………….....76

APPENDIX 3: Musical Sheet……………………………………………………………..…………..77

**TABLES AND FIGURES**

TABLE 1: Review of music-induced movement studies and a summary of motional features and musical factors. 29

TABLE 2: The algorithms of IOIs and articulation of performed sounds 37

TABLE 3: Effect of each motional feature on the produced sounds 49

FIGURE 1: Motional feature of height………………………………………………………………..33

FIGURE 2: Motional feature of direction ……………………………………………………………33

FIGURE 3: Musical sheet in the experiment ………………………………………………………....34

FIGURE 4: The velocity of performed tones in the approaching and for away condition in correspondence with the score time………………………………………………………….……......40

FIGURE 5: Comparison of results in the tapping session ………………………………….…….......43

FIGURE 6: The effect of different motional features on melody tempo………………….……..........47

FIGURE 7: Comparison of results in the melody session ………………………………….…….......48

FIGURE 8: Sample of the product “*Music Air*”……………………………………….……..........61

FIGURE 9: Instrument of Lenon Theremin……………………………………………….……..........61

**1. Introduction**

Humans engage with musical activities by moving their bodies. This has generated a close link between music and motion. The association between musical sounds and human motions in human responses to musical sounds is widespread, similar to other cross-modal association types including the integration of auditory stimuli with visual, spatial, and tactile impressions. Motions that are associated with musical sounds may be either real human movements (Kozak, Nymoen, & Godøy, 2012; Godøy, Haga, & Jensenius, 2006), a sense of motion in the listening experience (Eitan & Granot, 2006; Scruton, 1997), or even metaphorical aspects of musical sounds (Johnson & Larsen, 2003; Lakoff & Johnson, 1980).

Increasingly, empirical studies have examined the association between music and motion in the motion production settings in which humans move in response to musical sounds. Researchers have examined the effect of musical factors on induced motional patterns. In synchronized movement with music, previous evidence has demonstrated the influence of musical tempo and volume on synchronization speed and gait length. Using gesture-tracking techniques, researchers have examined unconstrained motional patterns, and analysed acceleration/deceleration, physical position, and the directness index of free human gestural movements with music (Kussner, Tidnar, Prior & Leech-Wilkinson, 2014; Caramiaux, Bevilacqua & Schnell, 2010). The investigation of motion has also been conducted in applied everyday settings to examine the impact of musical features (tempo, volume, metre) on human physical movements, such as walking, eating and general exercising (Leman et al., 2013; Stryns, Noorden, Moelants, & Leman, 2007). Among gestural mappings of musical sounds, several pairs of analogies between musical properties and motional features seem to be prevalent: musical tempo and motional speed; musical volume and distance index; and musical articulation and motional continuity.

This phenomenon has been explained from a theoretical aspect by the action-perception coupling theory. This suggests that the required specific motor actions used to produce sounds create a strong association between the action movements (inputs) and auditory outcomes (outputs) (Maes, Leman, Palmer, & Wanderley, 2013). Alternative suggestions make reference to the neurobiological origins of the connection between motion and music (Todd, 1999), and the contribution of embodied metaphors of motion in music (Johnson & Larsen, 2003; Lakoff & Johnson, 1980) when understanding musical sounds. The association between motion and musical sounds has produced new psychological perspectives of music cognition for interpreting musical meaning, particularly for ecological music cognition (Clarke, 2001) and embodied music cognition (Leman, 2008). Developed from the traditional music cognition theories, these approaches have gradually focused on the role of the human body in the perception and production of musical sounds.

Investigations of cross-modal mapping between musical sounds and motions have been largely examined in motion induction studies or linguistic description studies in response to music. The connection between music and motion in a musical production context has been investigated; however, studies are often of poor quality and limited in their scope. The analysis of motion is a focus for researchers who are interested in studying expressive music performance. To be more specific, researchers regard the expressive gestures of performers as a way of studying their performance intentions and their interpretation of music (Davison 1993; 1994). Researchers have also emphasised that performance-related movements can communicate emotions and the structural aspects of music to listeners and/or ensemble members (Moran, 2013; Davidson, 2002).

This research is curious about to what extent pianists could make use of the knowledge of music-motion association in a music production task, by switching the attention from analysis of “motions” to the outcome of “produced sounds”. Motional patterns (varying in walking speed, distance, height, and continuity) were represented in several videos in which a dancer walks in a particular motional manner. Pianists were asked to express this motion pattern in the performance of either a melody or single tone sequences. The tempo, volume and articulation of their expressive performances were defined as the dependent variables to examine the effect of distinct motional patterns on produced musical parameters.

Specific research aims include: (1) to identify whether visualized motional patterns inform the manner in which pianists perform; (2) to examine the applicability of previously demonstrated analogies such as musical tempo and motional speed, musical volume and distance index, musical articulation and motional continuity in the context of musical production; (3) to explore other potential mappings between musical feature and motional characteristics. The embodied perspective of music cognition related to the expressive performance intention of pianists is examined in this study by observing how perceived motional patterns are transformed into performed sounds. Research results are expected to reveal the embodied experience of pianists in their expression of musical sounds with distinct characteristics and whether pianists are capable of utilizing the knowledge of cross-modal mapping between music and motion in a creative music production environment.

**2. Literature Review**

**2.1 Embodied metaphors related to music and motion**

The metaphorical usage of musical motion has offered a platform for researchers to examine the prevalence of perceived sense of motion in the musical experience. Walker (2000) has not only systematically reviewed the use of metaphors of musical motion, but also indicated this is prevalent in musical learning and education contexts. Music teachers frequently use physical metaphors, for example, such as “rising” or “falling” to describe musical structure, “energetic” or “relaxed” to describe rhythm, and “building” or “resolving tension” to indicate harmonic structure. An empirical study conducted by Antle, Corness, and Droumeva (2009) found that the use of metaphors in a musical learning context led to improved task performance. Participants were required to generate sounds by moving in an interactive body-audio environment which generated sounds that varied based on pitch, volume, rhythm, and tempo through utilizing different velocity, physical location, continuity and magnitude. The study revealed participants who were given metaphors-based instructions by relating physical movements to changes in sound outputs (i.e. *faster* and wider movements are associated with *louder* sounds, *nearer* movements are associated with *higher* pitches) performed significantly better – they were more accurate and practiced for less time, compared to the control group which did not receive metaphorical instructions.

Johnson and Larson (2003) categorized metaphors of musical motion into three major types: “moving metaphors”, “landscape metaphors”, and “forcing metaphors”. The “moving” metaphor is simple to understand and widely applied in the description of musical concepts, for example, music sounds like “flying”, “rushing”, “speeding up”, etc. The metaphor indicates not only the temporal features of musical events since musical sounds happen in a dimension of time (e.g. music starts to go faster *here*), but also the spatial dimension of musical sounds (e.g. melody line *rises or falls down*). The musical “landscape metaphor” refers to the present moment where the listener is at a particular point along a journey, for example, “…once you reach the refrain, the dissonant part is behind you. We’re going faster here…” (p.71). According to Johnson and Larson (2003), the listener may either be a “participant” that is travelling and moving over a path in the musical listening journey, or be an “observer” that is observing the entire musical landscape from a distant standpoint. The musical score has been treated and imagined, in both perspectives, as a metaphorical representation and represents a path in virtual space. Musical “forcing metaphors” may be understood as “acting on listeners to move them from one state-location to another along some path of metaphorical motion” (p.75), for example, listeners feel “pushed” “pulled”, or “blown away” by music.

The categorization of motional metaphors by Johnson and Larson (2003) has enriched knowledge about mental representations of musical sounds, thus providing a new perspective to investigate the *musical meaning*--embodied approach of music cognition by linking internal representation of sounds with physical bodily experiences. Lakeoff and Johnson (1980) suggested that using metaphors enables humans to understand musical meaning by thinking with overlapping dimensions. Metaphors of musical motion were also thought to create a bridge between the concrete and specific bodily movements, and the abstract and conceptual musical meaning, allowing humans to understand the abstract domain by thinking in another concrete dimension.

Through reviewing the metaphorical motion in music, it suggested that our musical understanding is closely linked with the physical experience. This can be seen from the prevalent utilization of physical experience (i.e. rising, rushing, pushing etc.) in their linguistic descriptions of musical listening experiences. The capacity of associating concepts from cross-modal domains (physical/musical) may be explained by the theory of “cross-modal correspondence”. Significance of cross-modal correspondence lies in demonstrating how music and motion may be associated through a mental conceptualization process, and how the human musical mind reflects (extended) concepts of associations found in the real, vivid and situated physical environment.

**2.2 Rational Explanation from Cross-modal Correspondence Domains**

**2.2.1 General introduction.**

The close connection between music and motion is one of the association types underlying the cross-modal correspondence experience. Cross-modal correspondence refers to the integrated perceptions that happen among different sensory modalities such as the visual system, auditory system, tactical system, or the motion system etc. (Spence, 2011). The integration of multisensory perception can be affected by several factors. It is more likely to happen when stimuli from different modalities are presented closer in time or space (spatial and temporal factors), and occur as a result of the common linguistic meaning that is used to describe the stimuli from multisensory (semantic factor) such as the mapping between pitch and elevation (high/low). It may happen due to the similarity of basic stimulus features in different modalities (synaesthetic factor). Consequently, the perception of auditory musical pitch may be integrated with impressions such as visual brightness, physical sharpness, and motional vertical height (Evans & Treisman, 2010; Marks, 1987; Parise & Spence, 2009).

The *Nature* or *nurture* character of cross-modal correspondence has been the subject of debate for many years. On the one hand, several correspondence pairs seem to be in-born human characteristics: Associations between musical pitch and physical height/sharpness of objects could be detected in three-four month year old infants (Walker et al., 2009); the sensitivity for association between musical volume and visual brightness can be present among newborn babies (Wagner, Winner, Cicchetti, & Gardner, 1981). On the another hand, several cross-modal correspondence experiences may be significantly gained through external training such as linguistic and musical training in later life. The study of Dolscheid, Shayan, Majid, and Casasanto (2013) indicated the external linguistic training effect on the mental representation of musical sounds with distinct physical thickness and elevation. The study indicated that Dutch speakers who primarily thought musical pitch with physical height (high/low) tended to be associated with pitch and thickness (thin/thick) after a short session of matching pitch-thickness descriptors. Previous studies have suggested that musical expertise can influence the association of auditory pitch with horizontal locations, thus, musicians tended to associate higher pitches with right-hand space and lower pitches with left-hand space, while non-musicians were less likely to show this cross-modal association (Rusconi, Kwan, Giordano, Umilta, & Butterworth, 2006).

**2.2.2 Music and motion associations.**

The connection between music and motion was a form of "sensorimotor association" in the cross-modal correspondence as when one dimension (either auditory musical sounds or motional representations) was presented for listeners and a corresponding activation was evoked in the other dimension. The motions that are activated in other modalities may be represented as an increased motor excitability of the motor cortex (D’Ausilio, Altenmüller, Olivetti Belardinelli, & Lotze, 2006) or real gestural movements (Caramiaux et al., 2010).

The association between music and motion has been demonstrated to be nature for infants, humans and even other nonhuman species in previous empirical studies. Scruton (1997) and Truslit (1938) indicated that perceptual property of motional characteristics is the most universal and common phenomenon in the musical listening experience. Previous studies have also demonstrated synchronization between musical sounds and human bodily movements among infants. Eerola, Luck, and Toiviainen (2006) examined the ability of 2-4 year old children to musically synchronize and discovered that children synchronized with music by utilizing three main movement types: hopping, circling, or swaying. Zentner and Eerola (2010) further investigated rhythmic bodily engagement in 5-24 month old infants and discovered that infants made more bodily rhythmic movements with music, compared to speech. Furthermore, Zentner and Eerola (2010) found an association between musical tempo and motional speed (i.e. faster music tempo induced quicker movements). Several studies have also demonstrated that non-human species can synchronize. Patel, Iversen, Bregman, and Schulz (2009) revealed the sulphur-crested cockatoo was capable of synchronizing with a musical beat and could adjust its movements in accordance with the tempo of the stimuli. The study suggested musical beat synchronization is not specialized to humans as species with vocal learning ability, including some birds, cetaceans, and pinnipeds, can demonstrate this ability.

Cross-modal mappings between music and motion maybe mediated by musical expertise. Himberg and Thompson (2011) found differences between synchronization ability in experts and novices. The novices synchronized through their footsteps and their whole body was entrained to the beat-level of the metrical hierarchy. Whereas the experts demonstrated superior synchronization ability as they demonstrated entrainment to multiple metrical levels and with different parts of their bodies. Küssner, Tidhar, Prior, and Leech-Wilkinson (2014) also investigated differences in gestural cross-modal associations with musical sounds between musicians and non-musicians. The study revealed that even though several pairs of cross-modal mappings between music and gesture were detected in both musicians and non-musicians, musicians presented higher consistency for several mappings including musical pitch and motional height, musical volume and motional distance/height, and musical tempo and motional speed and muscular energy.

**2.3 Theoretical Explanation of Music-Motion Association Mechanisms**

**2.3.1 Three models proposed by Palmer.**

Palmer (1997) suggested three possible models to explain the connection origin between music and motion, and particularly introduced the causal relationship between rhythms and movements in a music performance context. The first model is the “*timekeeper model*”, which supports the idea that rhythm generates movements. It means that rhythmic information may be coded as an input to a motor system, therefore producing a series of temporally structured motions such as tapping under the guidance of an “internal clock or timekeeper”. The internal clock may regulate and coordinate temporally complex sequences (i.e. those coordination between hands and performers), and produce temporal variance in performed events (Palmer, 1997). The second model “*motor programming*” supports the view that movements generate rhythm. Musical production requires abundant bodily movements; representations of planned movements may be activated prior to the execution of actions and transferred to movement sequences to ensure the fluent and expressive performance.

The third explanation proposed by Palmer (1997) originates from the kinematic explanation that “music performance and perception have their origins in the kinematic and dynamic characteristics of typical motor actions” (Palmer, 1997, p. 132) and the common characteristics shared by musical structure and motional patterns. The kinematic origin of music has been discussed since the early centuries and is utilized to explain the relationship between musical tempo and intensity, for example that accelerated tempo typically relates to rising volume while decelerated tempo relates to falling volume. As musical phrasing features has origins in the kinematic variations of movements, researchers suggested that there is a connection between velocity (speed) and force (intensity) and that an acceleration/deceleration in velocity often relates to an increasing/decreasing in tension (Sachs, 1943; Stetson, 1905, cited in Todd, 1992). Related empirical evidence has been provided by researchers utilizing a model to explain the final *ritardando* in musical performance by linking its origin with the deceleration of last action in physical motion (Friberg & Sundberg, 1999). Other evidence may be observed as distinct metrical structure (beat levels) in musical sounds have potential resonance in various human limbs (Peckel, Pozzo, & Bigand, 2014; Toiviainen et al., 2010)

**2.3.2 Neurobiological perspectives.**

Todd (1999) proposed two possible mechanisms related to neurobiological origins underlying the perception of motion in music. One mechanism is the “vestibular mechanism”, supporting the rationale of connection mechanism with the evidence that the human vestibular system is sensitive to acoustic information in musical sounds and that slight changes in sonic energy such as amplitude, pitch, pulse length (related to articulation) may lead to the sensation of motion. The other mechanism refers to “audio-visual-motor” which is a higher-level information computation process and operates by transferring and interpreting the sensory information (auditory or visual stimuli) into sensory-motor images through an “internal model” in the cerebellum. Todd and Cousins (1999) provided an evidence for this mechanism with a correlation observed between the preferred tempo and the psycho-physical and anthropological information of participants (i.e. weight, dimension, height etc.), based on the hypothesis that participants should perceive the beat differently as each individual features a unique biomechanical feature (unique weight, height, length, and breadth, etc. of the body).

**2.3.3 Action-perception coupling.**

The action-perception coupling theory supports the natural association between music and motion in the human mind by integrating motor actions and sensory outcomes in an excitatory process where sensory events are created with particular motor inputs (Maes et al., 2013). Maes et al., (2013) argued that two types of models are involved in the action-perception coupling process--one is forward modelling that enables humans to predict sensory outcomes of the planned action prior to execution (motor to sensory) and the other is inverse modelling that allows human to recall and associate the motor actions that are required for the corresponding sensory outcomes (sensory to motor).

The internal model underlying the action-perception coupling process is significant for understanding the perceptual difference of musical sounds caused by musical training, especially the difference between musicians and non-musicians, as significant differences for motor requirements exist between them in musical sound production. Related empirical evidence indicates that task performances of musicians and non-musicians in the response to visual displays were affected differently by the concurrent auditory interference by utilizing stimuli-response compatibility approaches. Drost et al. (2005a, 2005b) found that unrelated auditory displays led musicians to experience significant interference when playing on a keyboard in response to visually displayed chords sequences or pitch intervals; while non-musicians were not affected by the unrelated auditory displays. Neuro-physiological evidence also indicates that greater activation occurred in motion-related brain areas in musicians than in non-musicians when exposed to musical sounds while pressing keys on a mute piano keyboard or passively listening to piano melodies (Bangert et al., 2006). Several studies have investigated whether musical training influences the perception of distinct musical attributes. Manning and Schurz (2013) demonstrated that perception of musical temporal structure may be improved by a pre-learning session of tapping along with the musical beat. Hofmann and Geobl (2014) indicated that participants who had expertise in playing the saxophone could better discriminate the saxophone sounds made by using various articulation techniques.

To summarize this section, the explanation of Palmer (1997) illustrated the casual mechanism of the connection between music and motor in the musical performance context, where interactions happen between human motor system and rhythm perception and kinematic basis might be responsible for this. Todd (1999) provided neurobiological evidence to make the mechanism of music-motion connection much convincing. The action-perception coupling theory explains the mechanism by dividing the conceptual process into two stages—motor inputs and sensory outputs, elaborating key factors that may contribute to this conceptualization process and interaction characteristics occurring in either forward or reversed manner. The action-perception coupling process is significant for understanding perceptual differences resulting from musical training effects and underlies the motivation for selection of subjects in the current research project—expert piano performers.

**2.4 Significance in Musical Meaning**

**2.4.1 Two psychological perspectives.**

By reviewing the metaphorical motions and embodiments of physical associations present in the gestural mapping of musical sounds, it turns out that musical listening is not purely a matter of the perception of acoustic information of sounds in terms of pitch, volume, timbre etc. It is more likely to be a conceptual way of listening that relate to the specification and meaning of musical sounds in physical contexts. So far, insights about the connection between music and motion, based on understanding musical meaning, has been discovered and highlighted. The research topic has been historically debated and conceptually differs from several psychological perspectives.

Traditional cognitive views on musical meaning argued a separation between the human mind and body. Foder (1983) supported the idea that understanding and comprehension of musical content is based on the information-process mechanism where musical events may be coded as a collection of symbolic features computed in the mind of musicians (cited in Matyja & Schiavio, 2013); Hutto (2009) proposed a method for comprehending the outside physical world by employing code to compute events into symbols, images, or neural configuration, where a virtual replica of the actual world is formed in the human internal mind. The traditional cognition approach seems to separate the human subjective experience of music from the external physical world by disregarding the significance of the human bodily experience in the formation of musical meaning during musical production or listening.

Clarke (2001) adopted an ecological perspective of musical listening and suggested the contribution of connecting the relationship between motion and music into the understanding of musical meaning via the notion of *sources specification*. Ecological cognition theory supports the notion that everyday sounds specify their perceptual meaning of sources, i.e. physical location, textures, dimensions etc. Clarke argued that it is inevitable then that musical sounds specify motional and gestural features of related sources, including both the real movements to produce the sounds and “the fictional movements and gestures of the virtual environment which they conjure up” (Clarke, 2001, p222). The fictional sense of motion enables listeners to engage with the music by acting amongst it, thus introducing an important element of musical meaning (Clarks, 2001).

Leman (2008) further proposed the embodied approach for understanding musical meaning and suggested the human body works as a mediator between physical music sounds and mental meaning in the human brain. The internal representation of musical sounds is no longer perceived in a passive manner during the musical perception and learning process as active participation of the human body in musical perception enables subjects to guess the inferential meaning (non-musical) of music and shape individual representations of events (Nussbaum, 2007). The body-based musical experience then, as related to the metaphors in musical motion discussed in Section 2.1, has offered the opportunity to understand and comprehend musical metaphors and semantic descriptions of music. Walker (2000) indicated that, without prior bodily movements in the musical experience, metaphors of musical motion as related to significance in musical understanding are inconsequential.

Research conducted by Casasanto and his colleagues (2013, 2012, & 2009) produced further comprehension for movements in shaping how humans subjectively experience an object and how objects are internally represented. Based on the hypothesis that distinct handedness potentially results in distinct mental representations as a result of different outcomes for interaction between handedness and the physical world, Casasanto (2009) discovered that right-hand users tended to combine more positive ideas with the right-forward space while associating more negative ideas with the left-forward space. The finding was opposite for left-hand users and consistent in the observation of 5 year old children (Casasanto & Henetz, 2012).

**2.5 Examination of the Motion-Music Connection in a Motion Production Context**

Researchers have investigated the transformation from musical sounds to motional patterns of the human body for many years. According to the embodied perspective of Leman (2008) on musical cognition, the various motional characteristics of human bodily movements may be viewed as distinct representations of perceptual differences for musical temporal structural, metrical structural, emotional expressiveness, and other expressive qualities of musical sounds such as timbral information. Two main domains of this study type will be reviewed, according to the complexity of bodily movements with music. The first level is the most basic and fundamental form of musical-induced movement -- synchronization movements with musical stimuli related to the temporal and metrical representations of sounds on human bodily movements; the other is a more advanced music-induced movement related to more complex motional elements including physical location, amount, mass, and smoothness. An additional section will summarize several specific analogies between motional characteristics and musical parameters that are well documented and demonstrated in previous studies.

**2.5.1 Synchronization with music.**

The human synchronized movement response to music refers to the co-ordination of the pulse and accent of human bodily movements with the temporal and rhythmic pattern of musical stimuli. Povel and Essence (1985) support the “internal clock” model view that listeners have an “internal clock” to code the temporal structure of musical sounds on the basis of perceived accents distribution, thus producing rhythmic movements that coordinate with auditory stimuli. Large and Palmer (2002) suggested that humans have an internal self-sustained oscillation model to attune with the rhythms of music performances; this enables humans to perceive the metrical categories of temporally changing auditory events and distinguish the underlying deviations of metrical categories. Leman (2008) then adopted an embodied perspective to explain the origin of synchronized motion with music and distinguished it with other forms of sensorimotor activity (dancing, gestural moving) with music. Synchronization was explained as a fundamental level of corporeal imitation for perceived musical structure and an outcome of positive interaction between agents and the external environment that is not necessary to involve any emotional processing. In contrast, attuning and empathy relate to higher-level musical features such as melody, harmony, and involve complex bodily movements (singing and dancing) and subjective intentions (feelings and emotions). The crucial difference between the two perspectives is the notion that synchronization originates from a passive perception (internal clock view) compared to synchronization being an active learning process (embodied view).

Synchronized movements with music may operate with different forms and be affected by various musical factors. Toiviainen, Luck, and Thompson (2010) observed that participants synchronize with music using different parts of their limbs in response to distinct metrical levels. The one-beat metrical level is commonly associated with vertical bodily movement while the four-beat level is associated with mediolateral movement and faster metric levels are associated with extremities, while slower beats associate in the central portions of the body. Leman and his colleagues (2013) conducted a study to examine the effect of expressiveness of musical pieces with the same musical tempo/volume on the synchronized walking. This study revealed that synchronized walking tempo of participants was consistent, however, their stride length showed significant differences: “activating” music (equalized phrasing, binary structure, perceived as bad/aggressive/loud/fast/stuttering) induced greater stride length whereas “relaxing” music (complex tonal pattern, more variances in phrasing and melody, perceiving as good/tender/softer/slow/fluent) induced less stride length. In other words, synchronization with music not only relates to the beat level of auditory events; it links with other attributes of musical structure such as metrical level, texture, and tonal pattern etc.

**2.5.2 Music-induced gestures.**

The examination of music-induced bodily movements has created a bridge to investigate the mental representation of perceived musical expressiveness by showing the correlation between motional representations and musical features. Human bodily movements can be captured by using motion-tracking techniques, where participants wear specially designed jackets or gloves to capture movement elements including velocity, position, and movement amounts. Perceived aspects of musical expressiveness are gathered by administering questionnaires. The research also confirmed the embodied perspective of music cognition with evidence of consistence between human gestural features and the linguistic description of perceived aspects of musical expressiveness, thus bodily movements revealed perceived musical features.

Maes, Dyck, Lesaffre, Leman, and Kroonenberg (2014) investigated the relationship between free bodily movements and the perceptual qualities of musical expressiveness. The authors used the Laban Movement Analysis (LMA) model to examine correlations between motion and music. Physical movement features were associated with particular expressive qualities of music such as intentionality and emotion. Movement acceleration was linked with metaphors indicating efforts weight (heavy or light) and motional smoothness was associated with metaphors indicating efforts flow (rigid or fluent). The study examined several features (acceleration, smoothness, size, height) of participants’ bodily movements and their subjective ratings of given antonymous metaphors in the musical expressiveness perception task. Results demonstrated an association between physical features of bodily movement and the verbal description of musical expressive qualities, irrelevant of musical expertise. Burger, Saarikallio, Luck, Thompson, and Toiviainen (2013b) conducted a study to examine the relationship between perceived emotions in music and music-induced movement. The correlational analysis results indicated that music-induced movement was associated with the emotional qualities of the music. An additional study by the same researchers (2013a) also suggested that music-induced movement could be affected by musical features such as rhythmic and timbral patterns (pulse clarity, percussiveness, spectral flux). For example, a clearly perceivable pulse could induce an increasing amount of movement at a global and entire body level while spectral flux with high frequency was highly correlated with the speed of head and hand movement, hand distance, and the amounts of movement.

**2.5.3 Analogies between motion features and musical attributes.**

In the following sections, we reviewed previous empirical studies that have examined the association between musical features and motional characteristics in a motion production context, and summarised into several apparent pairs of music-motion analogies. This forms the research hypothesis of current research project that will particularly examine these pairs of mappings in a musical production context.

**2*.5.3.1 Musical tempo & motion speed.***

The transformation from musical tempo to motional speed seems to be the most stable and apparent pair compared with other pairs of music-motion analogies. Faster musical tempo is associated with accelerated movements while slower musical tempo is associated with decelerated movements. In the real-world circumstance, several studies have revealed that the speed of activities such as driving (Brodsky, 2001; Konz & McDougal, 1968), drinking (McElrea & Standing, 1992), eating (Milliman, 1986), and even shopping (Milliman, 1982) tended to be significantly quicker when accompanied by fast tempo music. Dibben and Williamson (2007) indicated the negative impacts of faster music tempo on daily driving in their questionnaire survey and found that faster background musical tempo might distract the attention of drivers relative to other in-vehicle auditory sounds. Running speed on a treadmill, for example, tended to rise when subjects heard fast tempo music (Edworthy & Waring, 2006). The kinematics link between music and motion has also been applied to the gait treatment of patients with Parkinson Disease (Lim et al., 2005; McIntosh, Brown, Rice, and Thaut, 1997). The patients originally suffered with gait problems such as cadence coordination, reduced walking speed, shorter stride length, and even “frozen” movements (Lim et al., 2005). However, when music accompanied walking it acted as a cue to guide kinematic movement and could prove to be an effective treatment as opposed to using pure metronome stimuli (Styns, Noorden, Moelants, & Leman, 2007).

**2*.5.3.2 Musical volume & physical distance.***

The volume of a moving object indicates the information of physical distance of the sound source, i.e. whether it is approaching or leaving away. This relationship between acoustic information and distance perception can be explained by the ecological perspective of Clarke (2005) on musical listening, namely, that what we hear about the specification of musical sounds relates to its source information. In daily life, the volume of sounds can increase when its distance from the listener is closer (Eitan & Granot, 2006). A familiar example may be that the perception of the distance of a passing car is based on the perceived volume of its horn. According to Clark (2005), the capacity for living in the physical world may be enhanced with greater comprehension for perceptual meaning of physical sounds. In the circumstance of identifying the sound source, the relationship between physical distance and musical volume is negative, i.e. rising musical volume indicating decreasing distance while falling musical volume indicating increasing distance.

The perception of musical volume has an impact on the human physical movements. In this context, the relationship between physical distance and musical volume becomes positive. Research showed that the volume of music is related to its ability to motivate (Edworthy & Waring, 2006; Elliott, Carr, & Orme, 2005), thus louder music contributes to additional motivational characteristics and may induce greater exercise efforts (i.e. increased physical distance) as compared with quieter musical stimuli. Leman et al. (2013) demonstrated this positive correlation relationship with more systematic experimental control. Participants were required to synchronize their walking to the accompanying music. Louder music led participants to walk farther compared to the distance walked when listening to quieter music with the same tempo.

**2*.5.3.3 Musical articulation & motion continuity.***

The analogy between musical articulation and motion continuity is less studies by researchers. However, this relationship can be indirectly detected from the examination on perceived musical expressiveness and emotions. Friberg (2004) investigated the effect of interaction between motion patterns and musical sound features on perceived emotion of listeners. This study discovered that performance was perceived as angry when staccato rhythm was applied and jerky, fast, large motion cues were associated with sharp timbre, while sad associations were connected with legato rhythm and slow expression was associated with soft, small motion types. Kozak, Nymoen, and Godøy (2011) investigated the relationship between motion continuity and sounds attack types (smooth or sharp) by analyzing sound-induced gesture features. Induced motion was more continuous and smooth when listeners heard sounds that were played with smooth attacks; while movements were transformed into discrete and discontinuous patterns in response to sounds played with sharp attacks.

***2.5.3.4 Musical pitch & spatial location.***

Perception of musical pitch is typically linked to a perceptual feature of spatial location (Lidji, Kolinsky, Lochy, & Morais, 2007; Walker & Ehrenstein, 2000). Listeners report that change of pitch induces a sense of motion in a spatial dimension. Deutsch, Hamaoui, and Henthorn (2007) studied the perception of glissando illusion, with synthesized tones designed to include varying left/right locations and high/low pitches. The study indicated that right-hand users tended to perceive the glissando as moving in a spatial dimension, with sounds moving from low-left point when the pitch was lowest to high-right point when the pitch was highest along an elliptical path; however, left-hand users did not show this percept. Musicians and non-musicians in the musical induced motion-tracing studies were able to locate sounds with various pitches onto different spatial height. Higher pitches are associated with higher position while lower pitches are associated with lower position; the rising pitch contour induces upward hand movements and the falling pitch contour induces downwards hand movements (Küssner et al., 2014; Caramiaux et al., 2010; Godøy, Haga, & Jensenius, 2006).

**2.6 Examination of the Motion-Music Connection in a Music Production Context**

Different from researchers who are interested in examining the induced motional characteristics in response to musical sounds, researchers studying on the expressive music performance focused on the role of bodily movement in producing expressive sounds and communicating performance intentions to audiences. This research perspective made the examination on the mapping between music and motion switching from musical listening studies to a musical production context. The following section will review several studies relative to the examination of performance-related gestures in the expressive performance, illustrating with example from solo performance to co-ordinated performance.

**2.6.1 Motion and musical expressiveness.**

Gabrielsson (1995) investigated the variance of pianists’ performances in response to distinct emotional intentions such as angry, happy, sad, tender etc. and observed that elements of performed sounds (i.e. speed, articulation, volume) varied in accordance with distinct intentions. The study indicated that distinct intentions exert an effect on the expressiveness of musical sounds, though a systematic investigation of bodily movements in the musical performance was not conducted.

Davidson (2007, 2002, & 1994) investigated musical expressiveness in music performance by investigating the bodily movements of performers both quantitatively and qualitatively. Davidson (1993; 1994) developed a scientific paradigm utilizing motion-tracing techniques to investigate the relationship between the quantity of movements and the extent of expressive intentions by mapping the gestural data and intention onto a two-dimensional space. The studies revealed that in the performance of the same piece of music, greater expressive intention induced larger amounts of movements compared with the deadpan condition and a significant positive correlation between the *quantity* of gestural data and the *degree* of intention occurred. A more detailed motion tracking technique revealed that the *scale* of movement was positively correlated with the extent of expressive intention even though the pianists moved with similar movement contours.

Motions not only map the performance intention with distinct scales and quantities, they may also facilitate the performance and indicate the musical structure. Davidson (2011) suggested that one feature of performers’ gesture movements with music is a swaying motion. Musicians in the sitting position during performances, are more likely to sway around the sitting balancing position, while for musicians in the standing position, swaying with music occurred around the balancing positions of knees, feet and hips. Davidson suggested one explanation for this involves the necessity of pivotal movement to acquire accurate articulation. Another form of musical gesture in performance is *identifiable* function. Davidson (2007) performed a qualitative study of bodily movements in music performance and discovered that particular movements may be a significant indicator of musical structure expression or emotional intention, for example, head nodding with rapid gestures is likely to represent a mirror for repetition of the musical material (Davidson, 2011).

**2.6.2 Communicative aspects of gestures in music production.**

Studies reviewed in the last section indicated the close connection between the bodily movements of performers and their expressive performance intention. Researchers have also investigated the perception of performance-related movements from the perspective of listeners and ensemble players. This approach investigated the communicative function of motions by exploring a shared understanding of musical expressiveness between performers’ production of music and listeners’ perception of music, and between musicians in cooperative musical activities.

***Perspective from listeners.***

Researchers have observed the perception of musical expressiveness from the perspective of *listeners*. Davidson (2002) conducted a perception study investigating the correlation between performers’ bodily movements and listeners’ rating of expressive intention. The research confirmed the perceptual consistence between the performer and perceiver as participants rated performances as high in expressive intention when performers’ movements were exaggerated movements. Leman, Desmet, Styns, Noorden, and Moelants (2009) extended this evidence by investigating motion-tracking data obtained from both listeners and performers during a performance of Chinese Guqin music. The study hypothesized that if listeners and performers share a certain degree of sensitivity for musical expression then the extraction of gestural movement by listeners should be consistent with performers’ movement. The results indicated the velocity patterns of listeners movements significantly correlated with the velocity pattern of performers shoulder movements. These studies demonstrated that performer gesture movement may be interpretable from the perspective of listeners.

***Perspective from cooperative performance.***

Moran (2013) explored the communicative aspect of gestural movements with music among a duo who played North Indian music. As Indian music is transmitted from oral tradition rather than learning from musical notation and score, it is characterized with a culturally specific form of performance organization and improvised interactions. The author also intended to investigate how this communicative function of gestural movements may successfully contribute to co-ordinated musical performance through semi-structured interviews. This qualitative research revealed that gestural movements of musicians enable others to predict musical structure, to anticipate others’ expressive intention, and to obtain a sense of non-verbally negotiated performance tempo. For example, to indicate the accurate moment to take over a melody solo for a performer depends on observation of the movements of accompanists. Kochman, Demoucron, Moelants, and Leman (2012) similarly explored the communicative role of *respiration* in the cooperative vocal performance. Respiration was considered as a potential indicator of synchronization and embodied attunement between musicians: “Respiration allows not only for coordination, but also for engagement of higher-level intentional processes, such as expressive affect and feeling” (p.59).

Examining the communicative role of musical gesture in cooperative musical activities has highlighted the importance of *social perspective* of embodied musical gestures. Moran (2013) suggested that “As physical movement is increasingly recognized as central to the perspective and process of the cognition of the individual musicians…the immediacy and relevance of others' body movement in relation to oneself becomes paramount” (p5). Leman et al. (2008) also suggested that one function of music is to motivate active listener involvement in musical activities, allowing a “harmonious” feeling rather than an “out of sync” sense in a manner of unconscious corporeal imitation of musical sounds.

Leman (2008) argued that music-driven movement of listeners may be viewed as a corporeal imitation of sonic patterns for musical sounds. Musical communication between individuals is a model of encoding and decoding of patterns for corporeal articulations, where the musical idea/mind is encoded into sound energy through corporeal articulation and, in turn, will be decoded and comprehended as corporeal and cerebral understanding for musical sounds. The corporeal resonance/imitation during musical communication enhanced both performers’ and listeners’ subjective feeling of musical listening experience. Arousal, attention, and the feeling of presence may be enhanced for listeners and, for performers, auditory, visual or tactile feedback from listeners is received, stimulating the performance (Leman, 2008).

**2.7 Interim Summary**

To summarise what we have reviewed so far, above paragraphs can be divided into two major parts. The first part included the review of music-motion mappings in motion production contexts, which offers details of the musical and motional features that may interact and be associated. Reviewing this part offered inspiration of the research design for the current research project, i.e. which motional/musical features should be taken into account. Listening to musical sounds may not only evoke a sense of motion in the listening experience, but also induce actual bodily movements in either a lower musical synchronization level or a higher level of free gesture associations. The action-perception coupling theory particularly explains the occurring mechanisms of motion and music association and its relevance to musical structure, musical expertise, and personal backgrounds. The prevalence utilization of metaphorical motion descriptors in musical teaching/learning and linguistic descriptions of musical listening experience, suggesting that human understand musical sounds by referring to its relevance to human body. This capability of associating concepts from crossed domains has a crucial significance in understanding the musical meaning.

The second part refers to the literature review regarding the examination of bodily movements in a musical production context. This part indicates the significance of examining motions in an expressive performance, and offers an embodied perspective to study the expressive intentions of performers by studying the quantity, scale, and interaction patterns (head nodding or swing) of gestural movements. It also suggested the shared understanding of motion interpretation between listeners and performers, and between co-ordinated players. This gives rise to the hypothesis of current research project that whether and to what extent pianists have a consistent way to interpret certain motional characteristics (speed, spatial height, smoothness) with specific musical features (tempo, volume, articulation).

**2.8 Research Gaps**

The understanding of the connection between music and motion has been largely explored by the systematic analysis of motions in relation to musical sounds. This series of empirical studies has provided abundant convincing evidence of the transformation from musical parameters to human motions. However, this connection has rarely been investigated in an opposite way to study how the perceived motional patterns could be transformed into musical properties in a musical production context. Since researchers have argued that pianists use gestural motions to interpret the musical structure, facilitate produced sound, and communicate with audience and co-performers (Leman, 2008), it is thereby reasonable to predict that pianists are able to make use the knowledge of music-motion connection to facilitate an expressive music performance. Rather than examining the cross-modal connection from the viewpoint of a perceiver (listeners), this research intends to examine from the viewpoint of a producer (pianists). If the mappings occur and are consistent with the findings in the motion production context, it suggests that pianists could fully use the knowledge of music-motion mapping in an expressive performance; and the production of expressive sounds has its basis in the element features of physical movements.

**2.9 Research Aims**

This study examined the cross-model relationship of music and motion in a creative and improvised musical production context where pianists are asked to produce expressive performance on a given unstructured notes sequence without any expression instructions in response to various visualized motion patterns shown in the videos. Investigation of sound-induced gestures has indicated that possible pairs of analogies exist between music attributes and motion patterns, thus this study intends to examine the analogies of music-motion mapping in a musical production context to observe potential crossed relationships within pairs of analogies. Rather than designing motion characteristics with different types such as walking, running, sliding etc., this study intends to systemically categorize the motion features into four dimensions: speed (fast vs. slow), height (high vs. low), continuity (angular vs. smooth), and distance (increasing vs. decreasing). The examination of musical attributes contains three levels to investigate the expressiveness of improvised performance, including musical tempo (beats per minutes), articulation (duration between breaks), volume (key attack velocity). The specific hypothesises are as follows:

H(1): Motional feature of speed is connected with performance tempo of musical sounds, thus faster walking speed may be transferred into faster performance tempo, and slower walking speed may be transferred into slower performance tempo.

H(2): Transformation may exist from motional distance to musical volume, thus decreasing distance (forward movements) may induce gradually louder musical performance while increasing distance (backward movements) may induce gradually softer musical performance.

H(3): The effect of motional continuity may be transformed into musical articulation, thus movement with angular expression may be related to more staccato performance while movements with normal expression may be associated with more legato performance.

H(4): This study also makes the assumption that potential analogies between music and motion might occur besides above listed pairs. However, specific hypothesises cannot be defined and are expected to emerge with the data analysis.

**3. Methodology**

**3.1 Research Design**

The corresponding relationshipbetween musical attributes and motional characteristics was examined in a creative and improvised musical production context. Videos featuring a dancer moving in distinct motional characteristics were presented through iPad and participants were expected to imitate the movement feature in their performances after watching each video. Participants performed on a given series of tone sequence (without rhythmic structure and defined tempo/articulation/expression); they were expected to play dynamically and expressively on a MIDI piano corresponding to different videos. The effect of motional features was examined on three musical attributes including musical tempo, musical volume, and musical articulation. Eight videos were designed in this study with four fairs of features comparison, namely speed, distance, physical height, and continuity. Participants were asked to play three times for each performance. Two kinds of performance were examined including either playing on the single tone A or the given melody, therefore they would watch each video for twice times but were allocated separately in two sessions. In total, 8 (videos) ×2 (performance sessions) ×3 (times) ×13 (participants) = 624 pieces of music were recorded and analysed.

**3.1.1 Motional features.**

Eight conditions exist in this study with each containing one particular movement type in the video, constituting four pairs for comparison, including *speed* (fast or slow), *distance* (increasing or decreasing), *height* from ground (high or low), and *continuity* (angular or normal). The four factors are selected to represent four types of particular motional characteristics based on review of previous studies related to music-induced movements. The main elements of motional features and related musical factors were summarized and displayed in **Table 1**. The investigated movements in the listed studies were either real movements captured by motion-tracking techniques or imagined movements in the perception tasks.

# Table 1: Review of music-induced movement studies and a summary of motional features and musical factors.

|  |  |  |
| --- | --- | --- |
| **Musical factors** | **Motional features** | **Studies** |
| pitch, volume, tempo | ***velocity*, *vertical heigh****t*, muscular energy, ***forward-backward*** *movements.* | Küssner et al., 2014; |
|  | ***acceleration*,** impulsiveness, jerk, smoothness error, ***directness index***, size, ***height*.** | Maes et al., 2013 ; |
| pulse clarity, percussiveness, spectral flux | ***speed*** of movement, distance of hand, amount of movement, hip wiggle, shoulder wiggle | Burger, Thompson, Luck, Saarikallio, and Toiviainen, 2013; |
| spectral and temporal features of musical sounds | maximum acceleration, ***discontinuity*,** and total quantity of motion | Kozak, Nymoen, and Godøy, 2012; |
| volume, brightness, pitch | ***vertical position***, absolute ***velocity*,** absolute acceleration, hand distance | Nymoen, Godøy, Jensenius, and Torresen, 2012; |
| volume, sharpness | ***position*, *velocity*,** and acceleration | Caramiaux et al., 2010; |
| dynamics, pitch contour, pitch intervals, attack rate, articulation. | motional type, ***vertical direction***, *f****orward-backward movement****s*, right-left movements, ***speed*,** external force, energy involved. | Eitan and Granot, 2006 |

The motional features of *speed* and *distance* were selected following the review of listed studies to represent the crucial and fundamental characteristics of moving object motional features. *Physical distance* was not selected as the videos were systemically controlled around 10 seconds to balance the duration effects and the walking tempo may reflect physical distance in certain ways (i.e. quicker speed refers to farther distance in equal duration). *Physical height* from the ground was selected as the third motional feature, indicating the vertical distance between the feet and the ground. This was chosen as an analogy of physical position factor listed in the table. The *amount of movement*, additionally, was easily captured by the motion-tracking machine in music-induced movements research; whereas, movement is difficult to control and produce in particular amounts for a dancer. This motional feature may be reflected as a feature of *motional continuity* as angular movements contained more amounts of motion compared with the normal movements of walking action.

**3.1.2 Examination of musical features.**

The musical production task was designed to play with un-grouped tones of a melody piece to examine the extent pianists could play creatively and expressively in response to the visual stimuli. The idea was inspired by a study of Clarke, Doffman, and Timmers (in preparation) who investigated the change and development of musical creativity in the collative performance, where musical score material contained only notes for the performance movement without other notations such as articulation, durations, tempo, or rhythmic pattern, etc. In their research design, filled notes mainly represented the flowing quavers and could be improvised on the rhythm pattern by adding single or pairs of semiquavers by performers; bars were provided to separate phrases and ended with longer notes such as semibreves or dotted minims, etc., and were also treated as smaller elements to construct longer phrases. Inspired by this research, the current study examined the transformation from visual stimuli to performed sounds in a creative and improvised performance context. Audio features that required analysis were correlated with motional characteristics including *tempi, articulation, and volume* and were determined by the MIDI piano transcription system. The study was designed to play music of a particular melody while other auditory features such as timbral variance, harmonic patterns, and musical pitch were already defined by the selected material. The calculation of each audio character is illustrated Section 3.4.1.

Two performance sessions are involved in this study including tapping and playing. Participants were required to play a single tone on A3 sixteen times in eight conditions as the first “tapping” session, and then play one particular melody in eight conditions as the second “melody” session. Two performance sessions were designed to compare groupvariances between the tapping session and the melody session, and to determine whether participants are stimulated to produce more expressiveness with musical melody.

**3.1.3 Dependent variables and independent variables.**

Data analysis examined the effect of independent variables (i.e., motional characteristics including speed, height, distance, and continuity) on the dependent variables (i.e., performed sounds features) and investigated overall differences across two performance sessions. Video recording of figure movements and short interviews were additionally made as the complementary qualitative investigation approach.

**3.2 Participants**

Participants were recruited through email from the University of Sheffield Music Department and other social musical choirs. Thirteen pianists (Male = 1, Female = 12; Mean age = 32.25, SD = 10.05) participated in this study. The pianists were either semi-professional (N = 2, Mean training years = 5, SD = 1) or professional (N = 11, Mean training years = 18.5, SD = 7.34). Participants completed a questionnaire to gather demographic information, details of their musical training and piano accompaniment experience for dancing. Three participants indicated that they “seldom” accompanied dancers.

**3.3 Materials**

**3.3.1 Videos.**

Eight videos were created for this study to investigate four motional character types (speed, height, continuity, and distance) with opposite characteristics for each motional feature (i.e. 4 motion types × 2 extremes). Each video lasted approximately 10 seconds and was characterized with one particular motion type, in which a professional dancer expressed distinct motional characteristics by walking several times. The videos were recorded in an outdoor environment with the picture focusing only on the leg and foot motion of the dancer. The dancer was requested to walk to a rhythm based on a metronome beat while listening through earphones to maintain consistentwalking speed. Four versions of a play list were randomly assigned to participants with a fixed order of videos in each version. Close arrangement of videos with opposite features for one particular motion type was avoided. The description of each condition is as follows:

* *Condition of Speed*: The dancer walked at a comfortable and regular speed led by the digital metronome at approximately 80 beats per minutes (BPM). The videos for fast and slow conditions were edited by accelerating and decelerating the walking speed. Walking speed was increased to approximately 167 BPM for the fast condition and decreased to 50 BPM for the slow condition.
* *Condition of height*: The motional height feature was presented as the dancer raising her legs and foot either higher or lower from the ground (**Figure 1**). The dancer raised one of her feet higher with a short sto*p* for one second and stood on point with the other foot for the higher condition and, for the lower condition, the dancer moved slowly with the foot remaining close to the ground and the knees touching the ground. Motion speed in these two conditions is roughly equal to avoid impact of other motional features on research results.



*Figure 1*. Motional feature of height. Left one is “high” condition and right one is “low” condition.

* *Condition of distance*: The feature of “distance” indicates the physical distance between the dancer and the camera (**Figure 2**). Increasing distance means “leaving away” from the camera while decreasing distance refers to “approaching” to the camera. The two videos were constructed differently from other videos as the pictures were taken from the perspective of the camera while other videos were prepared with the subject in front of the camera moving horizontally (left-right). Speed of movement in both videos was equivalent.

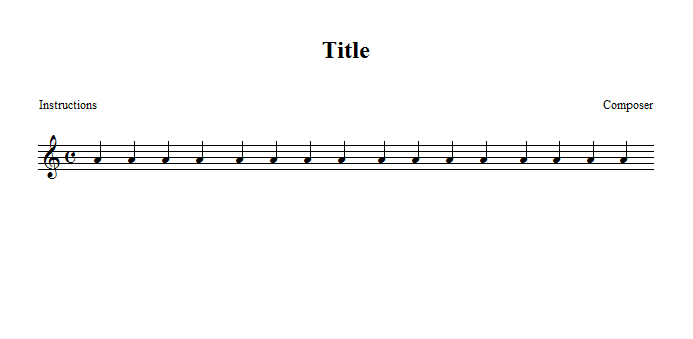


*Figure 2*. Motional feature of direction. Left one is “distance-decreasing” condition and right one is “distance-increasing” condition.

* *Condition of continuity*: The feature of “continuity” refers to the smoothness of movements of the dancer, i.e. walking angularly or walking normally. The speed of movement in two videos is not the same but the speed in the “angular” condition is roughly the same as “slow” condition.

**3.3.2 Musical score.**

Two performance sessions were designed for the study with the first tapping session configured to play a single tone on A3 sixteen times, thus the first musical score piece is written as sixteen quarter notes without bar lines. The second melody session contains a short musical melody piece composed by J.S. Bach as the piece features two melody parts played with both hands. The former melody part is played by the right hand and, in the latter part, melody is played by left hand. Original musical structure is regular (8 bars, 2 phrases) and the musical notes are correspondingly intensive (1 bar ×4 quarter notes) so that pianists had space to re-create the rhythm and change the temporal patterns according to individual expressive intention. All musical notes were written without rhythm patterns, durations, bar lines, articulations, and expressions in the written musical score for this experiment, leaving pitches and chord accompaniment patterns only (**Figure 3**).





# Figure 3. Excerpt 1 & 2 in the experiment

**3.4 Procedure**

Participants read an information sheet and provided their informed consent prior to the experiment. A background information sheet was then completed to gather participants’ level of musical training (i.e. the number of training years, accompaniment experience for dancers, etc.). Participants were directed to sit in front of the MIDI piano while the researcher sat in front of the computer to control recording software. Videos were displayed from an iPad with motional features names in the videos removed and replaced with numbers (from 1 to 8) to avoid supplying semantic meaning and cognitive instructions to participants.

Participants were requested to watch the video first and then to express the movement witnessed in the video by performing, with the verbal instructions like “Could you please express what you saw in the video in your performance?” Instructions such as “imitate the movement” that directly referring to the motional feature were avoided to use, in order to acquire the better improvisation effects. Video viewing and piano practice were limited to twice prior to the recording; however playing the music while watching the video concurrently was prohibited to avoid resonating with walking steps. Participants then played three times with short breaks between the two performances in each condition with finger movements captured by a camera located on the right-side of the piano. The two performance sessions included tapping and playing with participants instructed to complete the tapping session first followed by the playing session. Participants were required to complete two performance sessions and eight conditions in each session with three sets of repeated performances per condition (2 sessions × 8 conditions per session × 3 times per condition). Following experiment completion, participants were encouraged to discuss the performance experience submit opinions related to the most difficult and least difficult video to express. The input was recorded and applied as qualitative data in the further data analysis.

**3.5 Data Analysis**

**3.5.1 Background.**

The examination of audio recordings of music performance has provided a scientific and systematic way to analyse musical expressiveness owing to the development of music-related recording and computing techniques. Gabrielsson (2003) has suggested that the key examination parameters for every single sound are timing, amplitude, and pitch, by which more complex musical structure (tempo, dynamics, intonation, articulation and chord) may be detected and computed. Sonic Visualizer (Cannam, Landone, Samdler, & Bello, 2006) could be utilized as a platform for sound wave visualization, sonification, and editing. MIDI drum or Keyboard (Cook 1995; Sapp,2007) may be utilized to extract the rough timing data from sounds. Beat Root (Dixon 2001a, b) may be applied to track the beat times and estimate the tempo curves (See a review by Goebl, Dixon, & Schubert, 2014).

*MIDI pian*o was utilized in this study for sounds production and audio recording, and *Cubase* software was utilized to translate performed sounds into fundamental data including *onset-time*, *velocity*, *duration*. *Onset-time* was also used to calculate the inter-onset times (IOI) by subtracting the next onset tone with the former one and estimate the musical tempo (larger IOIs refer to lower tempi). *Velocity* was also utilized to estimate musical volume with larger values representing louder sounds while smaller values representing softer sounds. “*Duration*” was used together with IOI to estimate musical articulation by dividing duration values with IOI values: larger values refer to more legato performance while smaller values correspond to more staccato performance (P.S. if the value is larger than 1.00, the performance of first onset tone haven’t been released when the second onset tone is performed).

Other variables are also helpful to analyse the performance data besides above listed variables. *Score time* indicates the onset sequence of performed sounds, which may be utilized to conduct the regression analysis between the velocity and score time. “*Melody position*” was added to distinguish the melody hand or the accompaniment hand. The analysis of performance data will focus on the melody line in this study. The algorithms of each variable are indicated in the following **Table 2.**

# Table 2. The algorithms of IOIs and articulation of performed sounds.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **A** | **B** | **C** | **D** | **E** | **F** | **G** |
| **1** | **Onset-time** | **Duration** | **Key** | **Velocity** | **Scoretime** | **IOI** | **Articulation** |
| **2** | **1.293** | **0.478** | **C3** | **0.31** | **1** | **=A3-A2** | **=B2/F2** |
| **3** | **1.655** | **0.357** | **D3** | **0.27** | **2** | **=A4-A3** | **=B3/F3** |
| **4** | **1.944** | **0.289** | **E3** | **0.35** | **3** | **=A5-A4** | **=B4/F4** |
| **5** | **2.217** | **0.316** | **F3** | **0.42** | **4** | **=A6-A5** | **=B5/F5** |

**3.5.2 Cross-modal relationshipexamination.**

Mean values of IOIs, velocity, articulation were calculated to indicate the tempo, volume, and articulation respectively for each participant. Regression beta values between the velocity and score time (the time sequence of tones that are played on keyboard) were calculated to examine to what extent the volume of performed sounds gradually increased/decreas8ed as the dancer approached or moved further away in the videos. Finally, it is possible to examine the effect of motional feature on the performed sounds features for overall participants after conducting the data analysis for per participant.

* Musical tempo and motion speed: Mean difference of the IOIs between fast, slow, and normal condition will be compared by ANOVA, in order to examine the effect of visualized motional speed on the tempo of musical performance.
* Musical volume and motion distance: Beta values in the distance increasing and decreasing conditions will be conducted one-sample T-test, in order to examine whether pianists adjust the performance volume along with the walking distance. Beta values indicate the positive or negative regression relationship between performed volume and ongoing score time. We predict that beta values in the distance-decreasing condition will be significantly higher than 0 (decreasing walking distance induces rising musical volume); and predict that the beta values in the far away condition will be significantly lower than 0 (increasing distance induces falling musical volume).
* Musical articulation and motion continuity: T-test will be conducted to compare mean differences of musical articulation in the angular condition and slow condition for two performance sessions, in order to examine the effect of motional continuity on the performed musical articulation. The reason of choosing slow condition rather than regular condition is that the walking tempo of the angular and slow condition is roughly the same, which are around 50 steps per minute.

**4. Research Results**

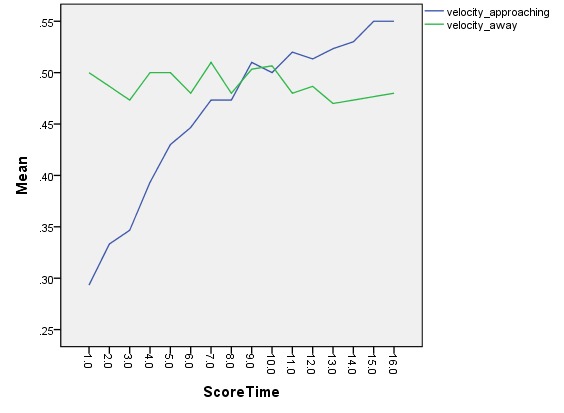
**4.1 Tapping Session Analysis**

**4.1.1 Tapping speed.**

As the IOI value indicates the performance speed (larger value means slower tempo), one-way ANOVA was conducted to compare the mean differences of IOIs between the fast condition, slow condition, and normal condition (as controlled group). Planned contrasts were performed. The results showed that the mean value of IOI in the fast condition (N = 13, Mean = .42, SD = .09) was significantly smaller than the mean value of the normal condition (N = 13, Mean = .61, SD = .12), *F* (1, 12) = 32.85, *p* < .01. Additionally, the mean value of the slow condition (N = 13, Mean = 1.13, SD = .26) was also significantly larger than the normal condition, *F* = 47.09, *p* < .01. That is to say, the tapping tempo in the fast condition is significantly faster than the normal condition, and the tapping tempo in the slow condition is significantly slower than the normal condition. The hypothesis that the motion speed could be transformed into the performed musical tempo has been confirmed in the first tapping session.

**4.1.2 Tapping volume.**

Regression was conducted for per participant in order to test the regression relationshipbetween the performed volume and the walking distance, through defining the velocity as the outcome (the dependent variable) and score time as the predictor (the independent variable). Beta values in the distance-decreasing/increasing conditions were collected to analyse one-sample T-test on SPSS, in order to examine whether all participants indicated significant regression relationshipbetween velocity and score time and whether the relationship is positive or negative. Below **Figure 4** displays how the tapping volume was varied in the distance-decreasing/increasing conditions along with the ongoing tones in the sample of the tapping performance of a participant. For this participant, his/her tapping volume was gradually increased in the distance-decreasing condition along with the ongoing tones, while the changes of volume in the distance-increasing condition were not as significant as the one in the contrasting condition.



*Figure 4.* The trajectory of tapping volume in distance-decreasing condition and distance-increasing condition in correspondence with the score time.

For the distance-decreasing condition, the results of one-sample T-test showed that the mean value of beta values (N = 13, Mean = .33. SD = .44) in regression analysis was significantly higher than 0, t (12) = 2.71, *p* < .05; In terms of the distance-increasing condition, the results indicated that the mean value of beta values (N = 13, Mean = -.22. SD = .22) was significantly lower than 0, t (12) = -3.53, *p* < .01. That is to say, in the tapping session, pianists tended to play increasingly louder when the dancer approached the camera compared to the pianists playing gradually softer when the dancer moved further away from the camera.

**4.1.3 Tapping articulation.**

Paired T-tests were conducted to example the mean difference of articulation between the angular and slow conditions. Larger value of articulation indicates a more legato performance while smaller value of articulation indicates a more staccato performance. The paired T-test results showed that the mean value of articulation condition (N = 13, Mean = .40, SD = .14) was significantly smaller than the mean values of slow condition (N = 13, Mean = .58. SD = .14), t (12) = -3.36, *p* < .01. This means that the tapping performance of participants is more staccato when responding to angular motional feature compared with the slow movements.

**4.1.4 Examination of crossed pairs of mapping.**

Above pairs of examination confirmed the hypothesized pairs of analogies, including musical tempo and walking speed, musical volume and walking distance, and musical articulation and walking continuity. We will further examine whether there is potential occurrence of crossed pairs of analogies. One-way ANOVA was conducted to compare the mean values of musical articulation in three conditions: the high condition, the low condition, and the normal condition. It was found that there was no significant difference of the mean value of articulation between the high condition (N = 13, Mean = .41, SD = .20) and the normal condition (N = 13, Mean = .45, SD = .12), *F* (1, 12) = .30, *p* > .05. However, there is a significant difference of the mean value of articulation between the low condition (N = 13, Mean = .60, SD = .17) and the normal condition, *F* (1, 12) = 9.60, *p* < .01. That is to say, tapping in the low condition is more legato than in the normal condition. In other words, the analogy not only exists between motional continuity and musical articulation, but also appears between physical height and musical articulation: higher movements induced more staccato tapping while movements with lower position induced more legato tapping.

The effect of physical height on the musical volume was examined by comparing the mean difference of velocity between the high condition and the low condition using paired T-test. The results showed that the mean value of velocity in the high condition (N = 13, Mean = .46, SD = .06) is significantly higher than the mean in low condition (N = 13, Mean = .41, SD = .07), t (12) = 2.61, *p* < .05. Beside the influence of walking distance, physical height has an additional impact on the musical volume.

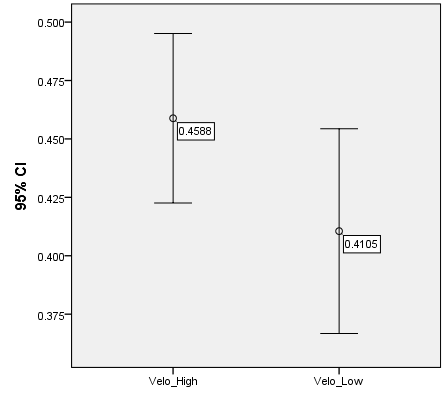
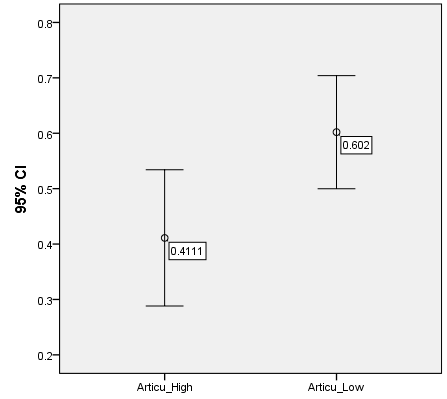
The effect of motional speed on the performed volume and articulation was examined. The result of paired T-test revealed the mean difference of velocity and articulation between the fast and slow conditions, indicating that the mean value of articulation in the fast condition (N = 13, Mean = -.36, SD = .22) was significantly smaller than the slow condition (N = 13, Mean = .58, SD = .14), t (12) = -4.35, *p* < .01; and the mean value of velocity in the fast condition (N = 13, Mean = .45, SD = .07) was significantly larger than the slow condition (N = 13, Mean = .37, SD = .07), t (12) = 4.15, *p* < .01. This research result revealed that the motional speed significantly influenced on the volume and articulation of the tapping: faster walking speed induced louder tapping sounds and more staccato performance, while slower walking speed induced softer tapping sounds and more legato performance.

We further examined the effect of other potential motional features, besides motional speed, on the tapping tempo. The results of the paired T-test revealed that the motional continuity had an additional influence on the tapping tempo, with angular motions inducing quicker tapping tempo (N = 13, Mean of IOI = .91, SD = .33) while normal motions inducing slower tapping tempo (N = 13, Mean = .61 SD = .12), t (12) = 3.94, *p* < .01. However, the effect of motional height (t (12) = .993, *p* > .05) on the tapping tempo was not significant.

In conclusion, there are strong connections in the proposed pairs of analogies, particularly for the associations between motional speed and tapping tempo, motional distance and tapping volume, and motional continuity and tapping articulation in the tapping session. The results revealed several pairs of crossed pairs of analogies including the transformation from motional height to tapping volume and articulation, and the transformation from motional speed to tapping volume and articulation. We additionally found the transformation from other motional features (besides walking speed) to tapping tempo was quite poor: only motional continuity indicated its influence on the tapping tempo. Following **Figures** **5** (from 5-1 to 5-7) summarized the main results of the effect of motional features on performed tones, in a version of displaying error bars.

**Figure 5-4**: crossed mapping of motional height onto tapping volume, which is significant, *p* < .05

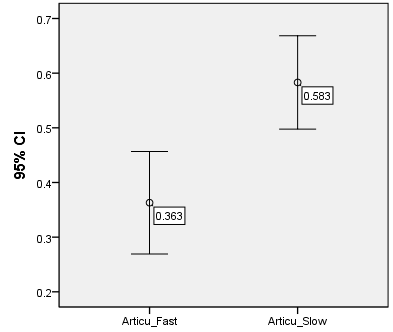
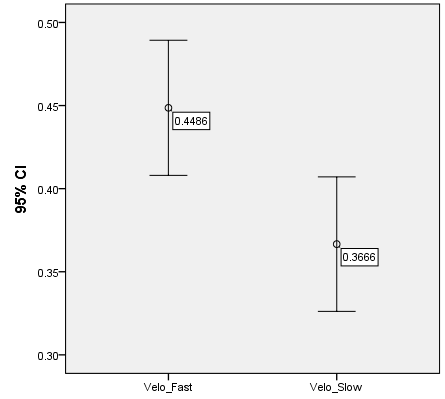
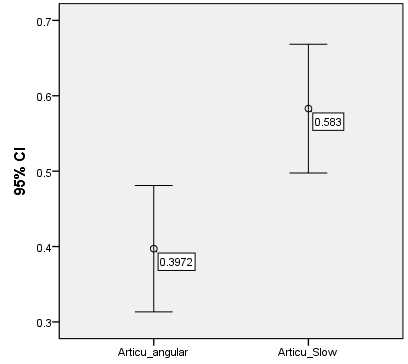
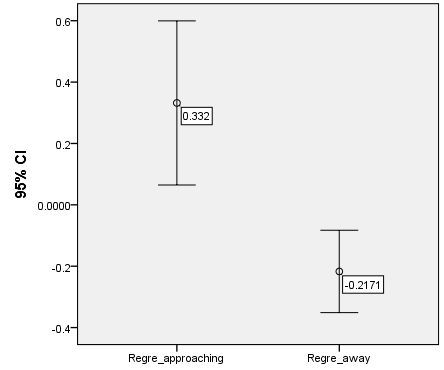
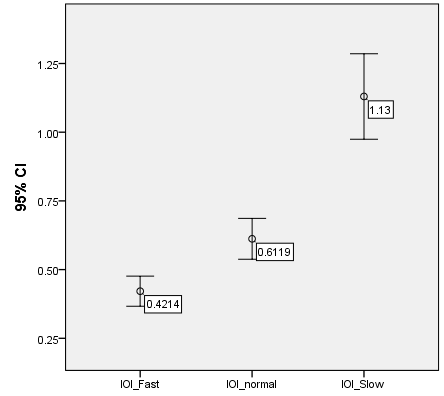
**Figure 5-5**: crossed mapping of motional height onto tapping articulation, which is significant, *p* < .05



**Figure 5-1**: The effect of motional speed on tapping tempo, which is significant, *p* < .05

**Figure 5-2**: The effect of motional continuity on tapping articulation, which is significant, *p* < .05

**Figure 5-3**: The effect of motional distance on tapping volume, which is significant, *p* < .05



**Figure 5-6**: crossed mapping of motional speed onto tapping volume, which is significant, *p* < .05

**Figure 5-7**: crossed mapping of motional speed onto tapping articulation, which is significant, *p* < .05

**4.2 Melody Session Analysis**

**4.2.1 Playing tempo.**

One-way ANOVA was conducted to compare the mean difference of IOIs in three different walking speed conditions, in order to examine the effect of motional speed on performance tempo in the melody session. The results indicated that the mean value of IOIs in the fast condition (Mean = .31, SD = .06) was significantly smaller than the mean in the normal condition (Mean = .42, SD = .10), *F* (1, 12) = 18.52, *p* < .0; while the mean value of IOIs in the slow condition (Mean = .55, SD = .18) was significantly larger than the mean in the normal condition, *F* (1, 12) = 8.30, *p* < .05. The result has confirmed the hypothesis that the motional speed has an influence on the performance tempo.

**4.2.2 Musical volume.**

Regression analysis was conducted for each participant in order to examine the connection between physical distance and musical volume. Beta values in the regression analysis for each participant represents the liner relationshipbetween score time and performed velocity values, which were further made one-sample T-test to examine whether the mean of beta values in the distance-decreasing/increasing conditions was significantly different from 0. The result of one sample T-test revealed that the mean of beta values in the distance-decreasing condition (N = 13, Mean = .35, SD = .34) is significantly higher than 0, t (12) = 3.66, p < .01, and the mean of beta values in the distance-increasing condition (N = 13, Mean = -.41, SD = .28) is significantly lower than 0, t (12) = -5.18, p < .01. That is to say, pianists played gradually louder as the dancer walked towards the camera and played gradually softer as the dancer walked away from the camera. This has confirmed the hypothesis of the connection between motional distance and performance volume.

**4.2.3 Musical articulation.**

Paired T-test was conducted to compare the mean differences of articulation between the angular condition and the slow condition, in order to examine the effect of motional continuity on the performed *articulation* in the melody session. The reason of choosing the slow condition rather than the normal condition is that the walking speed in the slow condition is controlled to be roughly equal with the angular condition. The result of paired T-test showed that the mean value of articulation in slow condition (N = 13, Mean = .96, SD = .18) is significantly larger than the mean value in the angular condition (N = 13, Mean = .66, SD = .34), t (12) = 3.35, *p* < .01. Since larger values of articulation refer to more legato performance, the result revealed that the performance is more staccato in the angular condition than in the slow condition. This has confirmed the hypothesis of the cross-model connection between motional continuity and performance articulation.

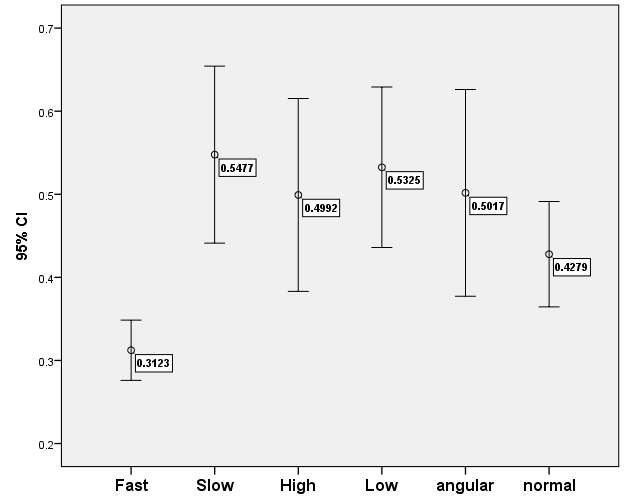
**4.2.4 Crossed-paired connection.**

Besides the examination of previously acknowledged analogies between motional features and musical characteristics, this study is also interested in the examination of other types of analogies between motion and music in order to explore the unusual forms of the transformation from motion to musical sounds as a supplement for previous empirical findings. The first pair of examination on crossed analogies was the effect of physical height on the performed articulation. We used paired T-test to compare the mean differences of musical articulation between the high condition and the low condition, in order to examine the effect of physical height on performed articulation. The result showed that the mean value of articulation in the high condition (N = 13, Mean = .72, SD = .27) was significantly smaller than the mean value in the low condition (N = 13, Mean = .96, SD = .24), t (12) = - 2.22, *p* < .05. That is to say, high movements induced led to a more staccato performance of the melody while low movements induced a more legato performance and this difference was shown to be significant. This result was consistent with the examination results in the tapping session in which tapping was more legato in the low condition while more staccato in the high condition. This result has confirmed the crossed analogies between motional height and musical articulation.

The second pair of examination on crossed analogies of motion and music is the connection between physical height and musical volume. Paired T-test was conducted to compare the mean difference of musical volume in two height conditions. However, the analysis results showed that the differences of volume between the high condition (N = 13, Mean = .45, SD = .06) and the low condition (N = 13, Mean = .46, SD = .07) was not significant, t (12) = - .61, *p* > .05. That is to say, there is no impact of motional height on the musical volume, which is not consistent with the findings in the tapping session.

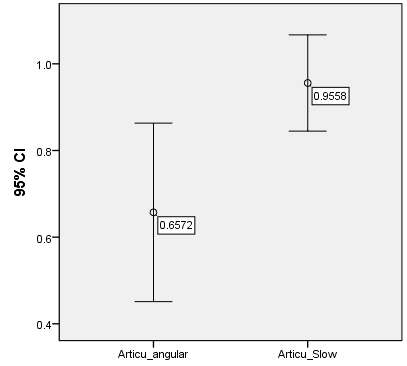
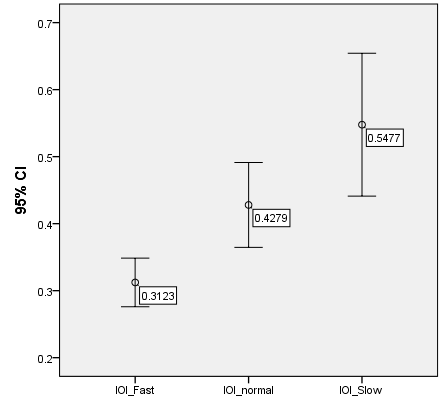
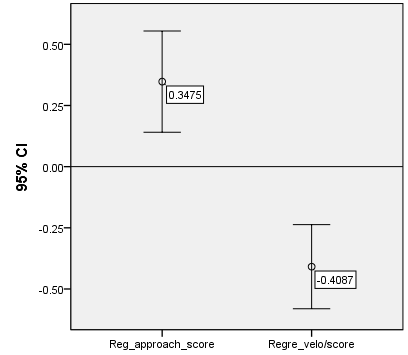
The connection of motional speed and musical volume and musical *articulation* was examined. Paired T-test between the fast condition and the slow condition revealed that the mean value of velocity in the fast condition (N = 13, Mean = .47, SD = .05) was significantly higher than the mean in the slow condition (N = 13, Mean = .42, SD = .07), t (12) = 3.76, *p* < .01. However, the mean value of musical articulation between the fast condition (N = 13, Mean = .81, SD = .33) and the slow condition (N = 13, Mean = .96, SD = .18) was not significant, t (12) = -1.947, *p* > .05. That is to say, there is a transformation from perceived walking speed to produced musical volume whereas not for musical articulation.

We finally examined the transformation from other motional features to musical tempo. Previous examination has indicated the significant effect of motional speed on performance tempo. Paired T-test between the high condition (N = 13, Mean = .50, SD = .19) and the low condition (N = 13, Mean = .53, SD = .16) indicated that the effect of perceived height on produced tempo was not significant, t (12) = -0.98, *p* > .05. The mean difference of melody tempo between the angular condition (N = 13, Mean = .50, SD = .21) and the normal condition (N = 13, Mean = .43, SD = .10) was not significantly either, t (12) = 1.75, *p* > .05 (as can be seen from **Figure 6**). That is to say, only the motional speed influenced performance tempo, while other motional features such as physical height and motional continuity did not influence performance tempo.



*Figure 6*. The effect of different motional features on melody tempo. Only motional speed (the first and second error bar) had the significant impact on melody tempo, *p* < .0; while the feature of physical height (the third and firth error bar) and motional continuity (the fifth and sixth error bar) had no effect on melody tempo.

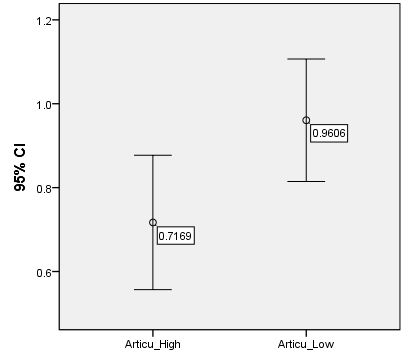
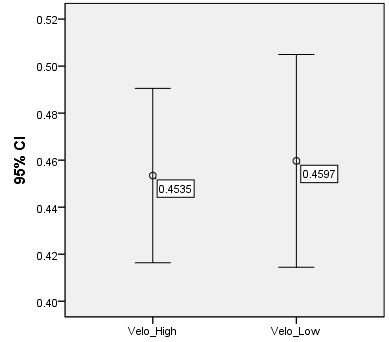
To summarise the analysis on the session of melody performance, it confirmed the proposed pairs of analogies between motional speed and musical tempo, motional distance and musical volume, and motional continuity and musical articulation. We additionally discovered several pairs of crossed analogies. For instance, motional height had an influence on the performance articulation while not on the performance volume; while the motional speed only had an influence on the musical volume while not on the musical articulation. However, there was no crossed effect of motional articulation and motional height on the performance tempo. **Figures 7 (7.1-7.7)** displays the effect of each motion feature on the produced musical characteristics by comparing the mean differences of error bars.



**Figure 7-1**: The effect of motional speed on melody tempo, which is significant, *p* < .05

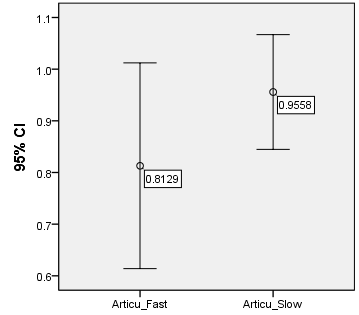
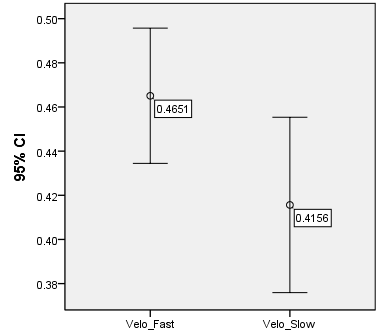
**Figure 7-2**: The effect of motional continuity on melody articulation, which is significant, *p* < .05

**Figure 7-3**: The effect of motional direction on melody volume, which is significant, *p* < .05



**Figure 7-4**: crossed mapping of motional height onto melody volume, which is **not** significant, *p* > .05

**Figure 7-5**: crossed mapping of motional height onto melody articulation, which is significant, *p* < .05



**Figure 7-6**: crossed mapping of motional speed onto melody loudness, which is significant, *p* < .05

**Figure 7-7**: crossed mapping of motional speed onto melody articulation, which is **not** significant, *p* > .05

## 4.3 Overall Results in Two Performance Sessions

Data analysis was conducted for tapping performance and melody performance separately. **Table 3** summarised the effect of motional features on performed musical attributes, indicating that the tapping performance slightly differ from the melody performance. These two groups of data shared large similarities including the speed/tempo analogy, continuity/articulation analogy, distance/volume analogy, and potential crossed mappings such as the speed/volume mapping and the height/articulation mapping.

**Table 3**: Effect of each motional feature on the produced sounds.

|  |  |  |
| --- | --- | --- |
| **Motional features** | **Effects on performance** | **Notes** |
| Speed | Faster movements induce faster, louder, and *more staccato*\* performance  Slower movements induce slower, softer, and more *legato*\* performance | \* Only detected in tapping performance |
| Height | Higher movements induce more staccato and *louder*\* performance  Lower movements induce more legato and *softer*\* performance | \* Only detected in tapping performance |
| Distance | Decreasing distance induces gradually louder performance  Increasing distance induces gradually softer performance |  |
| Continuity | Smooth movements induce more legato performance  Angular movements induce more staccato performance |  |

**5. Discussion**

This study has investigated the connection between motional and musical features in the context of a musical performance. Drawing on the previous studies, current research not only examined several analogies that are well demonstrated in motion-induction studies, but also explored potential mappings occurring on top of or in addition to these analogies. The results confirmed the applicability of previously demonstrated analogies in the musical production context, with the evidence of mapping of motional speed onto performance tempo, the mapping of motional distance onto performance volume and the mapping of motional continuity onto performance articulation. This study also revealed that the motional height had an impact on the musical articulation (higher/lower movement associated with more staccato/legato performance respectively), and the motional speed had an effect on the musical volume (quicker is louder, slower is softer). By comparing the results in two different performance sessions, performance on single note tapping tended to more likely be influenced by motional feature, as compared to performance on the melody: motional speed affected tapping articulation and motional height affected tapping volume. Interestingly, the performance tempo was strongly constrained and affected by the motional speed: in the tapping session, motional continuity affected the tapping tempo in addition to the motional speed; while in the melody session only motional speed affected the musical tempo results, whereas other motional features consequently did not.

**5.1 Connections between Motional Feature and Musical Feature**

**5.1.1 Mapping of motional feature onto musical tempo.**

The first pair of analogy of motion and music that was examined in this study was the connection between *motional speed* and *performance tempo*. The study found that the walking speed of the dancer in the video significantly influenced the tempo of performed tapping tones and melody. Previous behavioural studies have largely demonstrated this connection in human synchronised, accompanied and induced movement speed (e.g. walking, exercising, tapping) with musical sounds. Concerning the underlying mechanism, the most widespread explanation suggested by these studies was the *arousal mechanism*. This ascertains that musical sounds with faster tempos could induce higher arousal levels, which in turn works as a mediator to affect human body movements. This has been subsequently supported further by music inducing physiological responses in listeners (Hodges, 2010) and listeners’ reporting experiencing affective responses (Husain, Thompson, & Schellenberg, 2002). Another mechanism cited refers to the “*entrainment*” effect, in which the perception of the musical pulse underlying the external musical stimuli has an impact on the internal pulse of human bodily movements (Merker, Madison, & Eckerdal, 2009), alluding to the fact that people could synchronise their movement with musical sounds. Although these explanations were proposed in the motion-induction studies and cannot be directly used to explain the mechanism of this study, it has provided insights into the theoretical principles underlying the connection between motional speed and musical tempo. The results established in the current study suggested that this mechanism-based connection could occur with a reverse manner.

This research revealed that other motional features could barely affect the musical tempo. The only connection was found as the mapping between the *motional continuity* and the *musical tempo* during the tapping session, with faster musical tempo observed in the angular condition and slower musical tempo noted during the normal condition. However, this effect disappeared in the melody session. An explanation for observed mapping in the tapping session while not in the melody might stem from the characteristics difference within musical materials. As the angular movement contains three sub-steps in the completion of one step, participants could easily transfer these subtle pulses into the tapping on single tones, whereas hardly express this triple structure in a melody that contains four tones in one bar. This result not only strongly supported the evidence of intrinsic connection between motional speed and musical tempo, as demonstrated in previous movement production studies, but also indicated that the connection is somewhat stubborn and strongly combined. In contrast, other musical features were affected by not solely one motional feature. For example, musical articulation was affected by both motional continuity and motional height; and musical volume was influenced by both motional distance and motional speed.

**5.1.2 Mapping of motional feature onto *musical volume.***

The second pair of analogy that was examined in the current study was the connection between *motional distance* and *musical volume*. The study found that decreasing distance was associated with a gradually louder performance, while increasing distance was associated with a gradually softening performance. This mapping was consistent with humans everyday experience--the closer distance of two physical objects allows sounds to be louder, while the decreasing distance of two objects causes sounds to be much quieter. The fact that pianists utilized this knowledge in their performances suggests that humans think about musical sounds by associating them with physical experiences, thus supporting the ecological perspective of Clarke (2011) on musical cognition. Favoured by the ecological way of listening, Dibben (2001) suggested that the listening for musical sounds was no longer just perceptual information of musical attributes such as pitch, timbre, or dynamics (this is argued as musical listening by Gaver, 1993a). Instead, listeners can perceive specific meaning in the musical sounds such as physical source, acoustic characteristics, emotional content, even social features.

This research also revealed an effect of the *motional speed* on *musical volume* in both performance sessions. Faster motional speed is associated with both louder music and quicker tempos while slower motional speed is associated with both softer music and slower tempos. This finding has recognised another phenomenon regarding the close link between *musical temp*o and *musical volume*. These two musical features are regularly associated in the studies relative to the effect of musical features on human bodily movement or the investigation of expressive musical performance. Edworthy and Waring (2006) investigated the influence of volume and tempo on exercise performance, and found that the combination of faster musical tempo and louder musical volume was the most appropriate pairing to induce the optimal physical exercise outcome.. Langner and Goebl (2003) conducted a research on expressive performance of two compositions by Chopin and Schubert, through the analysis of musical volume and musical tempo. This study confirmed that performance volume and performance speed are often correlated: performers tended to perform louder during the height of the musical tempo while perform much softer when the musical tempo was at its minimum point. Bresin and Friberg (2000) investigated the performed musical volume and speed by referring to its relationship with distinct emotional intentions. This study found that a performance of musical pieces with “anger” and “happy” intentions tended to be quicker and louder while performances with “tender”, “fear”, and “sad” emotions tended to be slower and softer, as compared with “no-expression” condition.

**5.1.3 Mapping of motional feature onto musical articulation.**

This study also indicated another analogy between *motional continuity* and *musical articulation*. In order to control the influence of motional speed on the results, we compared the difference of musical articulation between the angular condition and the slow condition, due to the approximately equal walking speed. The results indicated that pianists tended to play with a staccato performance in the angular conditions, while play with legato performance under the normal conditions. However, few empirical studies have systematically examined this analogy; they investigated the musical-articulation-related motion and motion-related musical sounds separately. Eitan and Granot (2006) examined how listeners could associate imagined motion patterns with musical sounds varying with melody contour, pitch internal, and musical articulation. This study found that listeners associated the difference in musical articulation with changes in imagined distance: the gradual increase of staccato induced the imagined motion moving further way. What we have recognized about the motional-continuity-related music could be seen from the metaphorical description of musical structure, such as “uneven rhythm”, “fluent rhythm, or “galloping rhythm” (Gabrielsson, 2011).

The underlying explanation may be the fundamental capacity of pianists to imitate the motional regularity in their performance. The angular motion is characterised with un-continuous points in the action while the slow motion is completed without any intervals and pauses, therefore pianists could easily imitate this character of continuity or un-continuity in their execution of playing with their fingers. This stage of transformation into performance does not need high levels of information processing or cognitive concepts. Another stage of transformation from motion into musical sounds requiring higher levels of mental computation process, relates to the theoretical perspective regarding motion and emotion in music. Gabrielsson (2011) has summarised the relationship between musical articulation and perceived emotion. He suggested that a staccato performance may be associated with a perceived feeling such as happiness, energy, activity, fear and anger; while legato is usually associated with perceived emotions such as sadness, tenderness, solemnness, longing and softness. Drawing on this finding, we suggest that the angular motion and the slow movement of the dancer shown in the video might evoke distinct emotions in pianists, which in turn generated the difference of articulation patterns in their performance. However, this study failed to detect the subjective feeling of participants in the perception of the visual content. The emotional response will be taken into account in the future research design projects.

Additionally, this study has also established the connection between *motional height* and *musical articulation* in the tapping and melody sessions. Pianists tended to play with staccato tones, in response to the high movements while subsequently playing with legato tones when responding to the low movements. One explanation for this difference might be detected from the video recording of the finger movement of pianists during their performance. The video recordings revealed that the finger movement of pianists in the high condition is much higher than the finger movement in the low condition. Pianists tended to rise their finger (sometimes together with the wrist) to play the tones in the high condition, while tending to keep the scale of finger movement much smaller and pause much longer on the keyboard in the low condition. That is to say, pianists tended to imitate the movement features of dancers in their finger movements on the keyboard, treating their finger movements as a mirror of foot movements to express the physical height and treating the keyboard as a mirror of the ground to express the staying duration of fingers on the keys.

**5.1.4 Comparisons between tapping session and melody session.**

The similarities between the tapping session and the melody session are as follows: (1) both performance sessions demonstrated the proposed analogies such as motional speed and performance tempo, motional distance and performance volume, motional continuity and performance articulation (2) both sessions indicated several pairs of potential analogies, for instance, motional height and musical articulation, motional speed and musical loudness. In addition, there are few recognised differences between the tapping session and the melody session: (1) the motional height only displayed its influence on the musical volume in the tapping while not in the melody session; (2) the motional speed only exhibited its impact on the musical articulation in the tapping session while not in the melody session. The original idea to design two performance sessions is in order to compare the factorial deviations in distinct musical material circumstances. The similarities in both performance sessions demonstrated the character of commonality and prevalence of proposed analogies in various experimental designs, hereby supporting the convincing connection between music and motion.

Initially, it was found that the effect of motional height on the musical volume in the tapping session but not during the melody session. This transformation might be explained by the study of Leman et al. (2013) who found the relationship between the vigour of physical movements and musical expressiveness. This research demonstrated that musical sounds perceived as more “activating” evoke larger synchronized walking step size as compared to more “relaxing” music with the same music tempo and musical volume. In the current study, the movements with a high vertical height could be classed as motion with greater vigour, compared with movements with a low vertical height, therefore the motion with greater vigour (high condition), evoked performance with greater activation in musical performance (i.e. louder sounds). However, this assumption fails to explain the non-effect observed during the melody session. The reason for this could be that the musical melody contains more complex musical materials and textures, thus gives rise to the possibility of more outcomes. To a certain extent, this might attenuate the transmission from movement vigour (height) to musical vigour (volume).

Moreover, it was alluded to that the effect of motional speed on the musical articulation in the tapping session was observed, however not in the melody session. To be more specific, faster movements were associated with more staccato tapping, while slower movements were associated with more legato tapping. The association between musical tempo and musical articulation has been investigated rigorously in previous studies. For instance, Geringer, Madsen, Macleod, and Droe (2006) have examined the effect of musical articulation on the perception and preference of musical tempo. Two pieces of music from experts were manipulated with three kinds of tempo modulation patterns (gradually increasing, gradually decreasing and no change) and two kinds of articulation (legato and staccato). The results ascertained that in the condition of increasing tempo manipulations, all staccato performances were perceived as larger and increasing in musical tempo more than in the legato performance; this is also observed in the music with no-change manipulation, the staccato performance was perceived as slightly increasing in tempo. Although this study only indicated the relationship between staccato articulation and fast musical tempo, it still assists in the explanation of the association of faster movements with the staccato performance in the tapping session. However, it cannot effectively advocate the association of the legato performance with the slower performance. The reason for an absence of an effect of motional speed on musical articulation in the melody session is unknown. One possible explanation could be, as is indicated in Section 5.1.1, the association between motional speed and musical tempo is much stronger than is seen in other pairs of analogies, hence motional speed failed to affect the performance articulation in the melody session.

**5.2 Embodied Perspective on Musical Expression**

The research findings have supported the theory of embodied music cognition, by investigating the expressiveness of performed sounds and its relationship with visualized physical movements patterns. The performance of either a single tone or a melody by pianists was shown to be expressive and dynamic in response to distinct visual perceptions, varying with tempos, volumes, articulations, and even rhythmic structures. Embodied cognition argues that human bodily movements play a substantial role in shaping the mental representations of sounds. This study has implied that the musical expressiveness is not a virtual and subjective event created in the brain of a musician, nor a simple transcription of musical notation into auditory events as an information computing process; instead, it requires cognitive work to connect the desired sensory outcomes (volume, articulation, or timbre) with the corresponding motor actions. As Stevens (2014) has previously suggested, the expressiveness of musical performance is no longer only an auditory perceptual event; it is a multi-dimensional perceptual phenomenon involving the bodily movement from both a motoric and visual perspective. According to the action-perception coupling theory, this connection might stem from the gestural movements related to the production of the sound. As musical performance requires high amounts and expert levels of motor controls of finger and wrist movement in the production of sounds with specific features, these movement features have a significant influence in the formation and shaping of performers' cognition towards the sounds.

**5.3 Significance for Musical Pedagogy and Musical Technology Development**

**5.3.1 Expressive musical performance.**

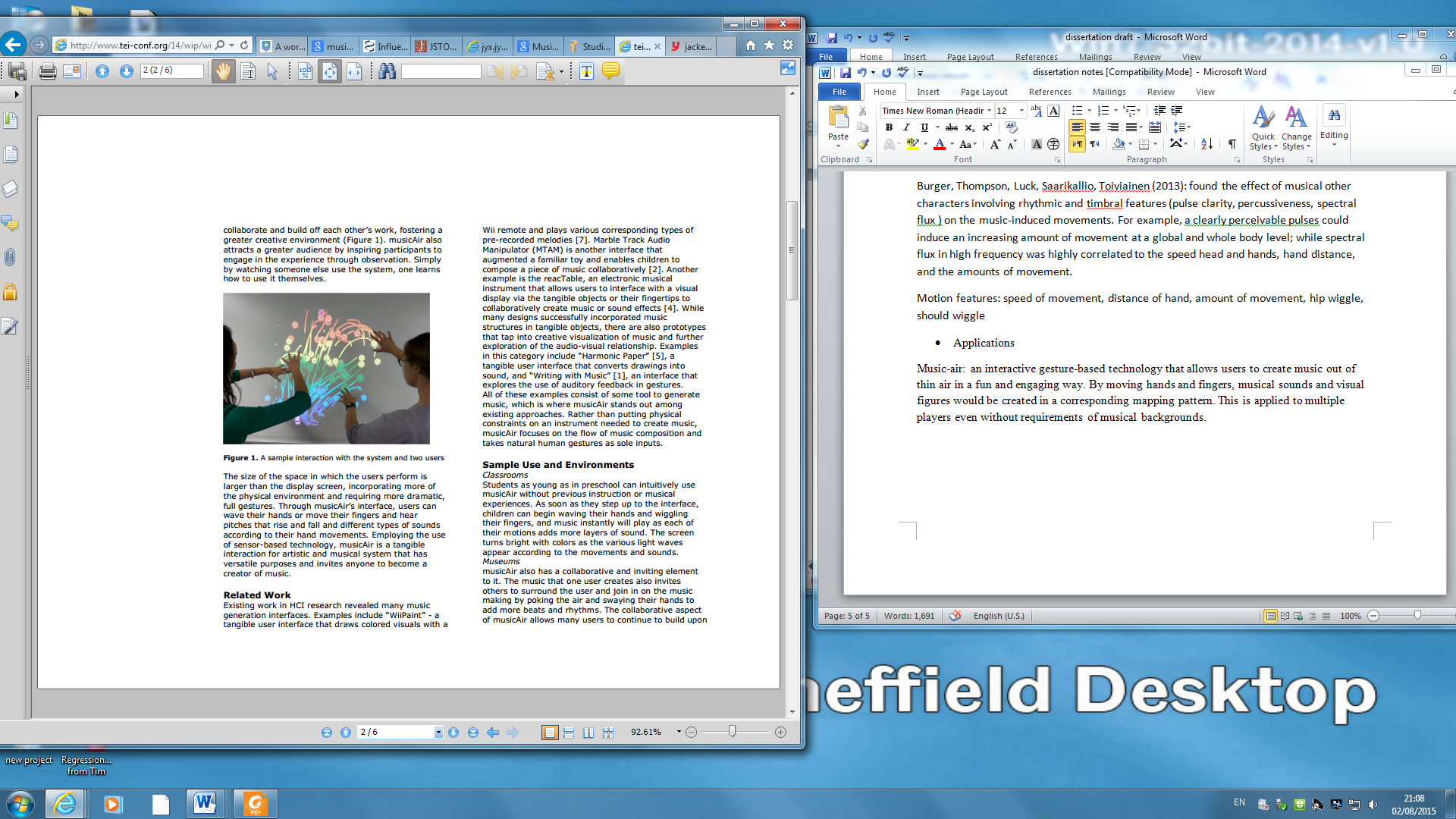
This research has several implications for musical pedagogy. The utilisation of motion-related descriptors might be beneficial to stimulate the expressive performance and improvisation abilities of students. As an example of this, the research results indicate that pianists were capable of playing the same piece of musical material with distinct expression by various musical tempos, gradually changing musical volume and distinct rhythmic patterns according to the perceptual visual contents. In terms of the verbal instructions that are given to elicit students’ expressive performance, the utilisation of imagery and metaphors by teachers seems to be quite prevalent; this is an attempt to evoke certain emotions towards the musical content (Woody, 2002). Woody (2002) has reviewed theories of emotion, imagery and metaphor within music pedagogy and concluded that the metaphors of musical motion such as “flowing” and “bouncing” are fundamentally important in the adequate understanding of the relationship between felt emotion and the production of musical sounds. Guile (2009) demonstrated that the application of the theory of effort by Laban into a musical learning context. After conducting an extensive training session on children, he found that the concept of movement effort feature is beneficial for their expressive and emotional musical performance. Therefore, it is entirely possible for music teachers to instruct students with certain motional patterns and encourage them to play using their own expression and interpretation, or even to change the musical structure, break the phrasing and play around with improvisations.

**5.3.2 Perception of musical attributes.**

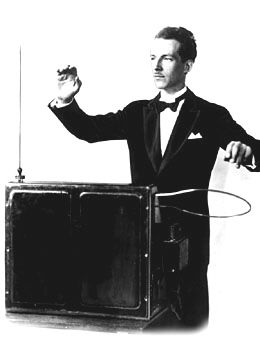
Musical teachers could teach students to feel the musical structure and get the basic understanding of the distinct musical features through moving in conjunction with sounds. Dalcrozian Eurythmics taught students to feel the coordination of musical materials and the shape of musical phrasing by instructing them to bounce a ball together and in coordination within groups (see a review of Davidson, 2011). In order to enhance the rhythmical detection ability of students, it is possible for musical teachers to guide students in feeling the pulse underlying the musical metrical structure by making synchronised movements such as tapping on fingers or foot along with the musical beat. It is also possible for music teachers to explain the temporal structure of music by making the musical tempo gradually change and using motional descriptors such as “slowing down from running to walking” to stimulate students' imagination, rather than lecturing them on the standard musical theories. In terms of the perception of musical pitches, musical teachers could inertly guide students to move their hand accordingly, rising or falling in the vertical height along with the melody contour. To feel the musical volume, musical teachers could instruct students to knock the table or a drum with differing efforts, students would feel the sounds become louder if they knock with harder efforts and sound would subsequently become softer when using little efforts. This approach has made huge contributions to the early education of children, in order to help them construct the knowledge of musical characteristics. The famous German composer and educator Carl Orff (1895-1982) has create a new musical pedagogy called “Orff-Schulwerk” (Orff and Walter, 1963) which is mainly concerned with the feeling and learning of music through making sounds with the body of children or through coordinated group activities. This teaching strategy has been widely used in schools and music classes globally. Additionally, this approach has been demonstrated its effectiveness regarding *social* functioning, in terms of positive effects on children in the circumstance of group learning and interactions (De Bruyn, Moelants, Coussement, & Leman, 2009). It was found that the synchronisation movements of children were much better when they were dancing in groups.

**5.3.3 Musical techniques.**

This research suggests the importance of developing creatively technical musical education materials and tools. Traditionally, musical educational material refers to musical notation and scores, as well as the hard-copy of musical writings. Recent gesture-sound interactive software and creative musical instruments has applied the knowledge of cross-modal mappings between music and motion into the real-world teaching context. For example, MusicAir, which was designed by Kwok, Lee, Okerlund, Zhu, and Shaer (2014), allows auditory-movement interaction as bodily movements leads to sounds being created. Based on the corresponding mapping between motion and sounds coded in the programme, this techniques allows players to create musical sounds and visual signals that they prefer purely by moving their hands and fingers (As indicated in **Figure 9**), which could be applied to multiple users without the requirements of musical backgrounds. Similar applications can be seen, such as BeSound (Volpe, Varini, Addessi, and Mazzarino, 2012), which is designed for children to explore the musical elements of composition such as rhythm, melody, and harmony by imitating the movement features of an object. This research indicated the importance of body-based interactive approaches in the musical education required during childhood. Additionally, the mappings of musical pitch and physical elevation, and musical volume and distance have been applied into the design of a digital instrument called the “Leon Theremin”. This was established in the early 20th century. It is played without physically touching the instrument with the hands: a higher pitch was played by moving the right hand closer to the pitch antenna, while louder notes are played by moving the hand away from the volume antenna with left hand (As displayed in **Figure 10**).



*Figure 8.* Sample of the product “*Music Air*”



*Figure 9***.** Instrument “*Lenon Theremin”*

**5.4 Limitations and Future Research**

This study has several limitations. Initially, it failed to design a perception task that detects the subjective views or emotional responses of pianists towards the visual content. As indicated earlier, there may be a mediator between the perception of motional patterns and its actual outcomes (i.e. performed sounds with distinct characteristics), which is the perceived emotions. According to the two-dimensional affective model by Russell (1980), it is possible to assume that the motional patterns might induce certain emotions which are either higher (or lower) in arousal or higher (or lower) in valence, which in turn have an impact on their expression of musical performance. Further research may add a perception study after pianists observe the visual stimuli, with several adjectives of distinct emotions listed for performers to indicate their rating of perceived emotion. According to Posner, Russell, and Peterson (2005) and Russell (1980), these adjectives will cover both the dimension of valence, that indicates the pleasure-displeasure continuum and the dimension of arousal that indicates the activation-deactivation continuum. In conjunction with the adjective descriptor of emotions, it is also possible to include adjectives that detect performers cognitive, social and even cultural opinions of the perception of the visual stimuli, such as being foolish or wise, feminine or masculine, pretty or ugly and cold or hot etc (see Eitan and Timmers, 2010).

The design of motional parameters has several limitations. In this study, four pairs of motional features were investigated its effect on performed music, each feature was divided into opposing patterns, namely motional speed (fast, slow), height (high, low), distance (increasing, decreasing), and continuity (angular, normal). It is conclusive that there are, in fact, more possibilities in the manipulation of motional features. For instance, Eitan and Granot (2006) categorised the motion patterns with specific movements such as "walking, running, jumping, crawling, and falling or sliding" (p.227); and added another factor of "energy" to indicate how many efforts each motion type was involved. Their approach has its own limitations in terms of failing to parametrically control specific motional patterns. Despite of this, it has inspired the future experiment design: (1) The movement in the video could be observed as normal human movements in daily life; (2) the change of one motional characteristic can be modulated, such as gradually increasing or decreasing the walking speed.

This research failed to examine the real gestural movements of pianists in their musical performance. Previous empirical approaches of examining the musical expressiveness of performed sounds has taken into account the gestural features of performers in their production of musical sounds. They found that there was a close link between the gestural features of performers and the musical characteristics of produced sounds. Further studies could establish further the motion-tracking techniques and examine the motional features of wrists and arms in their production of music and its correlation with sound features. This is the customary experimental approach to examine the expressive musical performance.

Future follow-up studies could design a recognition task for the pianists who have participated in this study, or conduct a perception study for listeners containing both non-musicians and musicians. The recognition task aims to examine whether pianists who are involved in this study have the capacity to recognise their own performance and indicate the audio recording with the corresponding motional pattern in the visual stimuli. The perception study may be designed as a listening task by using the audio recordings in this study to detect the perceived motional patterns. This listening test is specifically targeted at new participants containing musicians and non-musicians, aiming to examine the effects of musical expertise on their perceptual differences of musical sounds varying with distinct characteristics. It may also examine the consistency between perceived motional patterns by listeners and original corresponding motional patterns by performers.

**6. Conclusion**

This study has examined the cross-modal association between motion and music in a musical performance context. It found that musicians were capable of transforming the visualised motional patterns as observed in the video to their creative and improvised performance of both single tones and a short piece of melody with distinct expressive interpretations. The results of this study have not only confirmed the numerous and well documented pairs of motion-music analogies (speed/tempo, continuity/articulation, distance/volume), but also indicated additional interactions, such as the effect of motional height on musical articulation and the effect of motional speed on musical volume. These results extended previous empirical evidence of motion-music mapping into a creative and improvised performance environment with more systematic variation of motion variables.

Previous empirical studies that investigated the relationship between gestural movements and musical expressiveness have been mainly concerned with the quantitative characteristics of motion, such as the amounts or the scale of movements in response to music. This study extended the previous evidence, with a more detailed demonstration, in terms of expression of specific musical attributes in response to particular motional features. This study contributes to the embodied perspective on expressive music performance. Pianists perceive, describe, and understand musical sounds by referring to bodily experience, which in turn helps them to understand the physical movement and transform it into creative and expressive performance.

**References**

Antle, A. N., Corness, G., & Droumeva, M. (2009). What the body knows: Exploring the benefits of embodied metaphors in hybrid physical digital environments. *Interacting with Computers*, *21*(1), 66-75.

Bangert, M., Peschel, T., Schlaug, G., Rotte, M., Drescher, D., Hinrichs, H., ... & Altenmüller, E. (2006). Shared networks for auditory and motor processing in professional pianists: evidence from fMRI conjunction. *Neuroimage*, *30*(3), 917-926.

Bresin, R., & Friberg, A. (2000). Emotional coloring of computer-controlled music performances. *Computer Music Journal*, *24*(4), 44-63.

Brodsky, W. (2001). The effects of music tempo on simulated driving performance and vehicular control. *Transportation research part F: traffic psychology and behaviour*, *4*(4), 219-241.

Burger, B., Saarikallio, S., Luck, G., Thompson, M. R., & Toiviainen, P. (2013b). Relationships between perceived emotions in music and music-induced movement. *Music Perception: An Interdisciplinary Journal*, *30*(5), 517-533.

Burger, B., Thompson, M. R., Luck, G., Saarikallio, S., & Toiviainen, P. (2013). Influences of Rhythm- and Timbre-Related Musical Features on Characteristics of Music-Induced Movement. *Frontiers in Psychology*, *4*, 183. doi:10.3389/fpsyg.2013.00183

Cannam, C., Landone, C., Sandler, M. B., & Bello, J. P. (2006, Oct. 8-12). The Sonic Visualiser: A Visualisation Platform for Semantic Descriptors from Musical Signals. In: *proceeding of the 7th International Conference on Music Informational Retrieval (ISMIR 2006)* (pp. 324-327), Victoria, Canada.

Caramiaux, B., Bevilacqua, F., & Schnell, N. (2010). Towards a gesture-sound cross-modal analysis. In *Gesture in Embodied Communication and Human-Computer Interaction* (pp. 158-170). Springer Berlin Heidelberg.

Casasanto, D. (2009). Embodiment of abstract concepts: good and bad in right-and left-handers. *Journal of Experimental Psychology: General*, *138*(3), 351-367.

Casasanto, D., & Henetz, T. (2012). Handedness shapes children’s abstract concepts. *Cognitive Science*, *36*(2), 359-372.

Clarke, E. (2001). Meaning and the specification of motion in music. *Musicae Scientiae*, *5*(2), 213-234.

Clark, E., Doffman, M., Timmers, R., (in preperation), Creativity, Collaboration and Development in Jeremy Thurlow’s *Ouija* for Peter Sheppard Skærved.

D'ausilio, A., Altenmüller, E., Olivetti Belardinelli, M., & Lotze, M. (2006). Cross‐modal plasticity of the motor cortex while listening to a rehearsed musical piece. *European Journal of Neuroscience*, *24*(3), 955-958.

Davidson, J. W. (1993). Visual perception of performance manner in the movements of solo musicians. *Psychology of music*, *21*(2), 103-113.

Davidson, J. W. (1994). What type of information is conveyed in the body movements of solo musician performers. *Journal of Human Movement Studies*, *6*, 279-301.

Davidson, J. W. (2001). The role of the body in the production and perception of solo vocal performance: A case study of Annie Lennox. *Musicae Scientiae*, *5*(2), 235-256.

Davidson, J. W. (2002). Understanding the expressive movements of a solo pianist. *Musikpsychologie*, *16*, 9-31.

Davidson, J. W. (2007). Qualitative insights into the use of expressive body movement in solo piano performance: a case study approach. *Psychology of Music*, *35*(3), 381-401.

De Bruyn, L., Moelants, D., Coussement, P., & Leman, M. (2009). An interactive sound recognition game for primary school children. In *4th Conference of the European Network of Music Educators and Researchers of Young Children* (pp. 105-106). Università di Bologna. Facoltà di Scienze della Formazione.

Dibben, N. (2001). What do we hear, when we hear music?: Music perception and musical material. *Musicae Scientiae*, *5*(2), 161-194.

Dibben, N., & Williamson, V. J. (2007). An exploratory survey of in-vehicle music listening. *Psychology of Music*, *35*(4), 571-589.

Dixon, S. (2001a). Automatic extraction of tempo and beat from expressive performances. *Journal of New Music Research*, *30*(1), 39-58.

Dixon, S. (2001b, September). An interactive beat tracking and visualisation system. In A. Scholoos, R. Dannenberg, and P. Driessen (Eds), *Proceedings of the2001 International Computer Music Conference. Havana, Duba* (pp. 215-218). San Francisco, CA: International Computer Music Association.

Dolscheid, S., Shayan, S., Majid, A., & Casasanto, D. (2013). The Thickness of Musical Pitch Psychophysical Evidence for Linguistic Relativity. *Psychological Science*, *24*(5), 613-621.

Drost, U. C., Rieger, M., Brass, M., Gunter, T. C., & Prinz, W. (2005a). Action-effect coupling in pianists. *Psychological Research*, *69*(4), 233-241.

Drost, U. C., Rieger, M., Brass, M., Gunter, T. C., & Prinz, W. (2005b). When hearing turns into playing: Movement induction by auditory stimuli in pianists. *The Quarterly Journal of Experimental Psychology Section A*, *58*(8), 1376-1389.

Edworthy, J., & Waring, H. (2006). The effects of musical tempo and loudness level on treadmill exercise. *Ergonomics, 49*(15), 1597-1610.

Eerola, T., Luck, G., & Toiviainen, P. (2006). An investigation of pre-schoolers’ corporeal synchronization with music. In *Proceedings of the 9th International Conference on Music Perception and Cognition* (pp. 472-476). (Bologna: ICMPC–ESCOM).

Eitan, Z., & Granot, R. Y. (2006). How music moves. *Music perception: An Interdisciplinary Jounal, 23*(3), 221-248.

Eitan, Z., & Timmers, R. (2010). Beethoven’s last piano sonata and those who follow crocodiles: Cross-domain mappings of auditory pitch in a musical context. *Cognition*, *114*(3), 405-422.

Elliott, D., Carr, S., & Orme, D. (2005). The effect of motivational music on sub-maximal exercise. *European Journal of Sport Science*, *5*(2), 97-106.

Evans, K. K., & Treisman, A. (2010). Natural cross-modal mappings between visual and auditory features. *Journal of vision*, *10*(1), 1-12.

Friberg, A. (2004, October 28-30). A fuzzy analyzer of emotional expression in music performance and body motion. In J. Sundberg & B. Brunson (Eds.) *Proceedings of Music and Music Science,* (pp.28-30),Stockholm, Sweden.

Friberg, A., & Sundberg, J. (1999). Does music performance allude to locomotion? A model of final ritardandi derived from measurements of stopping runners. *The Journal of the Acoustical Society of America, 105*(3), 1469-1484.

Gabrielsson, A. (1973). Similarity ratings and dimension analyses of auditory rhythm patterns. 1. *Scandinavian Journal of Psychology*, *14*(1), 138-160.

Gabrielsson, A. (1995). Expressive intention and performance. In R.Steinberg (ed.), *Music and the mind machine* (pp. 35-47). Springer-Verlag, Berlin, Heidelberg.

Gabrielsson, A. (2003). Music performance research at the millennium. *Psychology of music*, *31*(3), 221-272.

Gabrielsson, A. (2011). The relationship between musical structure and perceived expression. In Hallam, S., Cross I., & Thaut, M., (Eds.), *Oxford Handbook of Music Psychology*. Oxford University Press. Oxford, UK.

Gaver, W. W. (1993). What in the world do we hear?: An ecological approach to auditory event perception. *Ecological psychology*, *5*(1), 1-29.

Geringer, J. M., Madsen, C. K., MacLeod, R. B., & Droe, K. (2006). The effect of articulation style on perception of modulated tempo. *Journal of Research in Music Education*, *54*(4), 324-336.

Godøy, R. I., Haga, E., & Jensenius, A. R. (2006). Playing “air instruments”: mimicry of sound-producing gestures by novices and experts. In *Gesture in Human-Computer Interaction and Simulation* (pp. 256-267). Springer Berlin Heidelberg.

Guile, L. M. (2009). *Motion and Meaning in Music: Practical Investigations Into the Use of Laban's Theory of Effort as a Tool in Music Practice*. (Doctoral dissertation, University of Sheffield, Department of Music).

Hodges, D. (2010). Psychophysiological measures. In Juslin, P. N., & Sloboda, J. A. (Eds.), *Handbook of music and emotion: Theory, research, applications (p.279-311). Oxford,* Oxford University Press.

Hofmann, A., & Goebl, W. (2014). Production and perception of legato, portato, and staccato articulation in saxophone playing. *Frontiers in psychology*, *5*. 1-10.

Himberg, T., & Thompson, M. R. (2011). Learning and synchronising dance movements in South African songs–Cross-cultural motion-capture study. *Dance Research*, *29*(2), 303-326.

Husain, G., Thompson, W. F., & Schellenberg, E. G. (2002). Effects of musical tempo and mode on arousal, mood, and spatial abilities*. Music Perception*, 20(2), 151-171.

Johnson, M. L., & Larson, S. (2003). " Something in the Way She Moves"-Metaphors of Musical Motion. *Metaphor and symbol*, *18*(2), 63-84.

Kochman, K., Demoucron, M., Moelants, D., & Leman, M. (2012, Sep. 4-8). Respiration as an indicator of embodied music cognition in collaborative vocal performance. In *5th International Conference on Spatial Cognition* (pp. 44-45), *13*(1), Rome, Italy.

Konz, S., & Mcdougal, D. (1968).The effect of background music on the control activity of an automobile driver. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 10(3), 233-243.

Kozak, M., Nymoen, K., & Godøy, R. I. (2012). Effects of spectral features of sound on gesture type and timing. In E.Efthimiou, G. Kouroupetroglou, S, -E. Fotinea (Eds.): *Gesture and Sign Language in Human-Computer Interaction and Embodied Communication* (pp. 69-80). Springer-Verlag, Berlin Heidelberg.

Küssner, M. B., Tidhar, D., Prior, H. M., & Leech-Wilkinson, D. (2014). Musicians are more consistent: Gestural cross-modal mappings of pitch, loudness and tempo in real-time. *Frontiers in psychology*, *5*. 1-15.

Kwok, I., Lee, C., Oakerlund, J., & Zhu, Y. (2014 Feb. 16-19). MusicAir: Creating Music Through Movement. Poster in *8th International Conference on Tangible, Embedded and Embodied Interaction*. Munich, Germany.

Lakoff, G., & Johnson, M. (1980). The metaphorical structure of the human conceptual system. *Cognitive science*, *4*(2), 195-208.

Langner, J., & Goebl, W. (2003). Visualizing Expressive Performance in Tempo—Loudness Space. *Computer Music Journal*, *27*(4), 69-83.

Large, E. W., & Palmer, C. (2002). Perceiving temporal regularity in music. *Cognitive* Science, *26*(1), 1-37.

Leman, M. (2008). *Embodied music cognition and mediation technology*. Mit Press.

Leman, M., Desmet, F., Styns, F., Van Noorden, L., & Moelants, D. (2009). Sharing musical expression through embodied listening: a case study based on Chinese guqin music. *Musical perception: An Interdisciplinary Journal*, *26*(3), 263-278.

Leman, M., Moelants, D., Varewyck, M., Styns, F., van Noorden, L., & Martens, J. P. (2013). Activating and relaxing music entrains the speed of beat synchronized walking. *PloS one*, 8(7), e67932.

Lim, I. V., Van Wegen, E., De Goede, C., Deutekom, M., Nieuwboer, A., Willems, ... & Kwakkel, G. (2005). Effects of external rhythmical cueing on gait in patients with Parkinson's disease: a systematic review. *Clinical rehabilitation*, *19*(7), 695-713.

Lidji, P., Kolinsky, R., Lochy, A., & Morais, J. (2007). Spatial associations for musical stimuli: a piano in the head?. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(5), 1189-1207.

Maes, P.-J., Leman, M., Palmer, C., & Wanderley, M. M. (2013). Action-based effects on music perception. *Frontiers in Psychology*, *4*, 1008. doi:10.3389/fpsyg.2013.01008

Maes, P. J., Van Dyck, E., Lesaffre, M., Leman, M., & Kroonenberg, P. M. (2014). The coupling of action and perception in musical meaning formation. *Music Perception: An Interdisciplinary Journal*, *32*(1), 67-84.

Walker, B. N., & Ehrenstein, A. (2000). Pitch and pitch change interact in auditory displays. *Journal of Experimental Psychology: Applied*, *6*(1), 15-30.

Marks, L. E. (1987). On cross-modal similarity: Auditory–visual interactions in speeded discrimination. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(3), 384.

Matyja, J. R., & Schiavio, A. (2013). Enactive music cognition: Background and research themes. *Constructivist Foundations*, *8*(3), 351-357.

McElrea, H., & Standing, L. (1992). Fast music causes fast drinking. *Perceptual and Motor* skills, *75*(2), 362-362.

McIntosh, G. C., Brown, S. H., Rice, R. R., & Thaut, M. H. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *62*(1), 22-26.

Merker, B. H., Madison, G. S., & Eckerdal, P. (2009). On the role and origin of isochrony in human rhythmic entrainment. *Cortex,* *45*(1), 4-17.

Milliman, R. E. (1982).Using background music to affect the behavior of supermarket shoppers. *The journal of Marketing*, *46*(3), 86-91.

Milliman, R. E. (1986).The influence of background music on the behavior of restaurant patrons. *Journal of consumer research*, *13*(2), 286-289.

Moran, N. (2013). Music, bodies and relationships: An ethnographic contribution to embodied cognition studies. *Psychology of Music*, *41*(1), 5-17.

Nussbaum, C. O. (2007). *The musical representation: Meaning, ontology, and emotion*. Mit Press, Cambridge MA.

Orff, C., & Walter, A. (1963). The Schulwerk: Its origin and aims. *Music Educators Journal*, *49*(5), 69-74.

Palmer, C. (1997). Music performance. *Annual review of psychology*, *48*(1), 115-138.

Parise, C. V., & Spence, C. (2009). ‘When birds of a feather flock together’: Synesthetic correspondences modulate audiovisual integration in non-synesthetes. *PLoS One*, *4*(5), e5664.

Patel, A. D., Iversen, J. R., Bregman, M. R., & Schulz, I. (2009). Experimental evidence for synchronization to a musical beat in a nonhuman animal. *Current biology*, *19*(10), 827-830.

Peckel, M., Pozzo, T., & Bigand, E. (2014). The impact of the perception of rhythmic music on self-paced oscillatory movements. *Frontiers in Psychology*, *5*, 1037. doi:10.3389/fpsyg.2014.01037

Povel, D. J., & Essens, P. (1985). Perception of temporal patterns. *Music Perception*, *2*, 411-440.

Posner, J., Russell, J. A., & Peterson, B. S. (2005). The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology. *Development and psychopathology*, *17*(3), 715-734.

Repp, B. H. (1993). Music as motion: A synopsis of Alexander Truslit's (1938) Gestaltung und Bewegung in der Musik. *Psychology of Music*, *21*(1), 48-72.

Rusconi, E., Kwan, B., Giordano, B. L., Umilta, C., & Butterworth, B. (2006). Spatial representation of pitch height: the SMARC effect. *Cognition*, *99*(2), 113-129.

Russell, J. A. (1980). A circumplex model of affect. *Journal of personality and social psychology*, 39(6), 1161.

Sapp, C. S. (2007, September 23-27). Comparative Analysis of Multiple Musical Performances. In: *Proceeding of the 8th International Conference on Music Information Retrieval* (pp. 497-500). Vienna: Austrian Computer Society.

Scruton, R. (1997). *The aesthetics of music*. Oxford: Clarendon Press.

Shove, P., & Repp, B. (1995). Musical motion and performance: theoretical and empirical perspectives. In J.Rink (Ed.),*The practice of performance: Studies in musical interpretation* (pp.55-83). Cambridge: Cambridge University Press.

Spence, C. (2011). Crossmodal correspondences: A tutorial review. *Attention, Perception, & Psychophysics*, *73*(4), 971-995.

Stevens, C. J. (2014). Implications for Cognitive Studies of Musical Expressiveness. In Fabian, D., Timmers., & Schubert, E. (Eds) *Expressiveness in music performance: Empirical approaches across styles and cultures*, pp. 335-9. Oxford University Press, Oxford, UK.

Styns, F., van Noorden, L., Moelants, D., & Leman, M. (2007). Walking on music. *Human movements science*, *26*(5), 769-785.

Todd, N. P. M. (1992). The dynamics of dynamics: A model of musical expression. *The Journal of the Acoustical Society of America*, *91*(6), 3540-3550.

Todd, N. P. M. (1999). Motion in music: A neurobiological perspective. *Music Perception*, *17*(1), 115-126.

Toiviainen, P., Luck, G., & Thompson, M. R. (2010). Embodied meter: hierarchical eigenmodes in music-induced movement. Musical perception: An Interdisciplinary *Journal*, 28 (1), 59-70.

Volpe, G., Varni, G., Addessi, A. R., & Mazzarino, B. (2012, June 12-15). Besound: embodied reflexion for music education in childhood. In *Proceedings of the 11th International Conference on Interaction Design and Children* (pp. 172-175). ACM, NY, USA.

Wagner, S., Winner, E., Cicchetti, D., & Gardner, H. (1981). " Metaphorical" Mapping in Human Infants. *Child Development*, *52*(2), 728-731.

Walker, M. E. (2000). Movement and metaphor: Towards an embodied theory of music cognition and hermeneutics. *Bulletin of the Council for Research in Music Education*, *145*, 27-42.

Walker, P., Bremner, J. G., Mason, U., Spring, J., Mattock, K., Slater, A., & Johnson, S. P. (2010). Preverbal infants’ sensitivity to synaesthetic cross-modality correspondences. *Psychological Science*, *21*(1), 21-25.

Woody, R. H. (2002). Emotion, imagery and metaphor in the acquisition of musical performance skill. *Music Education Research*, *4*(2), 213-224.

Zentner, M., & Eerola, T. (2010). Rhythmic engagement with music in infancy. *Proceedings of the National Academy of Sciences*, *107*(13), 5768-5773.

**Appendix 1**

**Participant Information sheet**

1. **Research project title:**

What is the relationship between visual motion patterns and performed music features?

1. **What is the project’s purpose?**

This research aims to examine the translation of visual motion patterns to the performed musical patterns in a musical production context. Specifically, it will examine to what extent performed music patterns including tempo, articulation, loudness and dynamics will be different after you watching each video.

1. **What will happen to me if I take part?**

You will be asked to play on MIDI piano after watching each video. There will be two performance sessions – tapping (playing a single tone) and playing (with a musical score), but the videos for each performance session are the same (8 videos in total, each around 10 seconds). A musical score without any bar line, tempo, rhythmic pattern and articulation will be given to you and you are expected to play with your own expression and interpretation after watching each video. Your performance will be automatically recorded and stored in the PC. (P.S You could watch the videos for more than twice times if you would like and you could also ask for practising for a while before you get ready for the recording of performance.)

1. **Do I have to take part?**

You could withdraw your participation at any time during the experiment without giving any reason.

1. **Is there any possible disadvantage or risks of taking part?**

There will not be any physical and psychological harm to you during the experiment.

1. **What are the possible benefits of taking part?**

You will be entered into a prize draw of a chance of winning £30 Amazon voucher. If you would like to be entered in to a draw, please leave your email address here: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

1. **Will my taking part in this project be kept confidential?**

Your performance recording will be used for research only and the auditory recording will be deleted from the PC after data analysing.

1. **What will happen to the results of the research project?**

The research results will be written into the dissertation as a formal assignment in the completion of MMUS degree of the researcher. It might also be presented at future conferences or published in a journal.

1. **Contact for further information**

Please contact Shen Li (email: [sli37@sheffield.ac.uk](mailto:sli37@sheffield.ac.uk)) or my supervisor Renee Timmers (email: [r.timmers@sheffield.ac.uk](mailto:r.timmers@sheffield.ac.uk)) for further information.

**Appendix 2**

**Background Information**

|  |  |
| --- | --- |
| *Normal hearing* | Yes / No |
| *Normal or corrected-to-normal vision* | Yes / No |
| *Age* |  |
| *Gender* | F / M |
| *Years of playing piano* |  |
| *Years of music lessons* |  |
| Are you still actively playing? | Yes / No |
| Experience with accompanying dance | Never/Seldom/Sometimes/Usually/Always |
| *Number of hours spent playing/ practising piano per* ***week*** |  |
| *Approx. number of hours spent listening to music per* ***week*** |  |

*Thanks for your completion!*

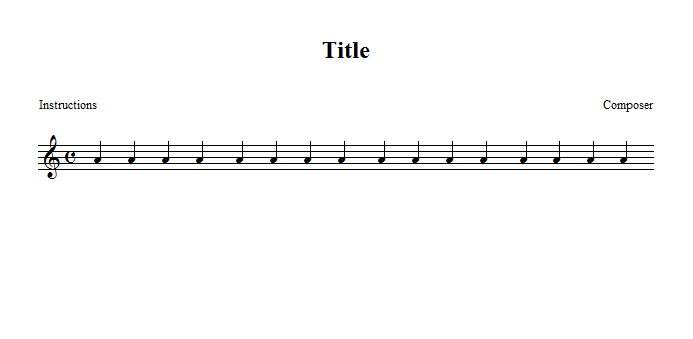
**Appendix 3**

**Musical sheet**

*1) In this study, you will see a short video with a person walking in a certain way. After that, we would like you to play a musical excerpt and express the movement you saw in the video in your performance of that excerpt.*

*2) Please play* ***three*** *times (with short break between performances) after watching each video. You can practice if you wish before the recording.*

**Session 1:** please play on A for sixteen times (4 bars × 4 quarter tones). After completing this session (finish watching the last video), then move to next session.



**Session 2:** please play the musical score below.

