How the Body Conducts Music: Exploring Head Movements in Two Classical Guitar Performances.

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Abstract

Musical sounds and the body are interdependently linked in music performance. The key to musical expression lies in the way the body conducts music over time. In this study, General Tau Theory (Lee, 2005) was used as a theoretical framework to explore the head movements made by a classical guitarist during two performances. The musician's head movements were analysed in conjunction with sound intensity and temporal features of the music. Differences in expression between the performances were established by listeners' ratings of audio recordings. Tau-G guided head movements were not found to be related to intensity glides of individual notes, and the tau-coupling constant (k) did not vary between expressively different performances. Significant differences between the two performances in tau-guided head movement timing and musical tempo characteristics suggest that the body's role in musical expression lies in expressive timing. However, limitations in this study prevent firm conclusions being drawn from these results. Ways of eliminating these defects are discussed and future directions for the application of Tau Theory to body movement in music are identified.

"The material of music is sound and bodily movement"

– Aristides Quintilianus[1]

"Every musical manifestation should rest on a joint physical and intellectual basis, demonstrating the inseparability of body from soul."

– Emile Jaques-Dalcroze[2]

1.1 The Body in Music

The body is holistically involved in music performance. This proposition is supported by evidence from a wide variety of research areas. In order to develop a fuller understanding of how musicians convey musical thought and expression in performance it is necessary to investigate the role that the body takes in shaping music.

Conductors use their bodies to guide their orchestra and to draw out the expressive character of the music. Beethoven was the first composer to conduct without a

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[1] Aristdes Quintilianus c. 300 AD. Retrieved March 10th, 2006 at http://www.auditory.org/postings/1998/36.html.

[2] Jaques-Dalcroze, E. (1967). *Rhythm Music and Education.* p. 75

musical instrument, as he was "concerned to convey the music's expression, rather than just a regular beat."[3] This was presumably to allow the freedom of his whole body to channel the music to the orchestra. A conductor's gesture "is absorbed within his overall body movement – including seemingly capricious gestures, changing postures and different facial expressions."[4] Clearly, the dynamics of the whole body are important for leading the musical expression of an orchestra.

The dynamics of the body are rooted to musical expression more deeply than just the practice of conducting. There are arguments that our perception of music is constituted by percepts of bodily motion (Todd, 1999, Clarke, 2005). Repp and Knoblich (2004) provide evidence that pianists are able to recognise recordings of their own performances best, due to the way their music resonates with their own "action identities"[5]. Musical tempo variations that correspond to the temporal contours of human movements are perceived as being more musically expressive than, for example, linear temporal patterns. (Juslin, Friberg & Bresin, 2002, cited in Eitan & Granot, in press). In performance, Friberg & Sundberg (1999) found that the body velocity of runners stopping closely resembled the temporal dynamics in musical ritardandi. Indeed, Juslin (2003) argues that biological movements should form the template to understanding the motion principles ascribed to music perception.

In support of this general claim, there is evidence that the link between music and movement has been there from an early stage in human life, both developmental and evolutionary. From a very young age children move their bodies with the musical

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[3] Lawson, C. (2002). Performing Through History. p. 11.
[4] Goodman, E. (2002). Ensemble Performance. pp. 158-159.
[5] Repp, B. H. & Knoblich, G. (2004). Perceiving Action Identity. pp. 604.

shape of communication that flows between parent and child (Malloch, 1999-2000). The concert pianist Evgeny Kissin began playing the piano at the age of 2, a crucial age in development, when sensory-motor representations of the world are forming (Piaget, 1972, cited in Gleitman, et al., 1999). Kissin's exploration of body actions and music at this key time in his life may provide some clue to his superlative status as a musician. Music and the body are not just aligned in our developmental history, but also our prehistory. Recently, it has been argued by Steven Mithen (2005) that music has evolved in synchrony with the evolution of the human body and that the complex musical language we now have is a product of bipedalism. This claim is bolstered by the fact that evolutionarily older parts of the brain are involved in music perception (see below).

Neurobiological research gives further grounding to the claim that music perception is founded in human body motion. It has been discovered that the cerebellum, a part of the brain involved in the timing of simple biological movement, is implicated in the perception of harmony and melody (Parsons, 2001). Auditory processing of music resonates to the motor cortex of the brain (Thaut, 2005), an effect that can be observed in the behaviour of trained pianists, who are unable to override the motor associations they have with musical pitch changes in a performance task (Drost, Rieger, Brass, Gunter, and Prinz, 2005).

That perception and action are so closely interrelated in music is in line with the more general idea that the content of perception is composed by actions (e.g. Noe, 2004, Hurley, 1998). Musical actions - body movements - give form to the content of musical perception, for both the perceivers of music (audience, listeners), and for the performers themselves. If music creates in the listener a perception of motion (Todd, 1999), this must be communicated from the performer to the listener.

Expressive information is available in movement (Pollick, 2003) and body movement in music can conduct expression in the sound (Camurri, Mazzarino, Ricchetti, Timmers, and Volpe, 2004) or in the visual information created by the non-sound-producing movements of a performance (Davidson, 1993, 1994). The visual information from musicians' body movements, e.g. the upper body or head movements, are sufficient for the audience to gain information about the expressive intentions of the musician, and for musically untrained listeners, this may be the primary source of expressive information (Davidson & Correia, 2002). Thus, aside from constituting the performers' own perceptual form of their performance, movements made by the whole body may also be naturally selected for by the success of how they convey the performers' expressive intentions to an audience.

This communicative aspect of body movement and expression in music has often been studied in the form of musical or expressive gestures (Cadoz & Wanderley, 2000, Camurri, et al., 2004). David McNeill's work (1992) has shown that body gestures that accompany verbal communication are not superfluous or even supplementary, but are actually part of the thoughts being communicated. In his words, "gesture and speech are different expressions of the same conceptual content"[6]. Given the close relatedness of verbal communication and music (Trevarthen, 1999-2000, Schogler, 1998), this statement could theoretically be

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[6] McNeill, D. (2005). McNeill Lab Gestures Topics. Retrieved 5th March 206 at http://mcneilllab.uchicago.edu/topics/topics.html

paraphrased; body gesture and sound production are different expressions of the same musical content.

Given the ideas discussed in this section, it seems to claim that only sound-producing body movements are important in music performance is as mistaken as claiming that the only important body movements for a sprinting are those made by the legs.

As an aside, it should be noted that it is not just body *movement* that is significant in music performance. Body posture is of great importance for musicians. For example wind instrument players must have the correct posture to allow the respiratory system to function optimally (Fuks & Fadle, 2002). Body posture is important for musical expression also, because those parts of the body that do not move during performance must be positioned so as not to inhibit the freedom of the musician's expressive movements. Indeed, good posture even seems to affect the quality of musical performance (Boonshaft, 2002). Therefore, the body really is involved *holistically* in music performance.

1.2 Music Performance is Perceptually Guided Body Movement in Time

To build a theory of how the body movements of musicians conduct their performances and guide expression, it is necessary to understand how movement is perceptually guided in time.

Timing is of central importance in music, and is the basis of how musicians convey structure and expressive communication (Clarke, 1999, Schogler, 1999-2000). Musicians vary from strict timing in structurally and expressively meaningful ways. These temporal variations are never completely absent in musical performance, even if the musician tries to play without them (Seashore, 1938, cited in Palmer, 1997). This phenomenon is most likely due to the physiological construction of the human body, its natural motions, and the way we biologically control movement in time. Palmer (1997) has noted, "musical rhythm is often defined relative to body movement"[7], and Iyer (2002) gives an account how the temporal features of music relate to the temporal features of our natural biology. Thus, an exploration of body movement during music performance should be based on a biologically plausible account of how movement is controlled in time.

Perceptual guidance of body movement in music performance is not based in any one modality. Movement is perceptually guided by vision, pitch, sound intensity, force, etc. Also, similar expressive movements occur across different musical performances on different instruments. A theoretical framework for studying expressive body movement guidance in music must account for how changes in different sense modalities are controlled and co-ordinated by universal principles in time.

A biologically plausible, modality-independent framework for studying musicians' expressive control of body movements in music performance is General Tau Theory.

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[7] Palmer, C. (1997). Music Performance. p. 128.

1.3 General Tau Theory

Developed from J. J. Gibson's ecological principles of perception (Gibson, 1979), and Nicholai Bernstein's theories of movement (Bernstein, 1967), General Tau Theory is about prospectively guided movement in people and animals (Lee, 1998, 2005, 2006).

Guiding movement is essentially the closure of 'motion-gaps', which can be gaps of distance, angle, force, sound intensity, anything. Tau theory claims that the closure of a motion-gap is continuously guided by controlling the time-to-contact between the effector (thing being moved) and the goal.

'Tau' (τ) is the name given to this variable and is defined as "the time-to-closure of the motion-gap at the current rate of closure"[8]. An example of tau can be given from the standard physics equation for movement over a distance: time equals distance divided by rate. Tau, here, is the time at each instant in the movement and decreases linearly if the rate of change of the movement remains constant over time. Furthermore, tau is a property of all movement, regardless of whether the motion-gap is distance, angle, force, etc. Information about metres, degrees, Newtons, etc., does not have to be attained and then scaled by the organism as tau information is sufficient to guide movement (Lee, 2005). It seems plausible from an evolutionarily perspective that Mother Nature has selected this single variable (tau) for her progeny, allowing organisms to guide their myriad movements through the world by a simple, universal device. In support of this idea, tau-guidance of movement has been found in studies of drivers braking (Lee, 1976), gannets fishing (Lee, & Reddish, 1981) and

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[8] Lee, D. (2006). How Movement is Guided. p. 5.

bats landing (Lee, Lishman, and Thomson, 1982), among other things (see Lee, 2006).

Further exploration into tau-guidance has revealed that the mechanism by which movements of organisms are tau-guided is that of ‘tau-coupling’ (Lee, 1998). This is where the tau of one motion-gap between an effector and a goal are kept in a constant ratio to the tau of a different motion-gap that is being closed simultaneously. This can be expressed in the following formula[9]:

$$\tau(X,t) = k*\tau(Y,t)$$

where $\tau(X,t)$ is the tau of the motion-gap between the effector and the goal, $\tau(Y,t)$ is tau of a separate motion-gap, and k is the coupling constant. Organisms can achieve this tau-coupling of movement as tau-information from the external world is directly present to the senses (see Lee, 2006 for mathematical proofs).

Not all movements are guided by mapping onto events in the external world. A swan has no external guide when it takes off from the water; an A Capella singer has no external guide for the pitch movements of her song. General tau theory has recently been extended to explain how organisms can not only control movement using external guides, but can also *intrinsically* guide their movements (Lee, 1998, 2005). It has been proposed that in self-guided movement, an organism generates within itself (most likely in neural oscillations) an internal tau-guide, named ‘Tau-G’ (τ_G). This internal Tau-G guide takes a temporal form that is the most ecologically universal in animal movement: motion under gravity. One tau-G oscillation (analogous to the tau

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[9] Taken from Lee (2005).

of an object's motion under gravity, from start point to peak to start point and back again) is represented in the following equation[10]:

$$\tau_G = t(T_G + t)(T_G + 2t)$$

where t is time (0 at goal) and T_G is the time taken for a complete oscillation. Tau-coupling to an intrinsic tau-guide is then expressed as follows[11]:

$$\tau(X,t) = k^*\tau_G(T_G, t).$$

This theory of intrinsic tau-guidance has been tested and confirmed in hand-to-mouth eating movements, babies suckling (both reported in Lee, 2005) and in musical performance (Lee, Schogler and Pepping, 2006), revealing that very different movements are controlled by the same internal guide.

In tau-guided movements, the coupling constant, k, is of particular importance in determining the form of the movement. Movements where k has a value between 0 and 0.5 are softer, coming to rest at the goal; movements where k has value between 0.5 and 1 result in a sharper movement, with some velocity still at the goal-point (Lee, 2005). Furthermore, the k value throughout a movement can be purposely altered, depending on the intended movement, and this variation in k value has been found to be relevant to expression in movement (Lee, 2006, Lee, et al., 2006). An analogy to illustrate this phenomenon can be drawn from Rudolf Laban's instructions on body language for dancers: "…the artist playing Eve can pluck the apple in more than one

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[10] Taken from Lee (2006).

[11] Taken from Lee (2005).

way, with movements of varying expression. She can pluck the apple greedily and rapidly or languidly and sensuously."[12] In this scene, the motion-gap stays the same, that is, the distance between Eve's hand and the apple, but the way that Eve closes that gap can be done with quite different expressive effects.

1.4 Tau in Music

General Tau Theory yields a valuable tool for studying expressive body movements in music performance, as it describes how movements are perceptually guided in time, and how the control of movements can be varied for different expressive effects. Woody (1999, cited in Davidson, 2005) named "goal imaging, motor production and self-monitoring"[13] as the three mental skills needed by a musical performer. These are all neatly accounted for by the main propositions of tau-guidance of movement theory.

The relationship between music and motion is also accessible from the principles tau-guidance. Music perception and performance are closely tied up with movement in the world. Todd (1992) found that dynamics and timing in expressive musical performance could be modelled using the properties of movement exhibited by objects moving under gravity. Similarly, Repp (1992) discovered that when altering the timing curves of a musical piece, listeners preferred those temporal profiles that corresponded to motion under gravity. The intrinsic tau-guide in General Tau Theory is derived from the same timing pattern, and so may be the key to musical movement.

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[12] Laban, R. (1980). The Mastery of Movement. p. 1.

[13] In Davidson (2005). Bodily Communication in Musical Peformance. p. 217.

Research has begun to look at General Tau Theory in music performance. One study (Fraenkel, 2001, reported in Lee, 2005) tau-analysed the pitch movements in legato singing. The analysis showed that the singer's pitch glides were closely coupled to an intrinsic tau-guide. Another study reported in Lee, et al. (2006) found that the tau-coupling of pitch glides matched the tau-coupling of tension in singers' larynxes. Furthermore, it was found that the coupling k-value was higher in 'stressed' pitch glides than 'un-stressed' ones, and that this pattern occurred in both the sound and laryngeal data. These results indicate that the tau-guided body movements of the singers controlled the expressive features of the music.

A study investigating the bowing movements of a double-bass player (Lee, et al., 2006) looked at tau-coupling in relation to sound intensity glides. The sound intensity glide of a musical event is the attack phase of the sound intensity profile. This intensity phase carries information about the type of action that produced the sound, e.g. a hammer striking a piano string (Sethares, 1999). The experiment compared the tau-data of bowing movements and intensity glides when a piece of music was played with 'sad' or 'happy' expressive intention. The results showed that k-values of bowing movements and intensity glides were greater in the 'sad' music than in the 'happy' performance, and that bowing movements had different kappa profiles (changes in k-value across the movement duration) between conditions. The results also showed that the duration of intensity glides and bowing movements were longer in the 'sad' condition. This resembles a finding by Gabrielsson (1995, cited in Palmer, 1997) that intensity glide durations of violin and flute performances were shorter in angry music than in sad music. The results from double-bass experiment take this further by demonstrating that these expressive effects are created by the guidance of the musicians' movements.

The above experiments have explored the sound-producing movements of musicians within General Tau Theory. Only one previous study has investigated tau-guided body movements that are not directly involved in the production of sounds. Lee (2006) reports a study looking at the hand gestures made by a Jazz singer during performance. They found that although durations of pitch-slides and hand gestures were different, k-values were similar for both, emphasising again that body movements and sounds are two sides of the same expressive coin in music performance.

1.5 Exploring Head Movements during a Classical Guitar Performance

Extending the research into tau-guided body movement in music performance, this study explored whether differences in tau-guided head movements varied with differences in the musical features and expression during two classical guitar performances.

Head movements during music performance have previously been shown to convey musical expressive intention (e.g. Clarke & Davidson, 1998, Davidson, 1994, Dahl & Friberg, 2003). The head is generally free to move during music performance and is the apex of the body, encapsulating upper body motion. The head may also play a role in the musician's perception of their own performance. Todd (1999) argued that the vestibular system is involved in music perception, which would be affected by head movements. Furthermore, a person's head nodding and shaking can affect her own attitude (Brinol & Petty, 2003), so perhaps similar gestures in music affect the performer's own expressive attitudes and intentions. Head movements are used in scaling actions (Lee, 2006), so if music does map onto movement in the world it is possible that there is an association for us between head movement and self-guided musical movement. Thus, there are reasons for thinking that head movements may be involved in how performers conduct a musical piece to themselves during performance.

Previous research into expressive body movements in musical performance has employed piano (e.g. Clarke & Davidson, 1998, Davidson, 1994), clarinet (e.g. Vines, Wanderley, Krumhansl, Nuzzo, and Levitin, 2004, Wanderley, Vines, Middleton, McKay, and Hatch, 2005), singing (e.g. Davidson, 2005, Lee, 2005), double bass (Lee, et al., 2006) & marimba (Dahl & Friberg, 2003). Gabrielsson (2003) called for "a need for an extended repertoire of instruments in performance research"[14]. The author had found no published studies addressing body movements in classical guitar performance so to help increase the inventory of instruments in performance research, classical guitar was chosen for this study.

Williamon and Thompson (2004) have drawn attention to the need for better ecological validity in psychological investigations of music performance. Most laboratory research into musicians' expressive body movements require participants

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[14] Gabrielsson (2003). Music Performance Research at the Millennium. p, 235.

to play with deliberately repressed, inflated or ‘normal’ expression (e.g. Wanderley, et al., 2005). This methodology allows comparison between pre-designated musical expressions, but is flawed, as the performer is not performing the music as would be natural in a real performance environment. To try and improve ecological validity, the classical guitarist in this study was not given any instructions about expression, but allowed to play the music naturally. In order to determine differences in musical expression between performances, listeners were later asked to rate recordings of the pieces on different expression scales. Listener rating scales were: ‘sad-happy’ (taken from the double bass study in Lee, et al., 2006); ‘stressed-unstressed’ (taken from the singing study, also in Lee, et al., 2006); ‘expressive-inexpressive’ (taken from a pianist study in Davidson, 1993).

Head movements were recorded using motion capture technology, and were tau-analysed. Sound intensity glides were extracted from audio recordings of the two performances and were also tau-analysed. This allowed comparison between k-values and durations of head movements and intensity glides in the two performances. Data about expressive variance in timing in both pieces was also obtained from the audio recordings. This was compared with variance in the durations of tau-guided head movements. These comparisons were then related to comparisons between listeners’ ratings of musical expression in the performance of both pieces.

In addition to exploring differences in head movements and expression between the two musical performances, variances in the k-values and durations of tau-guided head movements were compared with those of co-occurring intensity glides within each piece. This was done to discover if head movements change with the individual notes as the piece moves through time.

Hypotheses in this experiment were as follows:

- If one performance is rated as more ‘sad’ than the other, the mean k-value and time duration of head movements in this piece will be greater.
- If one performance is rated more ‘stressed’ than the other, the mean k-value of head movements will be higher.
- If one performance is rated more ‘expressive’ than the other, variance in timing in this piece will be greater.

Additionally, the following questions were explored:

- Are k-values and durations of intensity glides correlated with the k-values and durations of head movements that they occur during?
- Does the tau-coupling constant (k) vary during head movements between the two pieces, that is, do head movements have different kappa profiles between pieces?

As well as investigating the movements of the musician and the music produced, this study also explored the musician’s own perceptions of body movements in performance. Williamon and Thompson (2004) have argued that, whilst studying music performance from a third-person, scientific approach can be greatly informative, this method will always be incomplete in understanding music performance. To gain a full picture, investigators must understand not just musicians’ behaviour, but also what they are conscious of in their performance. The verbal reports of people are invaluable data in researching consciousness scientifically and are not just as clues for ‘real’ data, but should be treated as data in themselves (Dennett, 1991, 2005). Wanderley, et al. (2005) used a questionnaire in order to ascertain musicians’ perception of body movements in music performance. The present study also employed a questionnaire technique to inquire into the musician’s own consciousness of body movement in performance.

2. Classical Guitar Performances

2.1 Participant

The guitar performance participant was a male, music student at Napier University, Edinburgh. He had played classical guitar for 7 years and performs in public approximately once every 1-2 weeks. His participation was voluntary.

2.2 Apparatus, Set-up and Materials

Three Selspot motion-capture cameras, mounted at different heights were used to record the movements in 3-dimensional space of 5 infrared LED markers on the guitarist. Three markers were placed on a black skull-cap, worn by the participant. One marker was placed on the body of the guitar and another was attached to the back of the guitarist's right hand. These two markers on the guitar and hand were used to give a frame of reference for observing the movements of the head in the recordings. A microphone connected to a Tascam digital recorder? was used make audio recordings of the two performed classical guitar pieces. The performance recordings were carried out in a near dark room to avoid light interference with the Selspot cameras. Paper covered the guitar's body to remove reflections from the varnished surface.

Figure 1. shows the standard position for playing classical guitar, with an approximation of the three axes of motion in this study indicated.

Figure 1. An example of the standard playing position for classical guitar with Selspot axes approximately marked. (Taken from: http://www.keysignature.co.uk/images/artistes/59.jpg)

A short Questionairre[15] regarding the participant's perceptions of body movement in performance comprised 5 questions used in a study by Wanderley, et al. (2005).

2.3 Procedure

The participant performed two classical guitar pieces: 'Menuet in A major' by Guiseppe Antonio Brescianello and 'El Testamento de Amelia' by Miguel Llobet. These pieces were chosen because the participant had performed them often before and did not consider them technically difficult. The participant was asked to play both pieces as they would be played in an average performance setting. Both pieces were performed from memory.

The Selspot motion-capture data from the 5 infrared LED markers was recorded using Qualysis software, at a sampling frequency of 500Hz, over blocks of 78s and 96s for the first and second piece, respectively. The Qualysis data for movements during each piece were then converted into Microsoft Excel sheets and the Excel sheets were then converted into Microsoft Notebook files, to be readable by the Tau Analysis Server 8.0 program (T.A.S.). This software displays the amplitude-time and velocity-time curve of the movements of each marker in the x, y and z axes. These movement curves were smoothed by the program using a Gaussian filter set at a sigma level of 10.

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[15] See Appendix, A.1

The audio recordings were converted into WAV files using Praat 4.3.29 software, and edited to synchronise with the Qualysis movement data. Using the Praat software, the sound intensity profile of each recording was extracted and converted into Microsoft Notebook files, to be readable by the T.A.S. software. The amplitude-time and velocity-time curves of the sound intensity profile were smoothed using a Gaussian filter set at a sigma level of 2.

The questionnaire (A.1) was completed by the participant after the performances.

2.4 Tau Analyses of Head Movements

The data from the top head marker were used to analyse the head movements made by the participant during the two performances. Movements in different axes were treated as independent of each other and analysed individually.

The beginning and end of individual movements were identified as the time points immediately after and before the velocity went beyond 10% of the peak value of the movement. This method of selecting start and end points of movements was employed to remove noise from velocity data around zero.

The T.A.S. software was then used to calculate a recursive linear regression of $\tau(X, t)$ against $\tau_G(T_G, t)$ for each movement. Movements were called Tau-G guided if $r^2 > 0.95$, i.e. over 95% of the variance is captured in the model, indicating that the movement is closely coupled to an internal Tau-guide. A further calculation by the

Tau Server determines the greatest percentage of data points in the movement that maintain $r^2 > 0.95$. Only movements that were 80% or more tau-G guided were used in the analysis.

The duration, T, of each movement was calculated by subtracting the time at the start point from the time at the end point. The slope of the recursive linear regression model for each Tau-G guided movement is taken as an estimate of the coupling constant value, k, as this represents the average value of k during the movement. Movements with an estimated k-value higher than 1 were discounted from the analysis. This was because k-values >1 are very unlikely human movements (Lee, personal communication), implying these movements were likely to have been distorted by noise in the data.

Mean kappa graphs of head movements in each axis were created. Kappa (κ) is the proportion of tau of the movement over the tau-guide: $\tau(X,t)/\tau_G(t,T_G)$, and can be varied over the course of a movement. T.A.S. calculates κ at each point in a movement to give a kappa profile. These profiles were normalised into 50 time bins for each head movement and the mean kappa profile of all movements in each separate axis were derived for both performances.

Figure 2. shows the different stages in the Tau-analysis of a head movement in the X-axis during ‘Menuet in A major’.

Figure 2. Four stages in tau-analysis of head movement #40 in the X-axis in ‘Menuet in A Major’.

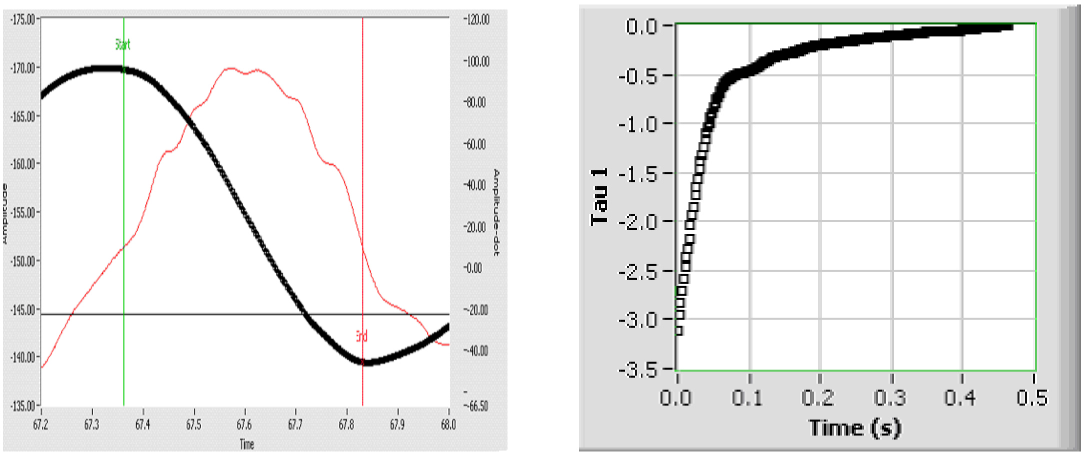

Fig 2a. The black line is the amplitude curve and the red is the velocity curve. The start and end point of the movement are marked by the green and red line respectively.

Fig 2b. Tau of the movement against time for each data point in the movement.

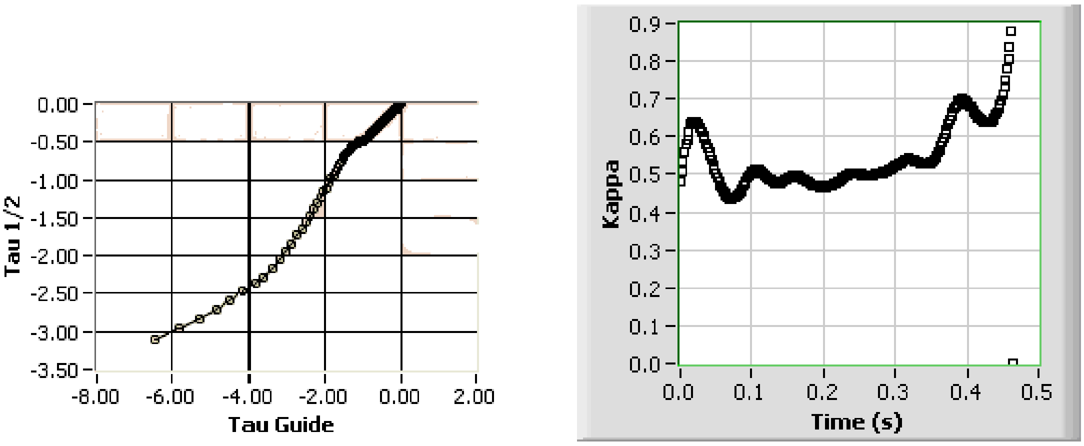

Fig 2c. Tau of the movement at each point against a Tau-G guide.

Figure 2d. Kappa (κ) against time at each point in the movement

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2.5 Tau Analyses of Intensity Glides

Data for the sound intensity glides of notes (corresponding to the attack part of the sound intensity profile) in each piece were tau-analysed using the same procedure as used for head movements (Section 2.4). The start and end points of each intensity glide were checked against the audio recording to ensure that only musical sounds - and not other noise sounds in the data - were analysed. All sound intensity glides matched 100% Tau-guided profiles. The duration and estimated k value were also calculated using the same method as for the head movements.

2.6 Expressive Variations in Timing and Tempos

Beat Inter-onset Intervals (bIOI's) are defined as the duration in time between intensity glides of notes on successive crotchet beats in the music. bIOI's were calculated from the sound intensity data for both pieces by subtracting the start point time of the intensity onset of one beat from the start time of the intensity onset of the successive beat. This was done in order to measure expressive variation in timing in the piece.

An approximate mean tempo was calculated for both pieces by dividing the total time of each piece (i.e. the time between the start point times of the first and last sound intensity onsets) by the number of beats in the piece.

3. Listeners' Ratings

3.1 Participants

21 participants (10 male; 11 female) were recruited voluntarily. They were all amateur musicians and had played a musical instrument for a mean average of 7 years (range = 3-14 years).

3.2 Materials/Apparatus

A questionnaire[16] was created using three separate Likert rating scales from 1 to 7 for each piece. The three scales used were 'Sad-Happy', 'Stressed-Unstressed' and 'Expressive-Inexpressive'. Higher ratings correspond to 'Happier' in the first scale, 'Unstressed' in the second, and 'Inexpressive' in the third. Audio recordings of each performance were played back using Windows Media Player through headphones.

3.3 Procedure

Each participant listened individually to the audio recordings of both classical guitar performances. They were then asked to rate each piece on the three scales, using the questionnaire provided. The order in which the audio recordings were played to the

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[16] See Appendix 2

participants was randomly varied to ensure that the order of listening did not bias the results.

4. Results[17]

4.1 Head Movements

144 head movements in Piece 1 and 71 head movements in Piece 2 were tau-analysed as described in 2.4. The results of these analyses are summarised in tables 1 & 2. The criterion for tau-coupling in Section 2.4 (>80%) ensured that all head movements were closely tau-coupled.

4.2 Comparisons of Head Movements Between Pieces

Comparisons of durations and estimated k-values of head movements in each axis (X, Y, and Z) were carried out using independent t-tests.

X-axis tau-guided head movements. A significant difference was found between the durations of tau-guided head movements in the X-axis ($t = -4.431$, $df = 67$; $p<0.001$), with the mean duration of head movements in the Piece 2 ($M = 0.638$s) being greater than the mean duration in Piece 1 ($M = 0.388$s). No significant differences were found in comparisons between the two pieces for estimated k-values ($t = -0.725$, $df = 67$; $p>0.05$)

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[17] Hereafter, 'Menuet in A major' will be referred to as 'Piece 1' and 'El Testamento De Amelia' as 'Piece 2'.

Y-axis tau-guided head movements. No significant differences were found by comparing the two pieces for durations (t = -0.578, *df* = 82; p>0.05) or for estimated k-values (t = 0.437, *df* = 82; p>0.05).

Table 1. Summary data for head movements in the X, Y and Z-axes during Piece 1.

		X-axis (N = 52)	Y-axis (N = 52)	Z-axis (N = 40)
k	Mean	0.526	0.521	0.541
	S.D.	0.157	0.137	0.121
T	Mean	0.388	0.483	0.391
	S.D.	0.183	0.236	0.137
%	Mean	97.981	96.856	99.014
	S.D.	3.877	4.996	2.097
r^2	Mean	0.970	0.963	0.966
	S.D.	0.016	0.013	0.015

Results: k, estimated coupling constant; T, duration between start point and end point; %, percent of data in movement accounted for by tau-G model; r^2, regression coefficient of $\tau(x)$ against τ_G of movement.

Table 2. Summary data for head movements in the X, Y and Z-axes during Piece 2.

		X-axis (N = 52)	Y-axis (N = 52)	Z-axis (N = 40)
k	Mean	0.561	0.507	0.560
	S.D.	0.208	0.135	0.174
T	Mean	0.638	0.512	0.589
	S.D.	0.254	0.210	0.193
%	Mean	93.829	97.476	95.630
	S.D.	6.128	4.610	5.449
r^2	Mean	0.958	0.965	0.959
	S.D.	0.008	0.014	0.012

Note: k, estimated coupling constant; T, duration between start point and end point; %, percent of data in movement accounted for by tau-G model; r^2, regression coefficient of $\tau(x)$ against τ_G of movement.

Z-axis tau-guided head movements. A significant difference was found between the durations of tau-guided head movements in the Z-axis ($t = -4.700$, *df* = 32.87; $p<0.001$), with the mean duration of head movements in the Piece 2 ($M = 0.589$s) being greater than the mean duration in Piece 1 ($M = 0.391$s). No significant differences were found in comparisons between the two pieces for estimated k-values ($t = -0.497$, *df* = 62; $p>0.05$).

Mean kappa graphs of all head movements in each axis were produced. This was done to explore whether the way that the participant controlled the coupling guidance of his head throughout movements differed between the two pieces. Kappa graphs are shown in figure 3. Kappa profiles were similar for head movements in both pieces for all three axes.

F-ratio tests were used to compare the variance in duration of the head movements in each axis between the two pieces. Variance in the duration of the head movements in the Z-axis in Piece 2 was found to be significantly greater than in Piece 1 ($F = 4.007$, *df* = 21, 39; $p<0.05$). No significant difference in variance of duration of head movements was found in either the X-axis ($F = 1.813$, *df* = 51, 16; $p>0.05$) or the Y-axis ($F = 0.325$, *df* = 51, 31; $p>0.05$).

Figure 3. Kappa profile graphs of all head movements in X, Y and Z axes for both pieces. Blue lines refer to Piece 1 and red lines to Piece 2. Standard Error bars are shown.

Figure 3a. Kappa Profiles of Head Movements in X-axis

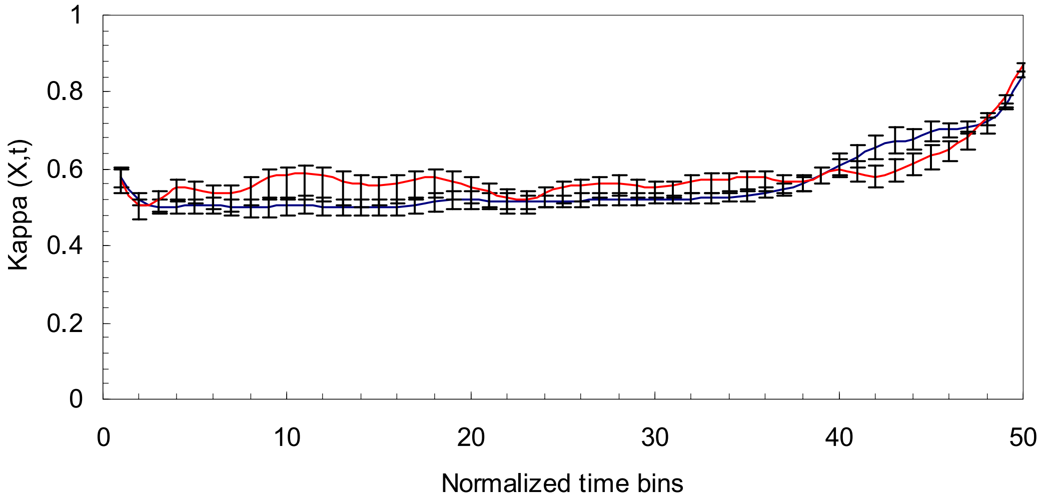


Figure 3b. Kappa Profiles of Head Movements in Y-axis

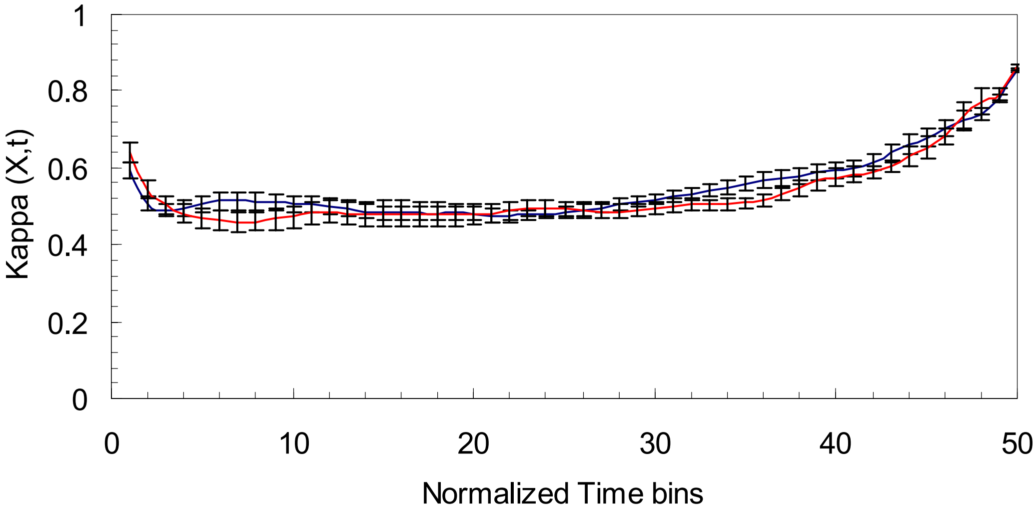
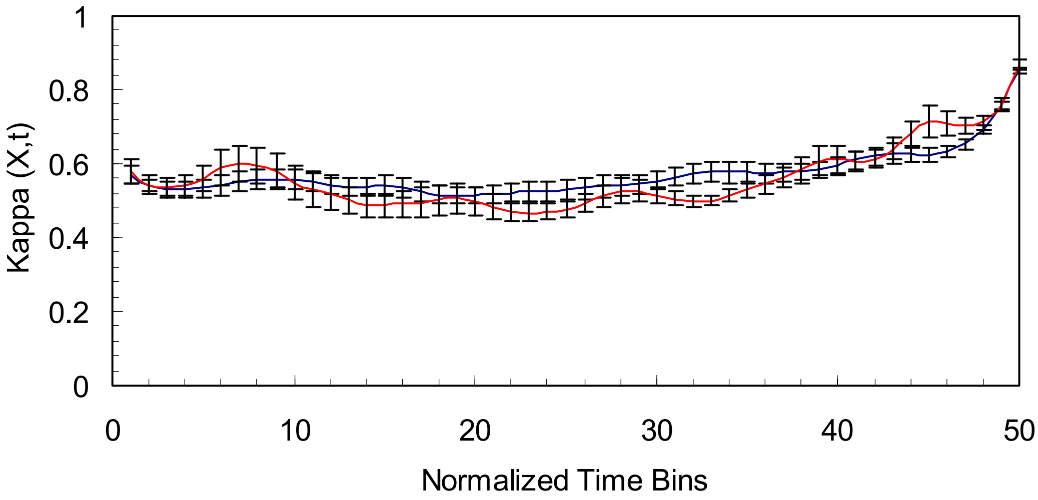


Figure 3 continued.

Figure 3c. Kappa Profiles of Head Movements in Z-axis



4.3 Intensity Glides

157 intensity glides in Piece 1 and 114 in Piece 2 were tau-analysed as described in 2.5. The results from analyses of both pieces are summarised in Table 3.

Table 3. Summary data for sound intensity glides in Piece 1 and 2.

		Intensity glides (Piece 1) (N = 157)	Intensity glides (Piece 2) (N = 114)
k	Mean	0.530	0.495
	S.D.	0.108	0.111
T	Mean	0.036	0.045
	S.D.	0.012	0.013
%	Mean	100	100
	S.D.	0	0
r^2	Mean	0.985	0.979
	S.D.	0.013	0.014

Note: k, estimated coupling constant; T, duration between start point and end point; %, percent of data in intensity glide accounted for by tau-G model; r^2, regression coefficient of $\tau(x)$ against τ_G of glide.

4.4 Comparisons of Intensity Glides Between Pieces

Intensity glides. A comparison of duration and estimated k-value of intensity glides was carried out using an independent t-test. Significant differences were found between the durations ($t = -5.349$, *df* = 270; $p<0.001$) and estimated k-values ($t = 2.649$, *df* =270; $p<0.01$) of the sound intensity glides in the two pieces. The mean duration of intensity glides in Piece 2 (M = 0.045s) was greater than the mean duration of intensity glides in Piece 1 (M = 0.037s). The mean estimated k-value in Piece 1 (M = 0.5301) was greater than that of Piece 2 (M = 0.4945).

4.5 Beat Inter-Onset Intervals and Tempo

A comparison of successive beat Inter-Onset Intervals (bIOI) between the two pieces was carried out using an independent t-test. A significant difference was found between the duration of the mean bIOI's between the two pieces ($t = -14.712$, *df* = 159.838; $p<0.05$), with the mean duration of bIOI's in Piece 2 (M = 0.819s) being greater than the mean duration of bIOI's in Piece 1 (M = 0.671s). Piece 2 had a slower tempo of ~73 bpm, compared with Piece 1 which had a tempo of ~89 bpm.

An F-ratio was used to compare the variance from the mean tempo in both pieces, showing a significant difference between the two pieces in variance in tempo ($F = 13.860$, *df* = 101, 86; $p<0.001$). This indicated that there was more deviation from the mean tempo in the second piece, compared with the first.

4.6 Correlations of Head Movements with Co-occurring Intensity Glides Within Both Pieces

Those intensity glides that co-occurred with head movements – i.e. occurred within the time frame of a head movement in real time – were identified within both pieces. Correlations were then calculated on the k-values and durations of co-occurring head movements and sound intensity glides. Where there were more than one sound intensity glide during a single head movement, the mean k value and duration of those sound intensity glides were used in the correlations.

In Piece 1, 44 intensity glides co-occurred with 39 head movements in the X-axis, 52 intensity glides during 38 head movements in the Y-axis, and in the Z-axis 36 intensity glides co-occurred with 31 head movements. Correlation data for Piece 1 are shown in table 4. No significant correlations were found between the three axes of head movements and intensity glides for k values or durations in Piece 1.

Table 4. Correlation coefficients of k values and durations for co-occurring intensity glides and head movements in Piece 1.

	Head Movements					
	X-axis		Y-axis		Z-axis	
Intensity Glides	k	T	k	T	K	T
k	-0.03	..	0.121	..	0.135	..
T	..	-0.43	..	-0.152	..	0.156

Note: k, estimated coupling constant; T, duration of head movement/intensity glide. Values are correlation coefficients (r^2).

In Piece 2, 44 intensity glides co-occurred with 39 head movements in the X-axis, 52 intensity glides during 38 head movements in the Y-axis, and in the Z-axis 36 intensity glides co-occurred with 31 head movements. Correlation data for Piece 2 are shown in table 5. No significant correlations were found between the three axes of head movements and intensity glides for k values or durations in Piece 2.

Table 5. Correlation coefficients of k values and durations for co-occurring intensity glides and head movements in Piece 2.

	Head Movements					
	X-axis		Y-axis		Z-axis	
Intensity Glides	k	T	k	T	K	T
k	0.086	..	0.089	..	0.159	..
T	..	0.106	..	-0.272	..	0.05

Note: k, estimated coupling constant; T, duration of head movement/intensity glide. Values are correlation coefficients (r^2).

4.7 Listeners' Ratings

A summary of the data from listeners' ratings of both pieces is given in Table 6.

Table 6. Mean listeners' ratings of Piece 1 and 2 on three Likert-type scales.

	'Sad'-'Happy'	'Stressed'-'Unstressed	'Expressive'-'Inexpressive'
Piece 1	4.0	4.3	4.5
Piece 2	3.0	4.3	4.0

Note: higher values correspond to ratings closer to the second adjective of each scale.

Average ratings in each rating scale of the two pieces were compared using Wilcoxon Signed-Rank Tests.

'Sad-Happy'. The comparison showed listeners rated Piece 2 as more 'sad' (M = 3.0) than Piece 1 (M = 4.0). This difference in ratings was significant (Z = -2.512, p<0.05).

'Expressive-Inexpressive'. Listeners rated Piece 2 as more 'expressive' (M = 4.0) than Piece 1 (M = 4.5). This difference was also found to be significant (Z = -2.514, p<0.05).

'Stressed-Unstressed'. There was no difference in listener ratings for musical 'stress' in the performances (M = 4.3 for both pieces), (Z = -0.110, p>0.05).

4.8 Participant's Responses to Questionnaire

The participant's open-ended responses to the short questionnaire (A.1) are reported verbatim below

1. Do you move a lot when you are in a solo performance environment?

"In a solo environment I move with the music, not violently but usually in tandem with the rhythm of the piece, swaying, relaxing motions for example, usually not big sudden movements."

2. Does this motion affect your performance? "I think it is part of the performance, when I play I move as well, if I didn't move then I think it would be detrimental to the music, so I think it affects the music in a positive way."

3. Have your teachers discussed aspects of motion with you?

"My teachers have not addressed the issue of moving on its own, but have told me just to relax when playing, as the instruction books also say, this relaxed state allows for greater playing and movement in balance with the music."

4. Did they (your teachers) encourage or discourage motions? What was their reasoning?

"They haven't spoken good or bad of it, but instead just address it as a natural happening when playing, some guitarists move more than others. I have a friend who plays the Classical guitar and he finds it much easier to play a piece if he moves his shoulders and back especially to the music."

5. Is there a part of your body that you move more than any other?

"Mostly the upper body, the shoulders and back."

4.9 Summary of Results

There were a high number of tau-guided head movements in performances of both pieces. The mean duration of head movements was longer for Piece 2 in the X-axis and Z-axes, but not in the Y-axis. There were no differences in the mean k-values or mean kappa profiles of head movements between pieces. The variance in duration of head movements was greater in Piece 2 in the Z-axis, but not in the X or Y axes. The duration of intensity glides were longer in Piece 2, and the mean k-value was smaller. Piece 2 had a slower tempo than Piece 1, and the variance around the mean tempo was greater. No correlations were found in the k-values and durations of head movements and co-occurring intensity glides. Piece 2 was rated ‘sadder’ and more ‘expressive’ than Piece 1, but there was no difference in ‘stress’ ratings. The musician’s responses to the questionnaire showed that the participant is aware of his own body movement during musical performance.

5. Discussion

This study explored the tau-guided head movements made by a classical guitarist during two performances in relation to acoustic and expressive features of the music. Head movements were found to be strongly Tau-G guided throughout both performances.

5.1 Time

The results show that the mean duration of tau-guided head movements was longer in Piece 2 than in Piece 1 in two of three-dimensional axes. Intensity glides in Piece 2 were also found to have a longer mean duration than Piece 1, as were the durations of musical beats, i.e. tempo. It was hypothesised that if one piece was rated 'sadder' than the other, then the durations of tau-guided head movements in this piece would be longer, which was found in the results. It is possible, however, that the longer head movements in Piece 2 were related to either longer intensity glides or slower tempo. The durations of head movements are closer in time-scale to beat durations than intensity glide durations, which are approximately 10 times shorter in time. There were no correlations found between head movements and co-occurring intensity glides. Additionally, a comparison of variance in duration of head movements between the pieces showed that head movements in the vertical axis were more temporally varied in Piece 2. This is mirrored in the comparison of variance from mean tempo of the performances, but not mirrored in the comparison of variance in intensity glide duration. Together, these results suggest that the head is moving in time with the tempo of the music rather than with the sound intensity glides of the music.

Variance in timing from a central tempo has been shown to be a key feature of expression in music (Clarke 1999), and it was hypothesised that if one performance was rated as more ‘expressive’, then this performance would show greater variance in timing. The larger variance of beats around the mean tempo in Piece 2 is consistent with listeners’ ratings of this piece as more ‘expressive’. Head movements in the vertical axis also showed a greater temporal variance in Piece 2 compared with Piece 1, suggesting a link between timing of head movements and expression. However, there were no significant differences in variances found in the X or Y-axes. Whether or not musical timing of head movement is a property only of the vertical axis of motion needs to be investigated.

A possible interpretation of these results is that the correspondence between timing of head movements and timing in the music is the product of technical constraints of the performance and not the product of musical expression. That is, the participant moves his head in time with the music in order to monitor the motion of his hands across the guitar. It may be true that the head moves with the technical demands of the composition, but this does not contradict the proposition that the head movements are expressive. The head does not necessarily have to move in time with the music to meet the needs of technical monitoring: it could jump very quickly between each fingering position. Indeed, given the standard playing position in classical guitar, it is not necessary for the head to move at all, as eye gaze shifting would be sufficient. The fact that the head does change with the timing of the music indicates that the participant's tau-guided head movements are linked to the expressive timing in the music, as well as any technical requirements of the performance.

No correlations were found for durations of tau-guided head movements with the durations of co-occurring intensity glides. This would suggest that head movements are not associated with the timing of individual intensity glides, and that control of duration of intensity glides comes from another part of the body, probably the hands.

5.2 Coupling

No significant differences were found between the mean k-values of tau-guided head movements during the two performances. Kappa profiles of average head movements were also similar; indicating that the way the participant guided head motion did not vary between different performances. Furthermore, k-values of head movements were not correlated with k-values of sound intensity glides. These results differ from the previous study reported in Lee (2006), in which the hand movements of the Jazz singer – movements that were not sound producing – varied in k-value with the music. The findings in the present study appear to show that the k-value in tau-guided head movements does not relate to the nature of coupling in the musical expression.

The k-values of intensity glides also behaved differently in this study compared with the double bass experiment (Lee, et al., 2006). Intensity glides in the double bass study had a higher k-value in the 'sad' condition, whereas Piece 2 in this study was rated 'sadder' yet had a lower k-value than Piece 1. One possible explanation for this is that there is an interaction between the k-value and some other feature of the music and movement when varying sad and happy expression.

The higher k-value in intensity glides in Piece 1 might be expected to correspond to greater ‘stress’ in this piece, after the results showing higher k-values in singers’ stressed pitch glides (Lee, et al., 2006). However, no difference was found in ratings of stress between the two pieces in this study. This again suggests that the variance in the coupling constant, k, is not sufficient by itself to explain certain variance in expression.

5.3 Musician’s perception of body movement in performance

The questionnaire (A.1.) responses given by the participant show that body movement during musical performance is something that he is conscious about. The participant believes that body motion is a natural part of solo music performance. He says that he moves “in tandem with the rhythm of the piece”[18], which is relevant given that his tau-guided head movements seem to vary temporally with timing changes in the music. He also reports that he is primarily conscious of movement in his “upper body, shoulders and back”[19]. Movements of these parts of the body will also move the head. This lends some credibility to the investigation of head movement in classical guitar performance.

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[18] Section 4.8

[19] Ibid.

5.4 Limitations of this Study

The first limitation of this study to discuss is the problem of generalising findings based on the data from one musician. The probability of individual differences of movement style and musical expression among musicians cannot be controlled for with only one participant. Some studies (e.g. Wanderley, et al., 2005) have used a number of musicians to overcome this. However, in exploratory studies using tau-analysis, the volume of data produced from even small passages of music makes this pragmatically difficult. The use of a single participant in tau studies may still be justified, though, as tau-guidance is based on biologically universal principles and so is more fundamental in all guided behaviour and likely to prevail in individual differences in music performance.

Another issue that may be a limitation in this study is the fact that the participant was still a student of music performance. It is probable that the way a musician moves their body during musical performance changes throughout the development of their musical career. To illustrate, Davidson (2005) cites the example of pianist Glenn Gould, whose body movements changed dramatically after his transition from a performing career to one as a predominantly recording artist. As the participant for this study was at a relatively early stage in the development of his musical career it is possible that his movements during performance do not reflect the movement style of a consummately trained musical performer. A positive of this fact is that the present study affords data for comparison with any future research into tau-guidance in musicians’ head and body movements.

While the present study tried to incorporate as natural as possible a musical performance, the motion capture equipment and darkened room are not features of natural performance environment and may have affected the study. One possible way to improve this method would be to use video recordings and to try to extract the movement profiles from the visual information. This may not provide as accurate data as motion capture does, depending on the resolution and frame frequency of the recordings, but it may go some way to achieving tau-analysis of performance in a genuinely natural setting.

Research into musical acoustics has shown that the intensity glides of musical sound convey information about the nature of the sound producing action (Sethares, 1999) and of the timbre of the music (Galembo, et al., 2001). However, these findings are drawn from musical acoustic research using, primarily, piano tones. This study found that the duration of intensity glides for a classical guitar were very short, suggesting that they may not convey information beyond the type of instrument from which the sounds originate. Further research in psychology in musical acoustics should study whether this variable should be employed in studying musical expression in classical guitar performance.

The results of this study show a possible link between the tempo of the music and timing of head movements during performance. To confirm this, it will be necessary to compare durations of head movements in performances of musical pieces with identical tempos, and also investigate how head movement duration varies as a function of tempo. An alternative approach would be to ask participants to move their heads slowly or quickly during performance, and observe how the timing of the music is affected. Until these experiments are carried out, firm conclusions about the relationship between timing of head movements and tempo cannot be drawn.

Another aspect of the results from this study that needs to be expanded on are the breadth of musical features available to tau-analysis. Differences in musical expression in the present study were measured by comparisons between whole performances and by sound intensity glides at the individual note level. There are, of course, many other levels in music in between these, where expression can lie, for example, over whole musical phrases; in crescendos and diminuendos; in rallentando of passages. These musical features were not explored here, but may well be implicated in body movements in music performance. Developing a means to apply tau-analysis to these musical dynamics will better facilitate the understanding of tau-guided movement in music.

Perhaps the most apparent limitation in this study is in the way expression in the music was measured. Previous studies have asked musicians to vary the expressive intentions of their performances in order to allow comparison (e.g. Davidson, 1993, Vines, et al., 2003, Lee, et al., 2006). As in Clarke and Davidson’s pianist study (1998), the participant in this exploratory study was allowed freedom over the musical expression so as to ensure a completely natural performance. The key limitation of this method is that expression must be inferred indirectly from interpretation of the music, making comparison difficult. As Juslin (2003) informs us, perception of expression in music is mot a simple matter. There are many different ideas, meanings and emotions intended in the performance, and not all of these are explicit, even to the performer. Further research into musical expression and performance is needed to throw light on this difficult methodological issue.

6. Further Issues

The results of this study yield a number of questions for further investigation in music performance psychology.

Differences in duration of head movements between performances were only found in the X and Z axes of movement. Differences in variance of head movement duration were found in the Z-axis only. This poses the question of why head movements do not vary between temporally in all physical dimensions. Eitan and Granot (in press) have argued that the relationship between music and motion is not necessarily a simple mapping of musical movement onto physical space. Interactions between pitch, intensity and time are all relevant to experiences of motion in events. Fast moving objects may be associated with increased tempo, but also with increasing pitch, or alternatively, with a sudden drop in pitch due to the Doppler Effect (Eitan & Granot, in press). A more thorough understanding of the complex auditory associations between music and motion are needed in order to fully understand how motion is engaged in music performance.

This study used listener ratings to measure expression in performance. It has been shown that visual information from body movement is also important for perceiving expressive intentions (e.g. Dahl & Friberg, 2004, Davidson, 1994). Investigations into how expression is visually perceived in tau-guided movements with different k-values and durations will help to differentiate body movements made for visual communication, with those that musicians use to conduct the sound of their own performances.

A somewhat different issue in the study of body movements in music performance is the role played by the brain and the neural system. Movements made during performance that create and shape the music are guided by timing in the neural system (Lee, et al., 2006), but can also be the effects of "motor representations"[20] that are triggered by the perception of the music (Koelsch & Siebel, 2005). Some movement in performance may be the residual effects of "as-if" motor representation between the brain and the body (Damasio, 1994, Seitz, 2005). This is a question for further investigation in the neuroscience of music performance.

As discussed in section 5.4 above, there are differential issues in the psychology of music performance and body movement. Performers may be constrained by their physiology, but they can also express their unique personalities in music performance (Palmer, 1997). Indeed, this is the reason that there are more than one professional pianist, violinist, guitarist, etc., in the world. Movement is sufficient to identify a person (Cutting and Kozlowski, 1977, cited in Davidson, 2005) so individuality is likely to be a feature of musical body movements. How do these individual differences manifest themselves in body movement in performance? Do these differences in performers match individual differences in audience taste? These questions will become answerable as more data on body movement in performance accrues.

A further area of relevance to the psychology of music performance is a musician's development over time. Issues include: how movements change across the development of a career; how movements change during the learning of new music;

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[20] Koelsch S. & Siebel, W. A. (2005). Towards a Neural Basis of Music Perception. p. 578

how body movement can contribute in teaching musical expression? Longitudinal studies into the development of musicians' expressive movements over time may augment the understanding of how movement and music are linked. The question of body movement in music teaching is discussed in Davidson & Correia (2002). How principles of tau-guidance in music performance can aid the pursuit of these research questions is an issue that needs to be explored.

One possible application of General Tau Theory to music teaching would be to tau-analyses recordings of movements in students' performances and then isolate movements that are poorly coupled. This may reveal specific patterns in problematic aspects of playing. Another function of General Tau Theory in music teaching may be to use tau-analysed movements from a different context – for example, in sports – and use these as metaphorical guides to the type of movement-expression intended in the music.

The converse of this suggestion is that principles of tau-guidance in music movement may be beneficial to athletes. Higher performing athletes seem to have better 'rhythm' (Sanders, 2006) and so the link between music and movement might be utilised in sports training. Of course, a clearer understanding of just how body movements are tau-guided in different musical performances is necessary for those musical performance movements to be of practical use in sports.

Conclusion

Understanding expression in musical performance requires understanding how body movements are conducted over time. This applies not only to sound-producing movements, but to movements of the whole body. This study explored the head movements made by a classical guitarist during two musical performances, in relation to auditory features in the music and listeners' perceptions of expression in the music.

The guitarist's head movements were recorded using motion capture technology and analysed according to the General Tau Theory of perceptually guided movement. Tau-guided head movements differed between the two performances only in the durations of head-movements, and in variance of duration in the vertical axis.

This pattern of timing in head movement durations was matched by patterns in the tempo of the music, although not for all axes of head motion. Tau-guidance of head movement was not related to tau-guidance of intensity glides. This suggests that timing of head movement follows the same expressive pattern as the movement of tempo in the music.

Listeners' ratings of audio recordings of the performances showed differences in the perceived expression of the music. The performance that displayed greater variance in timing – both in head movement and music – was perceived as more expressive. The same performance was also perceived as sadder, although this was not as clearly related to either the participant's body movement, or to the sound of the music.

There are a number of limitations in this study, making it difficult to form any conclusions on the basis of these results alone. The results of this study prescribe a number of further steps in order to suitably test the theory that tau-guided head movements in music performance are tied to the expression in the music.

There are sound reasons to continue this enquiry, however. The participant's questionnaire responses show that the upper body is something he is conscious of in performance, particularly in relation to the timing of the music. Also, a fuller understanding of musical body movement has utility in music education, and possibly in other area such as sport training.

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