PLAYING WITH FEELING: THE INFLUENCE OF FELT AND PERCEIVED EMOTIONS ON MOVEMENT FEATURES IN PIANO PERFORMANCES

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Tiivistelmä – Abstract This thesis studied the influence of - and combinations of - felt and perceived emotion on performer movement. Pianists played a piece with which they had an emotional connection in the following conditions: Technical (focusing on technical aspects), Expressive (expressing the music) and Emotional (*feeling* the emotion of the music). Thirty-six movement features (amount of movement, jerkiness of movement and postural features) were extracted from Motion Capture data and compared between different emotion types: 1) positive and negative felt emotion, 2) music-related and performance-related felt emotions, and 3) a combination of felt and perceived emotion (arousal and valence levels in the music). Positive emotions during a performance were related to expressive movement. *Performance*-related negative emotions (e.g. nervousness) were related to jerkiness of wrists whereas *music*-related negative emotions (e.g. feeling sadness of the music) were related to postural features. Expressive playing elicited the most expressive movement, whereas feeling emotion of the music elicited the most fluctuations of head tilt and the least jerkiness of technical movements. Interactions of perceived and felt emotions during performance seemed to also be reflected in movement. Although high arousal music elicited the most expressive movement in the Expressive condition, in the Technical and Emotional conditions, some expressive movements were significantly higher in the low arousal music compared to high arousal music. This difference in the Technical condition may be explained by the fact that expressive movement may facilitate the sound-production of the slow notes of low arousal music, but hinder execution of fast music typical in high arousal music. The difference in the Emotional condition may be a result of expressive movements reflecting a mixture of positive and negative felt emotion: the interaction of perceived emotion (e.g sadness of the music), aesthetic music-related emotion and positive performance-related emotions (e.g. enjoying the beauty of the music). Results also suggest that there are differences in jerkiness and postural features when expressing compared to feeling emotion when performing, especially in high arousal and high valence music as well as music of more nuanced mixed emotions (e.g. low arousal/high valence, nostalgia).	
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“To play a wrong note is insignificant;

to play without passion is inexcusable”

– Ludwig van Beethoven[1]

[1] Ferdinand Ries' account of playing *Adagio* variations to Beethoven and Beethoven's attitude towards 'fehlerhaftem Klavierspiel’ (faulty piano playing), (n.d.).

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1 INTRODUCTION

Movements are a vital part of music performance. Broadly speaking, movement can be distinguished between two types: technical and expressive. Technical movements are sound-producing gestures that involve the wrists, fingers as well as elbow and shoulders muscles (e.g. Furuya & Kinoshita, 2008). Expressive movements, such as greater movement and swaying of the head and torso (e.g. Castellano, Mortillaro, Camurri, Volpe, & Scherer, 2008; Chang, Kragness, Livingstone, Bosnyak, & Trainor, 2019; Davidson, 2007; Thompson & Luck, 2012) are evoked by knowledge of the structure, intention of timing and rhythm (Clarke, 1993; Palmer, 1997; Wanderley, Vines, Middleton, McKay, & Hatch, 2005), as well as emotional intention (Dahl & Friberg, 2004). Fewer studies have investigated how gestures may convey felt emotions of the performer, such as a emotions evoked by the performance itself (Lamont, 2012) or from becoming absorbed in the emotion of the music (Van Zijl & Luck, 2013). Research on felt emotion during music performance is important, as feeling the music is the very foundation of music performance: 'a musician cannot move others unless he too is moved… in sad passages, the performer must languish and become sad' (C. P. E. Bach, cited in Persson, 2001). Music performance research has also identified music-related emotion in terms of aesthetic responses (feeling joy when playing music), positive as well as negative performance-related emotions (Lamont, 2012), but so far no research has directly investigated how movement is linked to these emotions. Furthermore, no known music and movement research has explicitly explored mixed emotion (for example, a mix of music-related emotion of enjoying the music, when the emotion of the music itself is sad). There is a need to highlight that expression in a music performance may come from the performer positively experiencing and feeling the music to create a unique and exciting interpretation. As the notion of performing music with 'feeling' is present in theoretical musicology works (Reimer, 2004), this deserves further research also in the field of music psychology to understand how feeling the music may influence movement features, which may have significant and beneficial implications for music in both professional performance and educational domains. This thesis builds on earlier research exploring felt emotions in movement during music performance, specifically investigating how movement is evoked by (combinations of) the emotion of the music itself, positive and negative felt emotions, music-related and performance-related felt emotions during a music performance.

2 LITERATURE REVIEW

This literature review discusses relevant research from two angles: movement in music performance and emotion in music performance (Section 2.1 and Section 2.2, respectively). In bringing the two domains together (Section 2.3), I present further research questions that this thesis explores.

2.1 Movement in music performance

2.1.1 Measuring movement in music performance

There are various ways in which movement during music performance can be recorded and analysed for empirical study. In qualitative methods, videos of performances of pianists (usually case studies), are thoroughly analysed by observing particular gestures with reference to specific points in the music (Davidson, 1995; 2007; Delalande, 1995). Quantitative methods use technologies that record specific kinematic features in either two dimensional space - applying computer vision techniques to videos (e.g. Alborno, Volpe, Camurri, Clayton, & Keller, 2016; Castellano, Mortillaro, Camurri, Volpe, & Scherer 2008; Jakubowski et al., 2017) - or in three dimensional space - using Motion Capture (hereafter MoCap) techniques (e.g. Burger, Saarikallio, Luck, Thompson, & Toiviainen, 2013; Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2012; Saarikallio, Luck, Burger, Thompson, & Toiviainen, 2013; Thompson & Luck, 2012). Research using combinations of the two also exist (Wanderley et al., 2005). Both these techniques can extract motion cues such as velocity and quantity of movement, speed and jerkiness. Although the quantification of these motion cues through video analysis comes close to approximating MoCap measurements and proves less invasive and more naturalistic (Jakubowski et al., 2017), MoCap is more precise in extracting these motion features at body parts and joints both on a global and local level. It is also possible to analyse kinetic information, for example by electromyography (EMG), to ascertain movement and torque features (Furuya, Altenmüller, Katayose, & Kinoshita, 2010; Livingstone & Thompson, 2009). These types of methods can additionally be used in combination with other types of data in question, for example physiological or neurological data. Sound recordings can also be use in order to further understand how the movement can affect the music performance (Jensenius, 2018).

In measuring these movements, meaningful categorisation is required to further understand their functions. When observing gestures of the pianist Glenn Gould, Delalande (1995) categorized gestures into ‘composed’, ‘flowing’, ‘vibrant’, ‘delicate’, and ‘vigorous’ styles, where each style would occur at different points in the music, depending on articulation (*legato* or *staccato*) and dynamics (*piano* or *forte*). According to Jensenius et al. (2010), gestures in music can be categorized into different types (though these are not exclusive and often overlap):

1) Sound-producing (gestures that are directly involved with making sound),

2) Ancillary gestures (gestures that assist sound-producing gestures, but do not directly make sound),

3) Sound-accompanying gestures (gestures not required to make music) and

4) Communicative gestures.

In this thesis, the sound-producing gestures are broadly referred to as technical, and the ancillary gestures and sound-producing gestures as expressive gestures.

2.1.2 Technical movement

Sound production in piano playing mainly uses the fingers and wrists, where pianists are shown to have incredible fine-motor planning (Dalla Bella, Giguère, & Peretz, 2007; Goebl & Palmer, 2008, 2013; Novembre & Keller, 2011; Ruiz, Jabusch, & Altenmüller, 2009; Sammler, Novembre, Koelsch, & Keller, 2013). Certain factors (such as skill level, articulation, and individuality) influence how these technical movements are executed. Smoothness of these movements can indicate a higher level of proficiency in motor skills in music performances (Gonzalez-Sanchez, Dahl, Hatfield, & Godøy, 2019). In exploring the influence of skill level in technical movements, Furuya and Kinoshita (2008) compared movement organisation for keystrokes between skilled and unskilled pianists. The players with more experience utilised more complicated movements to the advantage of greater movement efficiency (therefore reduce possibility of damage), whereas those with less experience used more simplistic and less efficient movements. Another study found concert-pianists (compared to students and teachers) had more “erratic” (i.e. not useful) than “useful” movement while playing 16 bars of a Bach minuet (Ferrario, Macrì, Biffi, Pollice, & Sforza, 2007). This could be due to the fact that expert pianists spread their movements to other joints, such as the shoulder and elbow, to lessen the physical load for fingers and wrists (Furuya & Kinoshita, 2008). Timbral (e.g. pressed key *versus* struck key), dynamic and tempo differences have been shown to influence velocity in shoulder, elbow and finger movements (Furuya & Altenmüller, 2013; Furuya et al., 2010). It should also be noted, that there are many individual differences amongst pianists, regardless of their level of professionality (Bella & Palmer, 2011; Ferrario et al., 2007). Although a plethora of further research on mapping notes from a music score into motor actions is a whole research topic of its own, for the scope of this thesis, it is sufficient to ascertain that wrists and fingers are mainly involved with technical movements, while shoulders and elbows (in part) can also contribute to facilitating such wrist and finger movement in technical movements.

2.1.3 Expressive movement and gestures

Performer gestures are important for conveying expression (see Juslin, 2003) in conductors (Toivianen, Luck, & Thompson, 2010), in singers (Davidson, 2001) and in instrumentalists (e. g. Davidson, 2007; Wanderley et al., 2005). Comparing pianists' gestures in conditions with different expression intensities (deadpan, projected, exaggerated), increased expression elicited larger and stronger movement patterns (Davidson, 2007; Thompson, 2007; Thompson & Luck, 2012). More specifically, expression may be related to the amount of movement in locations such as the head, shoulders and upper torso, (Castellano et al., 2008; Davidson, 2007; Thompson, 2007; Thompson & Luck, 2012), posture fluctuations (Camurri et al., 2004; Wanderley et al., 2005) and swaying (Clarke 1993; Davidson, 2002). Audiences can also recognise these movement cues (from studies using audio-only, visual-only and audio-visual stimuli) as expressive intentions (Davidson, 1993; Vuoskoski, Thompson, Clarke, & Spence, 2014), tension changes (Vines, Wanderley, Krumhansl, Nuzzo, & Levitin, 2004) and musical expertise (Griffiths & Reay, 2018; Tsay, 2013), although this may depend on the percievers' musical training and the genre of the music (e.g. Baroque, Romantic or Modern; Huang & Krumhansl, 2011).

One approach to understanding why expressive movement occurs is the embodiment theory; a very broad concept that constitutes many sub-theories and hypotheses (Thompson, 2012), the theory derives from the idea that our cognitions are shaped by our bodily properties and how they interact with the environment (Leman, 2008; Shapiro, 2007; Varela, Rosch, & Thompson, 1991). In music perception, for example, pitches are called “high” or “low”, not because they exist in a position in space, but rather because of where these pitches resonate (in higher body regions for “high” pitches and in lower body regions for “low” pitches) together with bodily gestures that accompany them, such as raising eyebrows if singing high or frowning if singing low pitches (“orientation metaphors”; Lakoff & Johnson, 1980). In music performance, the embodiment theory outlines how our mind responds to music and shows that these reactions are somehow conveyed through a corporeal state, and consequently the body movement regulates our thought processes in performing (Leman, 2008). Many studies show that our body “embodies” the expressivity of the music (e.g. Davidson, 1993; Delalande, 1995; Wanderley, Vines, Middleton, McKay, & Hatch, 2005), and that this process is linked to our cognitions and emotions (Poggi, 2006). In support of the embodiment theory, expressive movements occur in relation to cognitive knowledge, such as context, style and structural features of the piece (metric, harmonic, melodic and phrase structures as well as cycles of tension and relaxation; Clarke, 1993; Huang & Krumhansl, 2011; Vines, Wanderley, Krumhansl, Nuzzo, & Levitin, 2004; Wanderley et al., 2005). Furthermore, expressive movements may provide a time-keeping mechanism, where structural and timing information (e.g. rhythm) is an input to the motor system, and movement can then regulate a cognitive sense of accurate timing (Palmer, 1997). Using more sophisticated technologies (motion capture, time warping algorithms), research by Wanderley et al. (2005) supports this embodied idea further, concluding that when clarinettists were asked to play without movement, performances were faster than their “standard level” performances and “expressive” performances.

In summary, different types (or combinations) of qualitative and quantitative methodologies can offer rich insight into movement features in music performance and their functions. Technical movements produce the sound and are also involved with manipulating timbre in piano performance. Ancillary and sound-accompanying movements not only visually articulate more expressive aspects of the music (such as phrasing, timing, tension and relaxation cycles), but also aid the cognitive regulation of structural and temporal precision of music performance (Clarke, 1993; Wanderley et al., 2005). This supports the embodiment idea that our cognitions and body movements are constantly influencing each other. In extending this theory to emotions and body movement, gestures would also embody the emotion of the music and the emotion felt by the performer. How performers may embody these emotions are discussed further in Section 2.3, after a brief review of emotion research.

2.2 Emotions in music performance

It should be noted that the definition of terms such as emotion and affect in the literature are sometimes unclear. For consistency, the terms of emotion and affect used in this thesis are defined by the definitions suggested by Juslin & Västfjäll (2008):

> Affect: an umbrella term that covers all evaluative – or valenced (i.e., positive/negative) – states such as emotion, mood, and preference.
>
> Emotion: relatively intense affective responses that usually involve a number of sub-components – subjective feeling, physiological arousal, expression, action tendency, and regulation – which are more or less synchronized. Emotions focus on specific objects, and last minutes to a few hours.

Within the music psychology domain, two main different types of emotion have been established, namely perceived emotions (the emotion of the music itself) and felt emotions (emotions induced by the music that are truly felt by an individual). For perceived emotions, most literature measuring musical emotions utilise either the discrete model (using categories based on basic, everyday emotions of happiness, anger, sadness and fear; Ekman, 1992) or dimensional models, which are based on the axes of valence (positive or negative) and arousal (Russell & Pratt, 1980). In comparing these two models, Vuoskoski & Eerola (2011) found that the dimensional model out-performed the discrete model for ambiguous musical examples. Although music research has used the discrete model and dimensional models to account for perceived emotion, these two models seemed inadequate to measure *felt* emotion in music as they do not consider the more nuanced or aesthetic emotions.

The Strong Emotions relating to Music (SEM; Gabrielsson & Lindström, 2003) and Geneva Emotional Music Scale (GEMS; Zentner, Grandjean, & Scherer, 2008) were created to account for felt emotions evoked by music, such as wonder and awe. As in music listening, the differentiation between perceived and felt is also clear in music performance (Van Zijl & Sloboda, 2010; Van Zijl & Sloboda, 2013). Here, felt emotion can further be defined and categorised into music-related felt emotion (in response to the music itself) and performance-related felt emotion (emotion felt in the context of performance). The term ‘emotional engagement' in this thesis refers to the extent that the performer is feeling the emotion of the music. Levels of emotional engagement are also defined in this thesis as follows: low emotional engagement refers to performer focusing on more technical aspects rather than emotional, medium emotional engagement refers to focusing on expressing the emotion, and high emotional engagement refers to truly feeling the emotion of the music.

2.2.1 Music-related felt emotions

Music-related emotions are evoked by the music itself. Based on research discussed below, I propose that these emotions can also be split further into 1) aesthetic responses (for example awe or enjoying the music itself), or 2) mirroring responses (actually engaging and feeling the explicit emotions of the music, e.g. feeling sad if the music itself is sad).

Music-related aesthetic emotions such as wonder and awe (Konečni, 2005; Lowis, 1998) occur during music performances (Lamont, 2011; Van Zijl & Sloboda, 2010). There is also physiological evidence to suggest that a greater level of aesthetic emotion (reported pleasant emotions) are reflected in a higher heart rate level when performing a Bach prelude (Nakahara, Furuya, Masuko, Francis, & Kinoshita, 2011). This study additionally found that heart rate was higher when performer played an 'emotional' version of the prelude, compared with a 'non-emotional' rendition of the same piece. This supports the idea that greater positive and stronger emotional feelings may increase a performer's experience.

Music-related mirroring responses of felt emotion are reported by many musicians as being essential in performing music: "a musician cannot move others unless he too is moved… in sad passages, the performer must languish and become sad" (C. P. E. Bach, cited in Persson, 2001). Although this seems to be a very common method that performers would use in order to perform expressively, and is often discussed in masterclasses and individual lessons (as well as from my own personal experience), there is less research in the music psychology domain exploring how felt emotions may be reflected in performance movement. This may be because movement affected by music-related felt emotion might be very subtle and it can be difficult to induce these emotions (and to establish how successful this induction may be). Nonetheless, a few studies have explored the role of feeling the emotion of the music in performance. Glowinsky et al. (2008) instructed professional violinists to perform a piece to convey anger, joy, sadness and peacefulness in two conditions: playing to express the emotion and playing after being induced with elation or sadness using the Velten mood induction procedure[2]. The study found that feeling elation resulted in a faster performance compared to that when just expressing joy (before induction). Lower heart rate variability occurred both after induced sadness and induced elation, suggesting that feeling the emotion made the participants calmer. Additionally, right arm muscle tension increased from expressing sadness to when the performers were induced with sadness. In another mood induction study, (Van Zijl & Luck, 2013; Van Zijl & Luck, 2013b) asked violinists to play in three different conditions: a "Technical" condition (where the emphasis was to play the notes correctly), an "Expressive" condition (emphasis on expressing composer's/score's intentions) and an "Emotional" condition (being induced with the emotion of the piece and strongly feeling this emotion when playing). During subsequent interviews, two out of eight participants said they preferred the "Expressive" condition. Six out of eight preferred "Emotional" condition, with some commenting on how much more they absorbed themselves in the music when conveying expressive intention. These interviews reveal the importance of engaging with the music to heighten enjoyment in performance. Such engagement also affected movement (for further discussion, see Section 2.3.3).

2.2.2 Performance-related felt emotions

Performance-related emotions in a music performance are induced by the actual performing experience. Lamont (2012) studied positive and negative emotions of musical performers, basing her questions on the Strong Emotions in Music Descriptive System (SEM-DS; Gabrielsson & Lindström Wik, 2003). She found differences in negative and positive emotions connected to a performance itself; she also observed that emotion could change throughout a performance. Other studies that have explored experiences of musicians in performance situations tend to involve negative experiences, such as being under pressure (Buma, Bakker, & Oudejans, 2015) or recovering from a mistake (Oudejans, Spitse, Kralt, & Bakker, 2016).

[2] Velten mood induction (Velten, 1968) is one of the most widely used from a range of emotion-inducing techniques (for a review see Martin, 1990), where participants read several positive, neutral or negative statements, focusing and trying to feel the statements. Example positive statements include "If you attitude is good, then things are good, and my attitude is good." Example negative statements include: "I'm discouraged and unhappy about myself" and "I have too many bad things in my life."

2.2.3 Mixed felt emotions

It should be noted however, that it is possible that performers experience a sense of mixed felt emotion, for example positive and negative emotions (such as excitement and nervousness) simultaneously (Gabrielsson & Lindström, 2003; Lamont, 2012; Van Zijl & Sloboda, 2010). Furthermore, emotions can be mixed in terms of music-induced felt emotion and performance-induced felt emotion, for example a performer may be nervous about the performance, but sad in the sense that they are performing a sad piece of music, or a performer may be sad when playing a melancholy piece, whilst at the same time also experiencing enjoyable sensations of the act of performance (a mix of the music-related aesthetic and mirroring responses). Additionally, different emotions may provide strategies to aid a music performance. For example, pianists revealed they focus on music-related information to cope with experiencing negative performance-related emotions, such as feeling frustrated when making a mistake (Buma et al., 2015; Oudejans et al., 2016).

Felt mixed emotions have been explored more in listeners, where music with mixed cues (fast/minor-key music or slow/major-key music) also elicit mixed feelings of sadness and happiness (Hunter, Schellenberg, & Schimmack, 2010). The phenomena of experiencing pleasure while listening to sad music has been frequently explored. One reason why we may enjoy listening to sad music is because it seems to be the emotion that evokes the strongest experiences (Bannister, 2018; Gabrielsson, 2002; Gabrielsson & Lindström, 2003; Lowis, 1998) and is used for emotion regulation (Saarikallio, 2011; Saarikallio & Erkkilä, 2007; Tol & Edwards, 2013; Tol & Edwards, 2015). There also might be a mediating factor: it may be that we are enjoying the sensation of “being moved” (Vuoskoski & Eerola, 2017) or appreciating the aesthetic and beautiful qualities of sad music (Vuoskoski, Thompson, McIlwain, & Eerola, 2012). However, this phenomenon is not explored thoroughly in performers. Further research may reveal why performers enjoy performing sad music and whether the same mechanisms of enjoying sad music in listeners exist in performers.

In summary, perceived emotion can be measured on a discrete (categories of emotion) and dimensional models (scales of arousal and valence). Felt emotion can be categorised in music-related emotions (further categorised in this thesis into aesthetic responses or mirroring responses of feeling the music’s emotion) and performance-related emotions (either negative or positive). Differences in emotional experiences can affect the performance, where mirroring responses of music-related emotion can help with expressing the music while a mixture of aesthetic and mirroring responses of music-related emotion may help with coping with negative performance-related emotion.

2.3 Emotions and movement in music performance

In tying the two research topics of movement and emotion together, this section reviews literature which deals with the embodiment of the emotion of the music (perceived emotion, Section 2.3.1) and emotion of the performer (felt emotion, Section 2.3.2) in music performance.

2.3.1 Perceived emotion

Music performers can communicate the emotion of the music (perceived emotion) through gestures, which has been observed in research using both the discrete and dimensional models (see Section 2.2). Using the discrete model of emotion, Dahl and Friberg (2004) asked participants to rate emotions in video recordings of a professional marimba player playing the same emotionally-neural piece with different emotional intentions (happiness, anger, sadness and fear). Sadness was the most successfully identified, followed by happiness and anger, though these were sometimes confused (i.e., participants mistook anger for happiness, and *vice versa*). When assessing which gestures may have contributed to emotional recognition, participants rated angry and happy performances as having large movements, with angry movements as faster and jerkier. Sad intentions were rated as small, slow and even movements. Fear was least well recognized and the gestures were less consistently rated, though participants tended to rate them as being small, fast and jerky. This provides evidence that emotional intentions can become embodied and expressed in a musical performance. The results of this study are relatively well supported by a wealth of literature from other domains (acting and dancing as well as music performance), which suggests that (and how) movement can display these basic emotions (see Table 1, compiled by the author for this thesis).

However, music does not always express these everyday emotions (Castellano et al., 2008; Konečni, 2005). Some research suggests that more music-specific emotions are required in music and emotion studies, for example the term “sadness” should be replaced by “peacefulness” and “tenderness” (Vuoskoski & Eerola, 2011). To this end, Huang and

Krumhansl (2011) compared the typically used five general emotions and more subtle adjectives (from Hevner's 1936 Adjective Circle) such as melancholy. Indeed, the participants preferred to choose the more subtle adjectives.

Another way of overcoming ambiguity of emotions, is to use dimensional models (Vuoskoski & Eerola, 2011). Castellano et al. (2008) combined emotional models creating conditions of 'musical' discrete emotions that had different positions in the valence and arousal space (dimensional model; Russell & Pratt, 1980), namely: *sad* (low arousal and valence), *allegro*[3] (medium-high arousal and valence), *serene* (low arousal, medium valence) and *over-expressive* (high arousal, undefined valence). In analysing a pianist performing a Beethoven sonata, velocity of head movements, peaks and timing (attack and release) of motion were found to be the main cues of these expressive emotions.

Table 1. Movement characteristics conveyed by emotion, where movement was elicited from [1] musical performance, [2] dance performance, [3] acted, [4] induced emotion on dance movement, or [5] innate characteristics

Emotion conveyed	Movement characteristic	Study
Happiness	Large movements	Dahl & Friberg, 2004[1]; Wallbott, 1998[3]
	Fast movements	Boone & Cunningham, 2001[5]; Van Dyck et al., 2013[4]
	Smooth movements	Burger et al., 2013
	Lifting shoulder	Wallbott, 1998[3]
	Raising chin	Wallbott, 1998[3]
	More rotation of body	Boone & Cuningham, 2001; Burger et al., 2013
Tenderness	More torso tilt	Burger et al., 2013[2]
	Less acceleration	Burger et al., 2013[2]
	Smooth movements	Burger et al., 2013[2]
Sadness	Small movements	Dahl & Friberg, 2004[1]; Wallbott, 1998
	Small amount of movement	Boone & Cunningham, 2001[5;] Van Dyck et al., 2013[4]; Wallbott, 1998[3]
	Slow movements	Dahl &Friberg, 2004[1]
	Smooth movements	Dahl &Friberg, 2004[1]
	Collapsed body posture	Wallbott, 1998[3]
Anger	Large movements	Dahl &Friberg, 2004[1]
	Jerkier movements	Burger et al., 2013[2]
	Lifting shoulders	Wallbott, 1998[3]

[3] Although not an emotion per se, 'Allegro' is a speed associated with cheerfulness

In summary, basic emotions may be effectively conveyed through gestures in general terms, since emotions may have certain movement characteristics, though fear is not necessarily conveyed as well (Camurri, Lagerlöf, & Volpe, 2003; Camurri, Mazzarino, Ricchetti, Timmers, & Volpe, 2004; Dahl & Friberg, 2004; Gabrielsson, 2002). However, more 'musical' emotional terms should be used in studying expression of emotions in music, or a dimensional approach (using arousal and valence) should be used to consider the ambiguity of emotion in music.

2.3.2 Felt emotions: Performance-related

Although no study shows explicitly the relationship between movement and performance-related emotions, perception studies and interviews provides evidence to support the idea that they are linked. These studies seem to focus on negative aspects of performance-related emotion in performance gesture, namely anxiety and nervousness. Kwan (2016) found that negative performance-related felt emotions (performance anxiety) impacted on ratings of expressivity and performance quality in visual-only ratings. This suggests that felt negative emotions are expressed through movement, though future research is required to explore this in greater detail as this was only a perception study (which did not further explore the movement features). As for interview data representing performance-related emotions, a clarinettist in Wanderley et al. (2005) commented that her movements "were exaggerated when she was nervous during performance" (p. 109). A performer in Lamont (2012) commented that when she "felt very nervous… even my fingers freezed up [sic]" (p. 584).

2.3.3 Felt emotions: Music-related

Expression, together with expression of emotion, in music performance is hard to teach directly, so one method is to feel the emotion of the music (Reimer, 2004; Woody, 2000; Woody, 2002). The importance of differentiating between just expressing perceived emotion and truly feeling emotion has been shown in research using actors and emotion induction. Wallbott (1998) found movement differences between good actors (who try to truly feel the emotion) and actors who simply used stereotyped movement for a particular emotion. Similarly, acted emotion was perceived more strongly compared to induced emotion (Wilting, Krahmer, & Swerts, 2006). Van Dyck, Vansteenkiste, Lenoir, Lesaffre, & Leman (2014) induced dancers with either a happy or sad emotion and asked them to dance to emotionally neutral music. Although movement analysis did not show any significant differences between the two emotions, observers were able to discriminate between the two emotions above chance level, especially for the female dancers. Saarikallio et al. (2013) showed that positive or negative felt emotions are also reflected when dancing to emotionally-neutral music. Without using any emotion induction, participants simply reported their affect upon arrival to an experiment and were told to dance freely. Those who reported higher positive affect positively correlated with a more open posture, further suggesting that felt emotion is expressed through movement.

There is only one study which has looked into movement features in performers explicitly feeling the emotion of the music in performance. Van Zijl and Luck (2013) found movement differences when performers expressed "sadness" (Expressive condition) compared to when they really *felt* the emotion (Emotional condition). In the former condition, violinists had a more upright posture, as well as the most speed, velocity and jerkiness of movement. By contrast, violinists' posture was significantly more bent and there was significantly lower speed, acceleration and jerkiness of movement in the Emotional condition. This research has only just begun to look at the relationship between emotional experiences and gestures in musical performance, but further research is needed to better understand this phenomena. This may have implications for learning and improving expressivity in music performances.

In summary, research to date has identified separate components of gestures during music performance that can exhibit the perceived emotion of music (with the emotions being expressed and rated using the discrete and dimensional models), and to some extent felt emotions: performance-related emotion (e.g. when nervous) as well as music-related emotions (feeling the emotion of the music). However, researchers have only just begun exploring how movement is intrinsically linked to the felt emotions experienced by the performer. They have thus far only looked at how feeling the emotion of the music is shown through movement and perhaps more could be done to identify how other types of emotion (e.g. performance-related and aesthetic emotions) are expressed through movement. Further research is also required in identifying the corresponding movement features that reflect negative and positive performance-related emotion. It should be noted that although research has identified mixed felt emotions in music performances (Lamont, 2012; Lamont, 2011; Oudejans et al., 2016) as well as a mix of felt and perceived emotion in the felt and perceived domain, i.e. feeling happiness when expressing a sad emotion (based on Vuoskoski et al., 2012), thus far no research has explored the relation between movement and mixed emotion in music performance. In order to further understand how movement is related to expression in music performance, future research is required to explore how movements in music performance may reflect a wider range of emotions, as well as how movements may reflect mixed emotions.

2.4 The current study

The main novelty of this research rests in assessing how movement features in music performance are: 1) evoked by music-related and performance-related emotions that have thus far not been explored in performer movement and 2) evoked by potential interactions of these emotions on performer movement. Critical evaluation of the results of this study could promote the emotional-wellbeing of performers and highlight the importance of felt emotions (both performance- and music-related) in creating an organically expressive performance.

In further investigating mirroring music-related emotions (feeling the emotion of the music, Van Zijl & Luck, 2013) on performer movements, the current research uses more ecologically valid music (i.e. complete musical works chosen by the performers themselves). The reason behind this is the fact that chosen works may have genuine personal meaning to the performers (Evans & Schubert, 2008) as opposed to using controlled and short music excerpts (Van Zijl & Luck, 2013) or emotionally-neutral pieces (Glowinsky et al., 2008). This increases the possibly of the participants feeling aesthetic music-related emotion. It also increases the range of types of music-related emotions that reflect the emotion of the music.

The current research uses a different and more ecologically valid method of emotion induction. Previously, performers have been induced with sadness through a story about the composer and their intention of the piece, then asked to think of the time when they felt the emotion similar to the one the composer experienced while writing the piece (Van Zijl & Luck, 2013; 2014). However, this method uses external factors (influences outside the performer's own self, such as knowledge of a musical style or composer's intentions) as well as internal factors (performer's own feelings; Lindström, Juslin, Bresin, & Williamon, 2003) to induce the emotions. The participants are being asked to feel emotions similar to those of the composer, but may this add a further consideration of personality traits such as empathy (Egermann & McAdams, 2013; Miu & Vuoskoski, 2016; Wöllner, 2012). As the focus of the present study is on the performer's *own internal* experiences, the performers will be asked to employ use their *own* imagery and memories, rather than externally prepared ones (based on 'Autobiographical Recall' technique, see Martin, 1990). This may reflect a more authentic way in which musicians induce emotions in performance, especially in multiple movement or work performances, where they often need to vary or change their emotional state to reflect the music. This 'induction' method is hoped to be more representative of realistic performance emotions and movement.

To assess the ideas brought forward from the literature review, the following research questions are posed:

1. How do positive and negative felt emotions influence movement features in a music performance?
2. How does emotional engagement of the music influence movement features in a music performance?
3. How does emotional engagement of the music influence movement features depending on the emotion of the music? (felt and perceived emotion interaction)

It is firstly hypothesised that positive emotions will lead to more expressive movement whereas negative felt emotions will lead to more subtle, smaller and slower movements. It is secondly hypothesised that feeling the emotion of music will have significantly different performer movement compared to expressing the music or focusing on technical aspects. It is thirdly hypothesised that the arousal and valence of the music will modulate how movement features change depending on whether pianists are expressing or feeling the emotion of the music, where engaging in high arousal and high valence music will increase expressive features (larger movement, with straighter posture) and engaging in low arousal and low valence music will have an opposite effect on movement (smaller, more smooth movement with more hunched posture).

3 METHODS

3.1 Participants

Ten pianists participated in this study (7 females, 3 males; 5 professional, 3 semi-professional and 2 amateur pianists). Further demographic information is displayed in Table 2.

Table 2. Participant demographics

	Age	Years of playing	Years of lessons	Hours of practice per week	Performances in a year
Mean	33.20	24.50	15.80	11.25	21.20
Standard Deviation	11.39	12.63	4.39	11.93	45.44

3.2 Apparatus

An optical motion capture system (Qualisys Oqus 5+) using 8 infrared cameras captured highly spatial and temporal information in *x*, *y*, (two horizontal) and *z* (vertical) dimensions at a frequency rate of 120 frames per second. A Yamaha Clavinova digital piano (CLP-370/340/330) was used for performances. ProTools (version 11.0.3) was used to record the interviews and the performances.

3.3 Materials

3.3.1 Musical stimuli

As listeners experience stronger responses to self-selected music (Evans & Schubert, 2008), it was assumed that this would be the case with performers. For the study, participants were asked to play a piece of their own choice, with which they had an emotional connection. Each performer chose a different piece (see Table 3).

Table 3. Pieces chosen by participants

Pianist	Composer and piece
1	Taneli Kuusisto - *Berceuse* from Trois Miniatures, Op. 4
2	Claude Debussy - Arabesque No. 1, Andantino con moto, from *Deux arabesques*
3	Claude Debussy - *La fille aux cheveux de lin* from Preludes, Book 1
4	Ludwig van Beethoven - Adagio cantabile from Sonata No. 8 in C minor, Op.13, *Sonata Pathetique*
5	Performer's uncle - Waltz (unpublished)
6	Claude Debussy - *L'isle joyeuse*
7	Ilmari Hannikainen - "Valse No. 1", from *3 Valses mignonnes,* Op. 17
8	Sergei Rachmaninoff - No. 5 in E-flat minor, Appassionato, from *Etudes-Tableaux*, Op. 39
9	Richard Wagner, arranged by Franz Liszt - *Isolde Liebestod*
10	Jean Sibelius - *Romance* from 10 pieces, Op. 24.

3.3.2 Measures

The Positive Affect and Negative Affect Schedule (PANAS; Watson et al., 2009), was used to measure felt affect before and after each condition (as explained below). This was chosen as it had been shown to have good internal reliability in both clinical (Ostir, Smith, Smith, & Ottenbacher, 2005) and non-clinical settings (Crawford & Henry, 2004). It has also been used in several studies to assess mood in a musical context (Fiveash & Luck, 2016; Van Zjl & Luck, 2013) as well as in motion capture studies (Saarikallio, Luck, Burger, Thompson, & Toiviainen, 2013). The schedule consists of 10 positive and 10 negative adjectives where subjects were instructed to indicate to what extent they felt a particular adjective on a scale of 1 (slightly or not at all) – 5 (extremely) (see Appendix A).

3.4 Procedure

3.4.1 Set up

The study was conducted in the Motion Capture Laboratory, University of Jyväskylä. The piano was placed in the centre of the room, slightly at an angle to obtain optimum view from the video recording camera (see Figure 1). Motion Capture (MoCap) suits (for the upper body only) were worn by participants, to which twenty-two markers were attached (see Table 4).

Table 4. Motion capture marker placements.

Amount	Place	Specific
Four	Head	One for each: front left, front right, back left and back right of head
Two	Neck	One on the front of the neck (top of sternum) and one on the back of the neck (top of thoracic spine, T1/C7)
Two	Shoulders	One for the left shoulder, one for the right shoulder
Two	Elbows	One for the left elbow, one for the right elbow
Two	Mid-torso	One marker at the front, one marker at the back
Four	Hip	One for each; front left, front right, back left and back right
Four	Wrists	Two for each wrist: one on the inner wrist, one on the out wrist.
Two	Fingers	One for each middle finger on each hand
Two	Piano	One on either furthest right and furthest left side of the keyboard

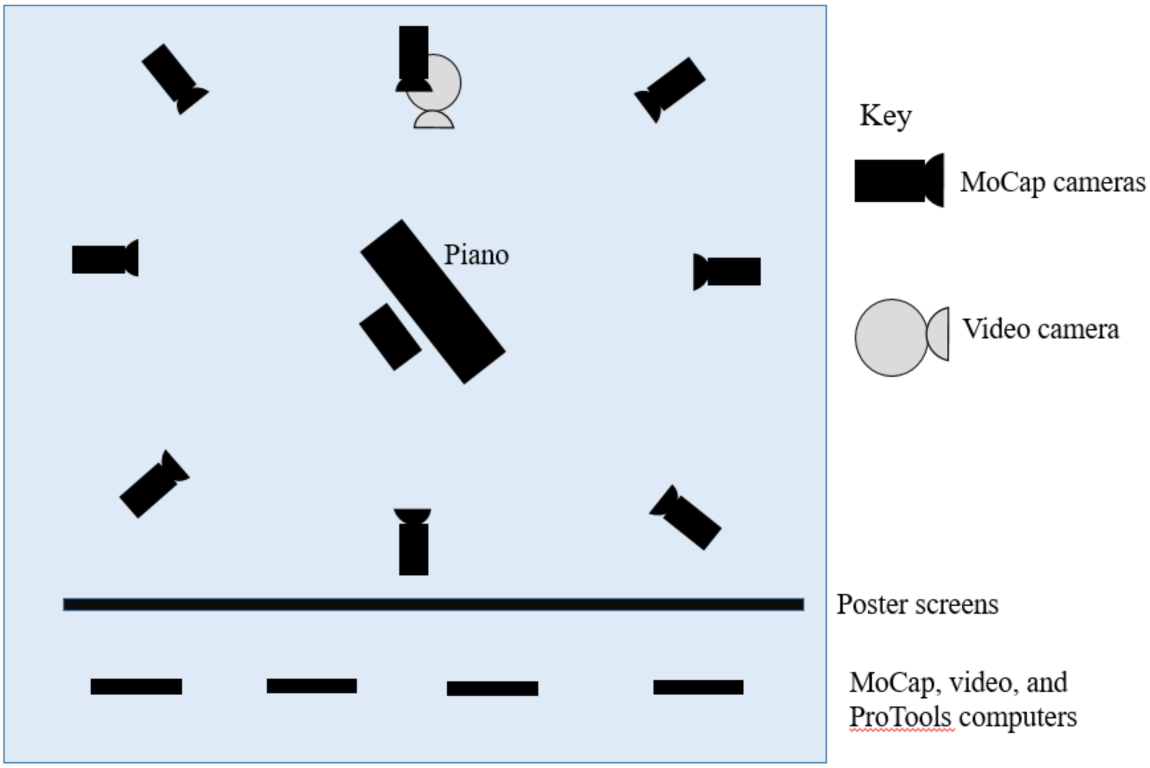


Figure 1. Set up of experiment

3.4.2 Performance conditions

Participants were given time to warm up and become accustomed to the piano and the MoCap suit. Once ready to start the experiment, they were reminded of their participation in the study[4] and completed the PANAS questionnaire, to record their baseline felt emotion. Participants were then asked to perform their selected piece in three conditions. The performance conditions (based on the conditions used by Van Zijl & Luck, 2013) were used as it was assumed they would evoke a range of positive and negative performance- and music-related emotion. Conditions were as follows:

[4] Participants were asked to confirm that they were comfortable with being filmed and recorded, and were told their data would remain anonymous. They were also told that they could take a break at any time, repeat a performance if they were unhappy with it, and that they were allowed stop the experiment completely if they felt uncomfortable or unwilling to continue.

- ‘Technical’ condition: participants were asked to play focusing on executing the score correctly, paying attention to phrasing, dynamics and tempo.

- ‘Expressive’ condition: participants were asked to play the piece expressively, as if they were communicating to an audience.

- ‘Emotional’ condition: participants went through an emotion induction (see Section 3.3.4). Once they felt they were absorbed in the music’s emotion, they were asked to play the piece again as if just playing the emotion, almost as if for themselves.

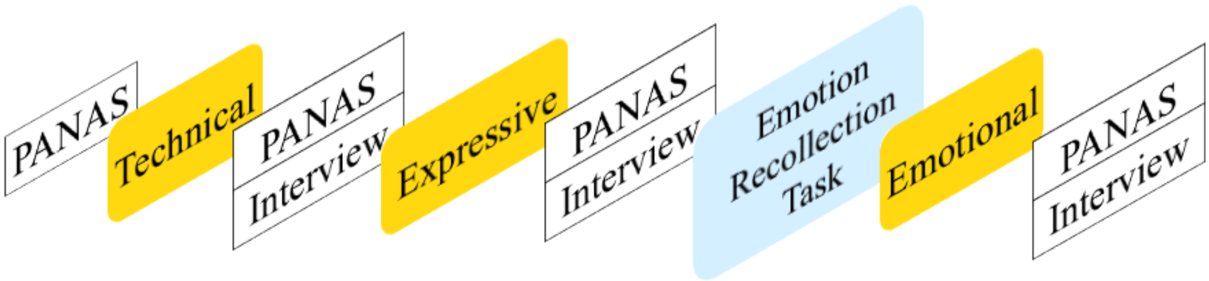


Figure 2. Order to experimental procedure

3.4.3 Emotional recollection task

To induce participants with the emotion of music, they were asked what emotion their piece conveyed for them. Upon identifying an emotion, they were then asked to recall a previous memory where they had felt this emotion (or to imagine a situation where they would feel this emotion). They focused on this emotion for at least one minute and to allow themselves to become absorbed and feel this emotion.

3.4.4 PANAS and interviews

After each condition, participants completed the PANAS questionnaire, followed by a post-condition interview, asking them whether, in their own words, they could describe the emotions they felt in that performance (in addition to PANAS ratings). After performing in all three conditions, the participants were asked some reflective questions:

1. Which performance did they feel was their best recording and why,

2. Which performance they felt was the most natural,

3. Whether they thought their movement changed in different conditions.

Finally, they completed a demographic questionnaire and were offered baked goods as a "thank you" for their participation and to counter any negative emotions induced by the emotion induction for the final condition (as food can induce positive emotions; Isen & Levin, 1972; Westermann, Spies, Stajl, & Hesse, 1996).

3.5 Pre-processing Motion Capture Data

Thirty recordings (10 pianists × 3 conditions) were collected.[5] Motion data was firstly (partly) pre-processed in the Qualisys system and then further pre-processed and analysed using the MoCap Toolbox, version 1.5 (Toiviainen & Burger, 2011) in Matlab (MATLAB software, version R2016b, MathWorks).

3.5.1 Gap filling trajectories in Qualisys

Missing trajectories were first manually interpolated using the Qualisys system (both polynominally and linearly, depending on which elicited more realistic movements). When a marker was not captured for more than 90%, or the gaps were too large to calculate realistic movement, the marker was eliminated (and treated as a special case, see second paragraph of Section 3.5.2). Motion data was exported to TSV files and further pre-processed using the MoCap Toolbox in MatLab.

[5] Any performances that the participants did were not happy with were deleted and their preferred choice of performance was taken forward into the analysis.

3.5.2 Secondary markers

The initial 22 markers were reduced to 12 secondary markers. This was executed using the *mcinitm2par* and *mcm2j*, *m2jpar* functions in the MoCap Toolbox in MatLab, mapping a set of original markers to onto one joint, which represents a secondary marker. In cases where all markers had a 98% or more trajectory fill, joints were created from the original markers as displayed in Table 5.

Table 5. Number of markers representing respective joints

Secondary marker	Joint	Markers to represent joint
1	Head	Four head markers
2	Neck	One on the front of the neck, one on the back
3	Mid-torso	One marker at the front, one marker at the back
4	Left Shoulder	Left shoulder, one for the right shoulder
5	Right Shoulder	Right shoulder
6	Left Elbow	Left elbow, one for the right elbow
7	Right Elbow	Right elbow
8	Hip	Placed front left, front right, back left and back right
9	Left Wrist	The two left wrist markers: one inner marker and one outer marker
10	Right Wrist	The two right wrist markers: one inner marker and one outer marker
11	Left Finger	Left middle finger
12	Right Finger	Right middle finger

When the trajectory of an original marker had 2% or more missing, secondary markers were calculated using markers with 98% or more trajectory fill. When a neck marker was missing (where one participant's ponytail covered the back neck marker), the two shoulder markers were used to represent the neck secondary marker (see Figure 3 A). When a hip marker was missing, two diagonal hip markers, were used instead of all four (see Figure 3 B). For the secondary marker to represent the mid-torso, the diagonal average between the hip and shoulder markers were used (see Figure 3 C). For the remaining thesis, these secondary markers will be referred to as simply markers.

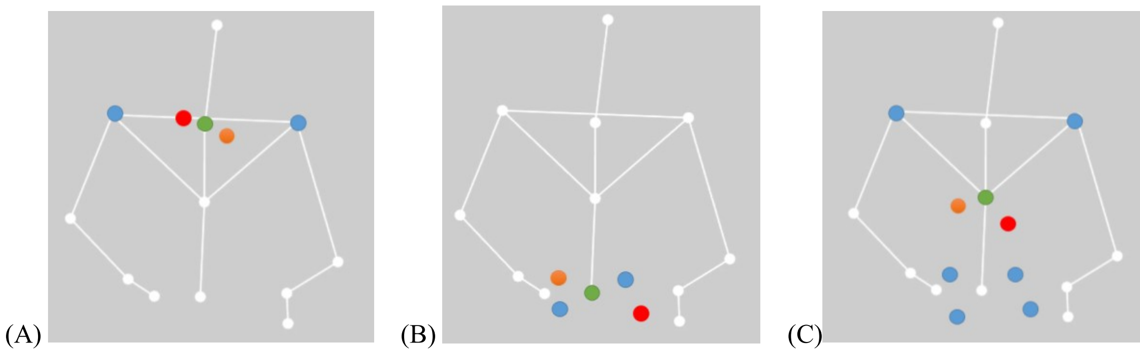


Figure 3. Transforming original markers to secondary markers: special cases. To represent the secondary marker (green) when the one original marker was missing (red), alternative markers were used (blue) and the 'pair' marker ignored (orange).

3.5.3 Gap filling trajectories in Matlab

Any further gaps in trajectories of joints were filled using the *mcfillgap* function (using linear interpolation). The maximum length of a gap fill would be one second, i.e., 120 frames.

3.6 Analysis

3.6.1 Movement analysis

Once all 30 files were trimmed, all missing data was interpolated and the 22 markers converted into 12 secondary markers, the following movement features were extracted:

- **Amount of movement (AM):** represented by total cumulative distance (*mccumdist*);

- **Jerkiness of movement (J):** represented by norm (*mcnorm*, obtaining Euclidean distance) of third-time derivative, calculated using numerical differentiation and a Butterworth smoothing filter, second-order zero-phase (*mctimeder*);

- Postural features

    - **Neck posture (NP):** represented by angle along the *y* dimension between neck marker and head marker (*mcsegmangle*);

    - **Back posture (BP):** represented by angle along the *y* dimension between hip marker and neck marker (*mcsegmangle*);

    - **Head tilt to the left (HTL):** represented by distance between head and left shoulder (*mcmarkerdist)*;

    - **Head tilt to the right (HTR):** represented by distance between head and right shoulder (*mcmarkerdist)*;

    - **Shoulder hunch (SH):** represented by distance between head and mean location of shoulders (*mcmarkerdist*);

    - **Piano lean (PL):** represented by distance between head and piano (*mcmarkerdist*);

The amount of movement was represented by cumulative distance of the entire “travelling” expanse for each performance and each of the twelve markers. Means for the jerkiness for each performance and marker were also obtained for all twelve markers. Means (*m*) and standard deviations (*sd*) were calculated for each neck posture, torso posture, head posture, head tilt (left), head tilt (right) and shoulder hunch for each performance. Regarding the back and neck posture, more negative values indicated the posture was more forward, and more positive values indicated the people were bending backwards. With regard to the standard deviations, the higher the standard deviation, it was assumed that there was more fluctuation of this posture feature. For example, if there was higher standard deviation for Piano lean, there was probably a lot of fluctuation of leaning towards and away from the piano. A total of 36 movement features were extracted from the MoCap data (see Table 6).

As different participants played different pieces, movement features were converted into values to allow comparison between individuals and further statistical analysis. Thus, movement features were rescaled using the Min-Max normalisation to allow comparison between participants. This technique had been used in other kinematic and movement analysis studies to allow comparison between individuals' kinematic features (Best & Begg, 2006), scaling the values between the ranges of 0 and 1.

$$z = \frac{x - \min(x)}{\max(x) - \min(x)}$$

It should also be noted that other features were computed, namely complexity of movement (*mccomplexity*) for each marker, as well as the rotation (*mcrotate*) of certain markers (such as the head and wrist movement). However, these features did not yield any significant or meaningful results and for conciseness of this thesis will not be further discussed.

As previous research had focused on either technical or expressive movements, the current study also broadly operationalised these movement features into two groups of either expressive (sound-accompanying gestures) or technical movements (movement related to producing the sound). In the expressive category was AM of head, shoulders (as found previously in Castellano et al., 2008; Davidson, 2007; Thompson, 2007; Thompson & Luck, 2012) and posture fluctuations (Camurri et al., 2004; Clarke 1993; Davidson, 2002). In the technical movement category was AM of wrists and finger, and jerk of elbow, wrists and fingers (Furuya, Altenmüller, Katayose & Kinoshita, 2010; Furuya & Altenmüller, 2013).

Table 6. Movement features extracted from motion capture data

Movement feature	Locations	Amount
Amount of movement	Head, neck, mid-torso, hip, left and right shoulders, left and right elbows, left and right wrists, left and right middle fingers	12 values
Jerkiness	Head, neck, mid-torso, hip, left and right shoulders, left and right elbows, left and right wrists, left and right middle fingers	12 means
Postural features	Angle for hip and neck markers	1 *m*, 1 *sd*
	Angle for neck and head markers	1 *m*, 1 *sd*
	Distance between head and left shoulder	1 *m*, 1 *sd*
	Distance between head and right shoulder	1 *m*, 1 *sd*
	Distance between head and mean shoulders	1 *m*, 1 *sd*
	Distance between head and piano keyboard	1 *m*, 1 *sd*
	Total movement features:	36 movement features

3.6.2 Piece analysis: general valence of pieces

To check whether participants did engage with the emotion of the piece, it was important to consider the emotion of the piece itself. Pieces were firstly categorised into two very general categories of either positive valence or negative valence – based on how the participants described their piece (extracted from Pre-emotional condition interviews, see Table 7). General valence of the piece is referred to for the rest of the thesis as Piece Valence.

Table 7. Evidence for categorising piece as positive or negative valence

Pianist	Piece	Interview evidence	Valence category
1	Kuusisto - *Berceuse*	'I played that piece at my ex-mother in law's funeral.'	Negative
2	Debussy - *Arabesque*	'It's basically positive [...] it's positive but of course there is a hint of sadness.'	Positive
3	Debussy – La fille aux cheveux de lin	'It's based on a poem [...] about a love thing [… a girl is] excited about a guy but also nervous.'	Positive
4	Beethoven - Adagio	'My mum wants me to play this song at her funeral […]. Oh, I'm getting all teary.'	Negative
5	Waltz	'It's beautiful [...] also the piece that was played in my wedding [sic].'	Positive
6	Debussy - L'isle joyeuse	'This is called the island of happiness. It is very bubbly and impressionistic piece.'	Positive
7	Hannikainen - "Valse No. 1"	'It is so beautiful, it gives me peace.'	Negative
8	Rachmaninoff - Apassionato	'[It] contain[s] a strong emotion message…'	Negative
9	Wagner/Liszt - Isolde Liebestod	'Heavy. So dramatic […] macabre […] heavy and difficult to move. Visceral.'	Negative
10	Sibelius - *Romance*	'It's a strong emotion […] maybe falling in love [...] patriotic in some way?'	Positive

3.6.3 Piece analysis: segmentation of different arousal and valence

All the pieces, apart from one (Debussy - *La fille aux cheveux de lin*), had changing emotions throughout the course of the piece. These pieces were split into segments according to perceived emotion (i.e. the emotion of the piece of music that was being played) and rated according to the Affect Scale (Russel, 1980), using arousal and valence across a 5-point Likert scale. The segments were rated by the experimenter and (to improve validity) four other individuals, three of whom had had musical training (i.e. either had a degree in music or extensive training on an instrument). The Affect Scale was chosen rate the emotion of the music as motion cues allow discrimination "between 'high' and 'low arousal' emotions and between 'positive' and 'negative' emotions" (Castellano, Villalba & Camurri, 2007) and because they are superior in representing more realistic ambiguous music emotion (Vuoskoski & Eerola, 2011).

Each piece segment was rated by arousal (1=very low arousal; 5=very high arousal) and valence (1=very negative valence; 5=very positive valence)[6]. The ratings from all five individuals (1 experimenter + 4 external raters) were averaged and rounded, giving 79 piece-segments with two ratings: one for arousal (1-5) and one for valence (1-5). As statistical tests (ANOVAs) were to be run with Arousal and Valence scores as between-subjects factors, the assumption that this independent variable must be a categorical factor was considered. Therefore, the emotion ratings were transformed into a scale or 1 – 3, giving each segment an Arousal value of either low, medium or high, and a Valence value of low, medium or high.

To categorise emotion and potentially provide confirmation of emotion rating validity, the *miremotion* function from MIRToolbox (Eerola, Lartillot & Toiviainen, 2009; Toiviainen & Lartillot, 2014). However, the results proved to be extremely different from the 'human' ratings and did not provide a valid classification of the segments emotion. Therefore, the MIR results were not used for this analysis.

3.6.4 Movement feature data sets

Two different data sets of Motion Capture data were created to answer the research questions. The first data set was formed by the movement features extracted from the full 10 pieces played in each of the 3 conditions. The second data set consisted of the movement features extracted from the 79 Emotional Segments in each of the three conditions (see Table 8).

[6] Administered as a Google Form

Table 8. Data sets

Piece and piece segments	Movement features
10 whole pieces	10 × 3 conditions × 36 movement features = 1080
79 segments of different perceived emotion	79 × 3 conditions × 36 movement features = 8532

3.6.5 Analysis of PANAS

PANAS scores obtained after each performance condition underwent baseline correction (using the PANAS scores from the very start as the baseline). Positive and negative scores were then calculated by summing the positive adjective scores and negative adjective scores, respectively.

3.6.6 Interviews

Interviews were transcribed and content analysed by phrases. The phrases were coded by categories of emotion as found by Van Zijl & Sloboda (2013) and Lamont (2012). Initial coding was guided by two main categories of perceived and felt emotion, with the latter category being further split into music-related emotion or performance-related emotion (Van Zijl & Sloboda, 2013). The music-related emotions were further split into aesthetic and mirroring emotion subcategories. The performance-related emotions had positive and negative sub-categories (Lamont, 2012). Typical sentences or phrases for each are shown in Table 9.

Table 9. Content Analysis categories for interviews

Perceived Emotion	Felt Emotion			
	Music-related		Performance-related	
	Aesthetic	Mirroring	Positive	Negative
Of course it is a very beautiful piece.	From here… it just gives me chills.	I was feeling a bit sad here, because I tried to express that feeling.	You just remember how wonderful it is to play.	I was starting to get worried about those passages.

3.6.7 Statistical tests

Statistics were calculated using SPSS and R. Statistical figures were made using R and *ggplot2*. As MoCap movement features can be grouped into high-level movement features (Niewiadomski et al., 2019) to represent more meaningful components (Luck et al., 2010; Toiviainen, Luck & Thompson, 2010; Burger et al., 2014) principal component analysis was conducted in order to reduce the number of movement features and variables. However, this did not yield significant results and thus each movement features was considered in the analysis as a separate component. Shapiro-Wilk tests confirmed that most of the data of the movement features was normal, apart from a few variables. Eyeballing the data on histograms (using SPSS) confirmed that none of these data was bimodal. Although using ANOVA tests with non-normally distributed data may increase the chance of a Type 1 error (finding a false positive, Oberfeld & Franke, 2013), they are still relatively robust against non-normal data from a small sample size (e.g. Ziegler, Beyer, Schmider, Danay, & Bühner, 2010), so parametric ANOVA and *t*-tests were run. Nonetheless, non-parametric tests were run and compared with the parametric results. As the parametric and non-parametric yielded similar significance values (Kruskal-Wallis and Mann Whitney tests for ANOVAs and *t*-tests respectively), only parametric ANOVA and *t*-test results are reported. Greenhouse-Geisser corrections were applied to any variables where the assumption of sphericity was violated and pairwise-comparisons used Bonferroni corrections.

PANAS scores were compared between conditions to check if the conditions did play a role in changing the felt affect and emotional engagement throughout the experiment. A mixed-design repeated-measures ANOVA was conducted each for positive affect scores (PA) and negative affect scores (NA) from the PANAS. Condition was set as the repeated-measures and within-subjects factor (three levels: Technical/Expressive/Emotional) and Piece Valence (two levels: Positive/Negative) was set as the between-subjects factor. Once these tests confirmed the conditions had an effect of manipulating felt emotion, a series of statistical tests were conducted to test the research questions.

To test the first research question (how felt affect may influence movement features), correlations and stepwise regressions were run to find an association between felt affect (PANAS scores) and movement features, both between and within conditions. In order to test the second and third research questions (whether emotional engagement had an influence on movement features, and whether this changed depending on the emotion of the piece), mixed-design repeated-measures ANOVAs were conducted for each of the 36 movement features as the dependent variable, [7] with Condition as the within-subjects factor (three levels: Technical/Expressive/Emotional) and Piece Valence (two levels: Positive/Negative) as the between-subjects factor. To test the third research question further, ANOVAs were run for the second data set (36 movement features extracted from 79 segments) with the within-subjects factor Condition (three levels: Technical/Expressive/Emotional) and the between-subjects factors Arousal (three levels: Low/Medium/High) and Valence (three levels: Low/Medium/High). For any significant interactions, additional one-way ANOVAs were performed to compare differences of movement features between levels of Arousal or Valence in each condition (Arousal or Valence level as the between-groups factor).

To further understand some of the results, interviews were content analysed. To check for some uncontrolled variables, a between-groups ANOVA between levels of experience (three levels: Amateur/Semi-professional/Professional) was performed. Independent sample *t*-tests were conducted to compare whether participants played with the music score or without the music score (off-by-heart). As multiple *t*-tests were run, *p* value thresholds were lowered using the Holm method to account for the many tests that were run (to avoid a Type 1 error).

[7] ANOVAs were run individual for the type of movement feature, i.e. a single ANOVA was run each for the (1) amount of movement in the 12 markers, (2) mean jerkiness in the 12 markers, (3) means of postural features calculated by angle, (4) standard deviations of postural features calculated by angle, (5) means of postural features calculated by distances between markers, (6) standard deviations of postural features calculated by distances between markers.

4 RESULTS

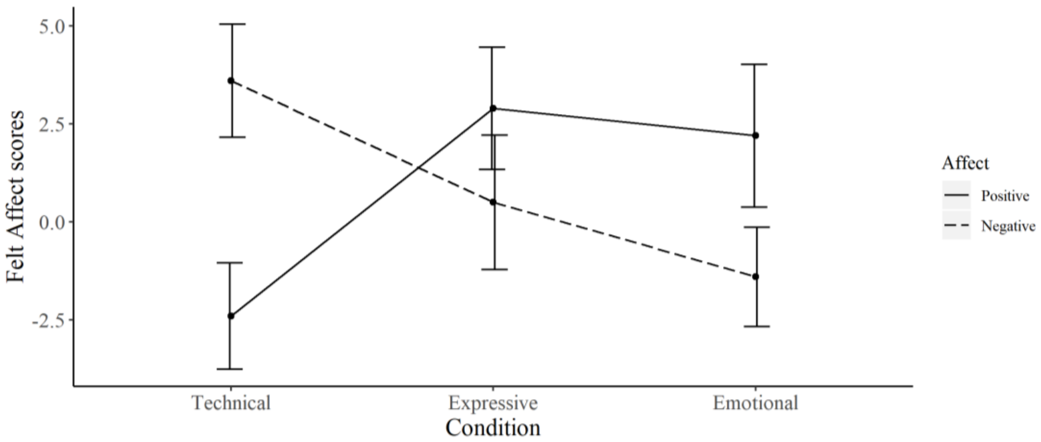
4.1 Checking for Emotional Engagement

Firstly, a mixed-design ANOVA (see Section 3.6.7) was run for the PANAS to ensure conditions had the desired effect of different emotional engagement. Non-significant Mauchly's Test of Sphericity results indicated that the assumption of sphericity had not been violated for either positive affect scores (PA) or negative affect scores (NA) (see Table 10).

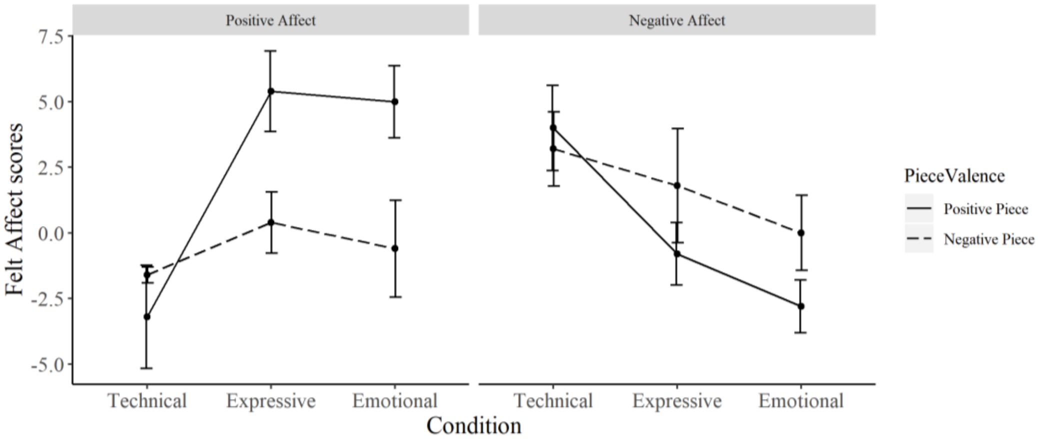
There was a significant main effect of Condition for PA and NA (see Table 10 and Figure 4). PA were lowest in the Technical condition, increased in the Expressive condition and then dropped slightly in the Emotional condition. NA was highest in the Technical condition, decreased in the Expressive condition, and further decreased in the Emotional condition. Pairwise comparison showed significant differences of PA between the Technical condition and Expressive conditions (p = .032) and between the Technical and Emotional conditions (p = .048), but not between the Expressive and Emotional conditions (p = 1.00). A significant difference of NA occurred between the Technical and Emotional conditions (p = .014), but not between the Technical and Expressive conditions (p = .241) and the Expressive and Emotional conditions (p = .104). As the participants were asked to feel the emotion of the piece, it was relevant to investigate whether participants felt the valence of the piece, i.e. PA should be higher and NA should be lower in the Emotional condition for positively- compared to negatively-valenced music. This was partially confirmed by a significant Condition × Piece Valence interaction PA (see Table 10, last three columns).

Table 10. ANOVA results for main Condition effects and Condition × Piece Valence interaction for PANAS

Measure	Mauchly's test of Sphericity	df	Main effect of Condition			Condition × Piece Valence		
			F	p	η_p^2	F	p	η_p^2
PA	$\chi^2(2) = 1.72$	2, 16	8.41	.00	.51	4.05	.04	.34
NA	$\chi^2(2) = 4.59$	2, 16	8.26	.00	.51	1.33	.29	.14



(A)



(B)

Figure 4. PANAS across Conditions. (A) Means and standard error bars for PA and NA scores in Technical, Expressive and Emotional conditions. (B) Means and standard error bars for PA in positive and negative pieces and NA in positive and negative pieces across conditions.

PA from Technical condition to Expressive condition increased greatly for positively-valenced pieces, but increased only slightly for the negatively-valenced pieces. PA dropped slightly in the Emotional condition in both positively- and negatively-valenced pieces. The pattern of NA was similar for both positively- and negatively-valenced pieces: starting high in the Technical condition and continuing to decrease in the Expressive and Emotional condition. To test if PA was higher and NA was lower in positive piece compared to negative piece, *t*-tests were run for the PANAS in each condition with Piece Valence as the independent group factor. Although no significant differences were found, PA was higher when engaging with positively-valenced pieces compared to when engaging with negatively-valenced pieces (almost significant in Expressive, p = .09 and Emotional, p = .11) (see Figure 4 B, PA). Similarly, NA was higher when engaging with negatively-valenced emotions compared to when engaging with positively-valenced pieces (see Figure 4 B, PA).

To summarise, participants overall had different emotions in different conditions, depending on the Piece Valence. In the conditions with greater emotional engagement, participants who played positively-valenced pieces showed more positive affect (higher PA, lower NA) compared to participants who played negatively-valenced music (lower PA, higher NA). The results suggest that the participants assimilated the general valence of the piece and did engage with the emotion of the piece in the Emotional condition.

4.2 Influence of Positive and Negative Felt Affect on movement features

Correlations and step-wise regressions were run between PA and movement features, and NA and movement features, both within (36 movement features) and between Conditions (36 movement features × 3 Conditions). Expressive movement features (amount of movement in head, mid-torso, left shoulder, left and right elbow, fluctuations of head tilt, shoulder hunch and piano lean) seemed to significantly correlate positively with the PA (see Table 11). Some of these expressive movements (AM of head, fluctuation of head tilt and piano lean) significantly correlated negatively with NA, suggesting that a more positive affect in the participants increased expressive movement (see Table 11).

Table 11. Correlations for Positive Affect (PA) and Negative Affect scores (NA) for amount of movement, jerkiness, head tilt right (HTR), shoulder hunch (Fl. SH), and fluctuations of back posture (Fl. BP), neck posture (Fl. NP), head tilt left (Fl. HTL), head tilt right (Fl. HTR), shoulder hunch (Fl. SH) and piano lean (Fl. PL). * *p* < .01, ** *p* < .01, *** *p* < .001

Amount of movement			Jerkiness			Postural features		
Location	PA	NA	Location	PA	NA	Feature	PA	NA
Head	.45*	-.403*	Head	ns	-.50**	HTR	-.41*	ns
Mid-torso	.49**	ns	L. elbow	ns	.50*	SH	-.38*	ns
L. shoulder	.46*	-.37*	L. wrist	-.418*	ns	Fl. BP	.39*	ns
L. elbow	.38*	ns				Fl. NP	.40*	ns
R. elbow	.60***	ns				Fl. HTL	ns	-.38*
						Fl. HTR	.43*	-.40*
						Fl. SH	.44*	ns
						Fl. PL	.42*	-.41*

Step-wise multiple regressions were run to explore the effect of felt emotion more rigorously. PA was predicted significantly by typically expressively movement features such as amount of movement of lower torso, jerkiness of neck and head tilt. NA was significantly predicted by jerkiness of left wrist, hip and fluctuations in Piano Lean. Step-wise regressions were run separately in each condition to further understand the relationship between the music-induced and performance-induced emotion.

Table 12. Regressions for movement features predicting Positive affect and Negative affect

	Model of Predictors	Regression equation	R^2	Standardised coefficients (B)
PA	AM of Hip	$F(2,24) = 11.54$, $p = .000$	.49	.63, $p = .000$
	Jerkiness of neck			-.49, $p = .003$
NA	Fl. of Piano lean	$F(3,23) = 11.33$, $p = .000$	.60	-.28, $p = .006$
	Jerkiness of hip			.49, $p = .002$
	Jerkiness of left wrist			.48, $p = .002$

Table 13. Regression for movement features predicting Positive affect and Negative affect across Technical (Tech), Expressive (Ex) and Emotional (Em) conditions

	Predictors	Regression equation	R^2	Standardised coefficients (B)
PA (Tech)	Jerk of left finger	$F(4,5) = 80.14, p = .000$	.99	-1.01, $p = .000$
	AM of right shoulder			-.79, $p = .000$
	Fl. Neck posture			-.36, $p = .000$
	Jerk of right shoulder			.33, $p = .000$
NA (Tech)	Jerk of left wrist	$F(2,7) = 18.37, p = .002$	.84	6.02, $p = .001$
	Jerk of right wrist			-3.81, $p = .007$
PA (Ex)	*No significant results*			
NA (Ex)	AM of left finger	$F(2,7) = 7.97, p = .022$	.50	.71, $p = .022$
PA (Em)	Head tilt R	$F(4,5) = 34.83, p = .001$	.97	-1.17, $p = .000$
	Back posture			.51, $p = .005$
	AM right wrist			-.34, $p = .015$
	Jerk head			-.26, $p = .047$
NA (Em)	Fl. Piano lean	$F(2,7) = 11.11, p = .007$	.76	-1.14, $p = .002$
	Fl. Shoulder hunch			.73, $p = .019$

In summary, PA seemed to be related to movement features that were broadly operationalised as expressive movement. NA in the Technical condition was related closer to technical movements, while NA in the Emotional condition was more related to postural features.

4.3 Influence of emotional engagement on movement

4.3.1 Amount of movement

ANOVAs with the amount of movement (AM) at each marker location as the dependent variable revealed significant main effects of Condition for mean AM in the head, neck, mid-torso, left shoulder, right shoulder, right elbow and hip (see Table 14). AM appeared to be highest in the Expressive condition, slightly lower in the Emotional conditions and lowest in the Technical condition (see Figure 5). Pairwise comparisons revealed that the main differences were between the Technical condition and Expressive condition (for the head, p = .001, neck, p = .002, mid-torso, p = .000, left shoulder, p = .001, right shoulder, p = .002, hip, p = .02) and the Technical and Emotional condition (for the neck, p = .02, mid-torso, p = .03, left shoulder, p = .02, and right shoulder, p = .02).

Table 14. ANOVA results for main Condition effects and Condition × Piece Valence interaction for AM. * p < .01, ** p < .01, *** p < .001.

Marker	Mauchly's test of Sphericity	df	Main effect of Condition			Condition × Piece Valence		
			F	p-value	η_p^2	F	p-value	η_p^2
Head	$\chi^2(2) = 7.18$*	1.22, 9.75	10.82	.001	.58	.86	.40	.10
Neck	$\chi^2(2) = 3.18$	2,16	18.83	.00	.70	2.07	.16	.21
Mid-torso	$\chi^2(2) = 3.97$	2, 16	13.07	.00	.62	1.29	.30	.14
L. shoulder	$\chi^2(2) = 3.29$	2, 16	18.06	.00	.69	1.82	.19	.19
R. shoulder	$\chi^2(2) = 3.80$	2, 16	18.22	.00	.70	2.21	.14	.22
L. elbow	$\chi^2(2) = 5.97$	2, 16	2.91	.08	.66	.39	.69	.05
R. elbow	$\chi^2(2) = 1.39$	2, 16	5.70	.01	.42	1.64	0.23	.17
Hip	$\chi^2(2) = 2.82$	2, 16	7.90	.004	.50	3.45	.06	.30

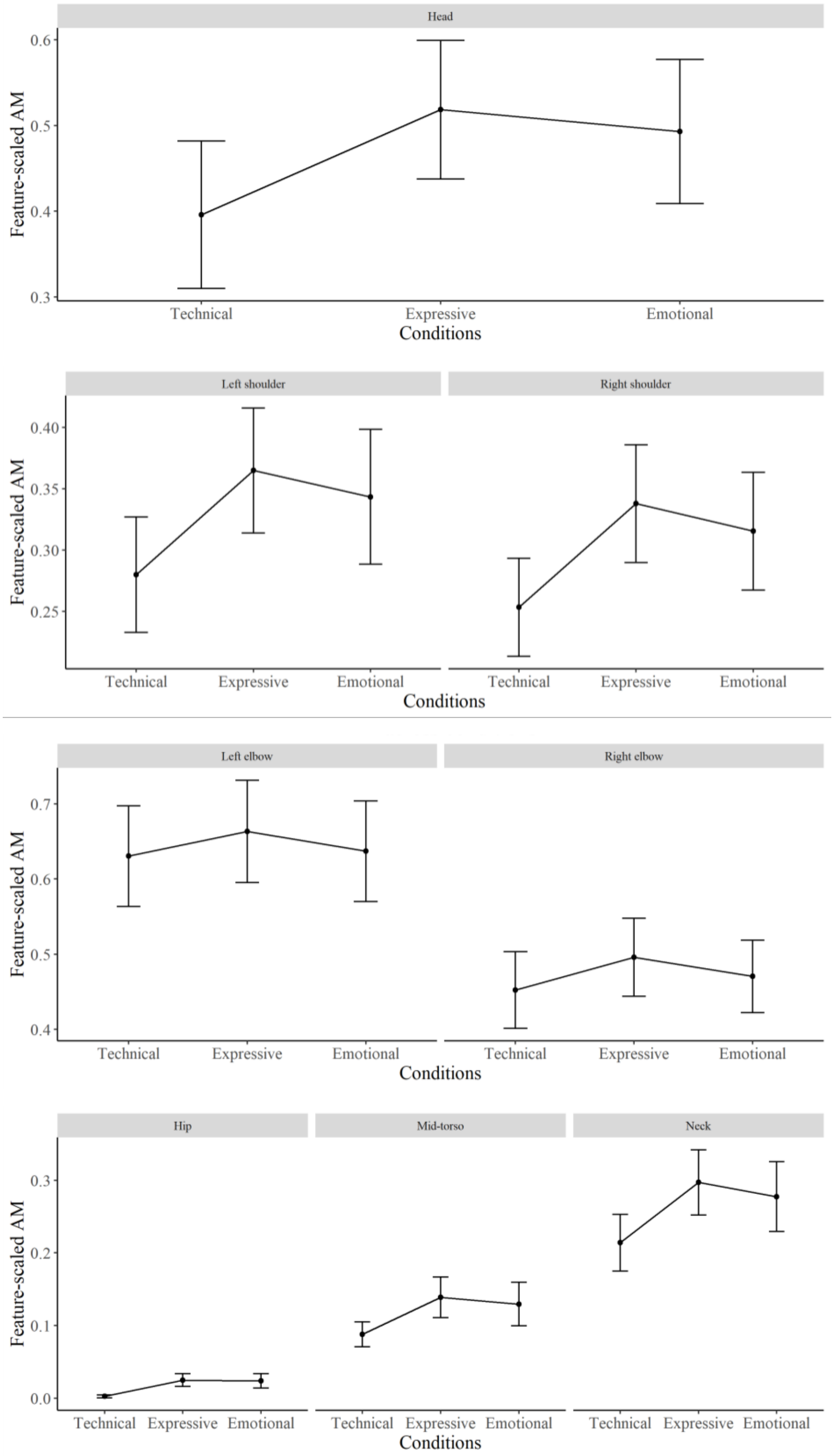


Figure 5. Mean AM with standard error bars in different marker locations (head, shoulders, elbows, and inner locations of neck, mid-torso and hip) across different conditions. Note differences in scale, which were adapted to visualise the effects more clearly.

4.3.2 Jerkiness of movement

ANOVAs with the mean amount of jerkiness in each marker location as the dependent variable revealed a significant main effect of Condition for the left elbow, left and right wrist, and left and right finger (see Table 15). Pairwise comparisons revealed significantly lower jerkiness in the Emotional conditions compared to Expressive (for left wrist, p = .01, right wrist, p = .01, left finger p = .02, and right finger, p =.02) and Technical (for left wrist, p = .02, right wrist, p = .02, left finger, p = .03, and right finger, p =.03) conditions (see Figure 6).

Table 15. ANOVA results for main Condition effects and Condition × Piece Valence interaction for jerkiness. * p < .01, ** p < .01, *** p < .001.

			Main effect of Condition			Condition × Piece Valence		
Marker	Mauchly's test of Sphericity	df	F	p-value	η_p^2	F	p-value	η_p^2
Left elbow	$\chi^2(2) = .54$	2, 16	4.69	.04	.33	1.15	.34	.13
Left wrist	$\chi^2(2) = .84$	2, 16	7.88	.004	.50	1.12	.35	.12
Right wrist	$\chi^2(2) = .76$	2, 16	4.24	.03	.35	1.51	.25	.16
Left finger	$\chi^2(2) = .67$	2, 16	11.51	.001	.59	.69	.51	.08
Right finger	$\chi^2(2) = .66$	2, 16	4.33	.03	.35	.64	.50	.07

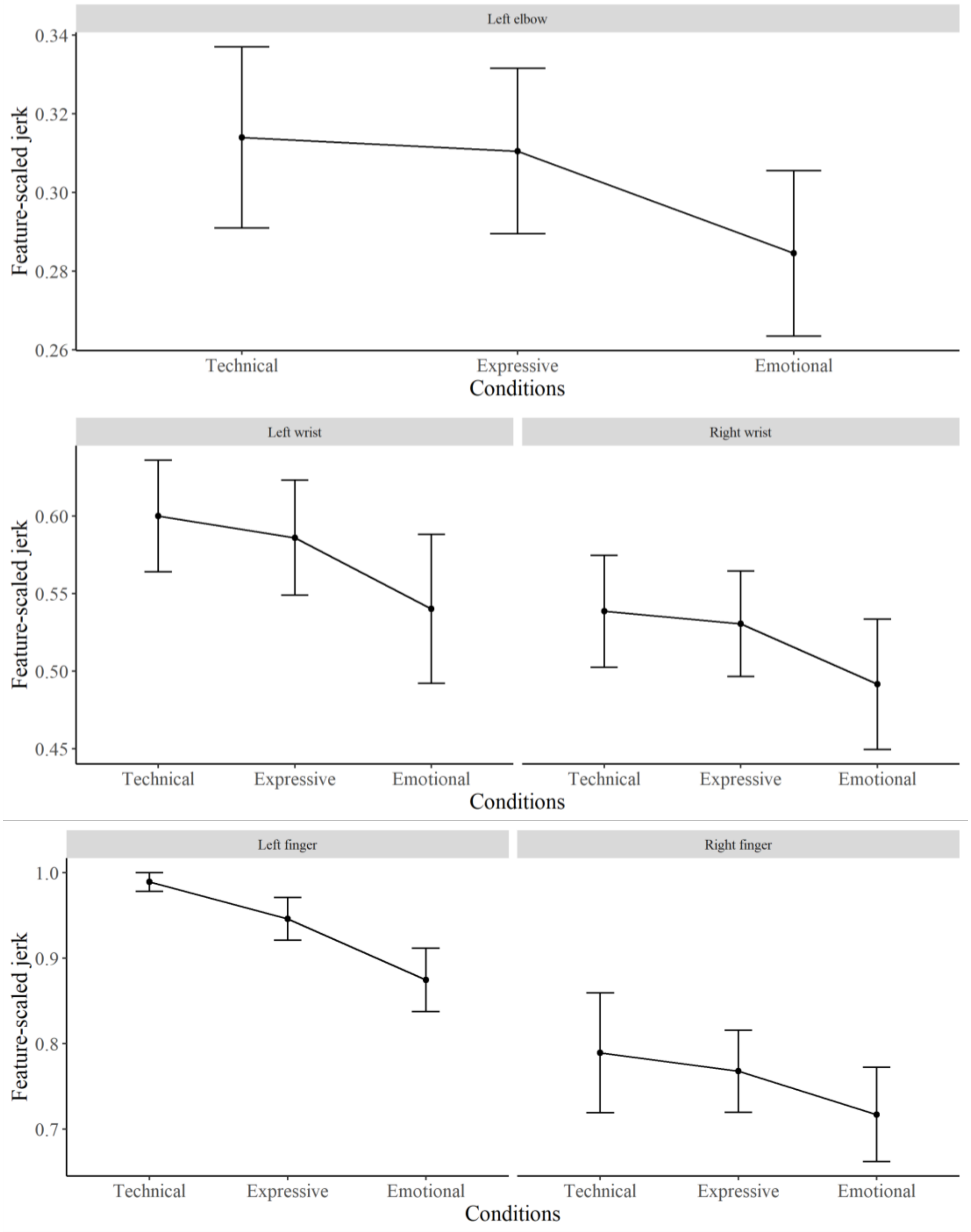


Figure 6. Mean Jerk with standard error bars in different marker locations (wrists, fingers and left elbow) across different conditions. Note differences in scale, which were adapted to visualise the effects more clearly.

4.3.3 Postural features

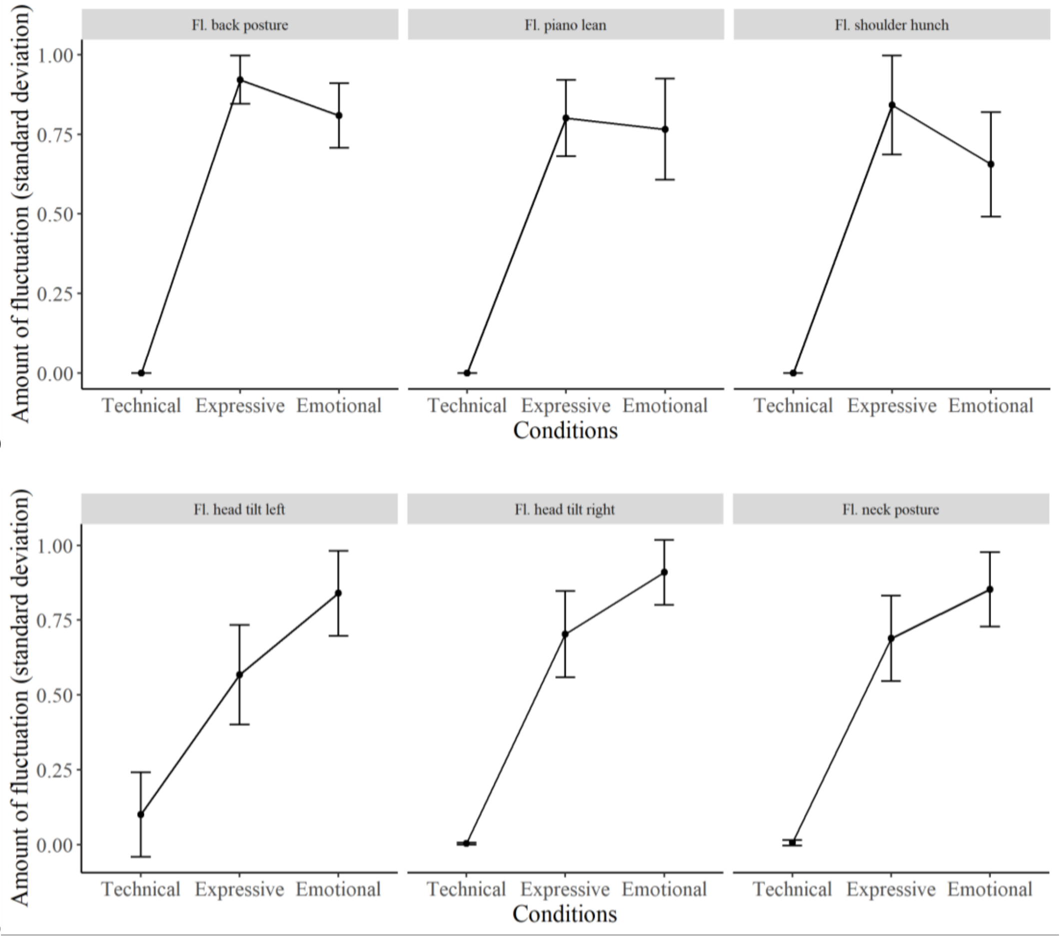
ANOVAs yielded significant main effect of Condition for mean neck posture and fluctuations (standard deviations) of back posture, head tilt and head lean towards piano (see Table 16).

Pairwise comparisons revealed significant differences between Technical and Expressive conditions (fluctuation of back posture, p = .000, neck posture, p = .001, head tilt left, p = .02, and piano lean, p =.000) and between Technical and Emotional conditions (fluctuation of back posture, p = .000, neck posture, p = .000, head tilt left, p = .02, head tilt right p =.000, shoulder hunch, p = .001, and piano lean p = .000). Estimated marginal means showed that fluctuations of back posture, postural lean and shoulder hunch were highest in the Expressive condition (see Figure 7. A). Fluctuation of neck posture, head tilt left and head tilt right were highest in the Emotional condition (see Figure 7. B).

Table 16. ANOVA results for main Condition effects and Condition × Piece Valence interaction for postural features. * $p < .01$, ** $p < .01$, *** $p < .001$.

Postural features	Mauchly's test of Sphericity	df	Main effect of Condition			Condition × Piece Valence		
			F	p-value	ηp^2	F	p-value	η_p^2
Back posture (fl)	$\chi^2(2)$ =6.61*	1.24, 9.93	77.70	.00	.91	.85	.40	.10
Neck posture (fl)	$\chi^2(2)$ = 8.39*	1.18, 9.42	25.11	.00	.76	.37	.60	.04
Head tilt left (fl)	$\chi^2(2)$ =1 76	2, 16	9.06	.005	.53	.96	.39	.11
Head tilt right (fl)	$\chi^2(2)$ = 7.26*	1.22, 9.73	33.16	.00	.81	.26	.67	.03
Shoulder hunch (fl)	$\chi^2(2)$ = 8.08*	1.19, 9.50	18.01	.001	.69	.08	.83	.01
Piano lean (fl)	$\chi^2(2)$ = 7.72*	1.20, 9.60	24.84	.00	.76	1.10	.33	.12

In summary, movement features that were broadly operationalised as expressive movement (AM in expressive body locations, postural fluctuations) increased with more emotional engagement with the music. Although some of these features reached their peak at the Expressive condition, other features (fluctuation of head tilt and neck posture) peaked in the Emotional condition. Jerkiness of technical movement (related directly to making the sound, i.e. wrists and fingers) was highest in the Technical condition, but decreased in the Expressive and further decreased in the Emotional condition.



(A)
(B)

Figure 7. Fluctuations of postural features with standard error bars across different conditions. Note differences in scale, which were adapted to visualise the effects more clearly.

4.4 Music's emotion influence on movement / emotional engagement

As movement has been influenced by emotional intention of the performer (e.g. Dahl and Friberg, 2004) as well as the felt emotion of the performer (Van Zijl & Luck, 2013), it was important to observe whether the piece's emotion modulated the influence of condition on the movement features; the third research question. To test this question, the interactions between Condition and Piece Valence in the first mixed ANOVAs (Section 4.2) were checked. No significant interactions of Condition × Piece Valence were found (see Tables 14, 15, 16 in Section 4.3). This may be because categorising whole pieces into either positive or negative valence perhaps is too big a generalisation: the emotion changed in all but one of the pieces.

To conquer this problem, ANOVA tests were run for movement features extracted from the 79 piece-segments rated for Arousal and Valence. As the main effect of Condition did not produce many further significant results (and have similar results to previous ANOVAs), only the interactions for Condition × Arousal, Condition × Valence and Condition × Arousal × Valence are reported.

4.4.1 Amount of Movement

The mixed design ANOVA with movement features from the 79 segments revealed a significant main effect of Condition on the movement features for expressive locations. More importantly, there were significant Condition × Arousal interactions for the head, neck, right shoulder and left elbow (see Table 17). There were no further significant interactions.

Table 17. ANOVA results for main Condition effects and Condition × Arousal interaction for AM. * $p < .01$, ** $p < .01$, *** $p < .001$.

Marker	Mauchly's test for sphericity	Condition				Condition × Arousal			
		df	F	p	η_p^2	df	F	p	η_p^2
Head	$\chi^2(2)$ =2.78	2, 140	13.65	.000	.16	4, 140	3.04	.02	.08
Neck	$\chi^2(2)$ = 3.81	2, 140	11.75	.000	.144	4, 140	2.45	.05	.07
Mid-torso	$\chi^2(2)$=3.2	2, 140	12.28	.000	.149	4, 140	3.35	.06	.06
Left shoulder	$\chi^2(2)$ = 2.50	2, 140	9.93	.000	.12	4, 140	2.27	.07	.06
Right shoulder	$\chi^2(2)$ =5.01	2, 140	10.34	.000	.13	4, 140	2.50	.05	.07
Left elbow	$\chi^2(2)$ =2.42	2, 140	.71	.50	.01	4, 140	2.66	.04	.07

To further understand the interaction, separate one-way ANOVAs were conducted with the movement features in each condition (AM for head, neck, right shoulder and left elbow in each of the 3 conditions) as the dependent variable and the Arousal level as thee independent variable. For the head, there were significant differences between Arousal levels in the Technical ($F(2,78)= 3.98$, p = .02) and the Emotional ($F(2,78)=3.13$, p = .05) conditions, but not for the Expressive condition. A significant difference between Arousal levels was noted only in the Technical condition for right shoulder ($F(2,78) = 3.27$, p = .04) and left elbow ($F(2,78)= 5.94$, p=.004). This suggests that AM differed depending on the Arousal mostly in the Technical condition. Figure 8 shows the pattern for the head, neck, right shoulder and left elbow. As expected, the Expressive condition elicited the most AM for high Arousal. However, contrary to our expectation, low Arousal elicited more AM in the Technical and Emotional conditions for head, neck, right shoulder and left elbow.

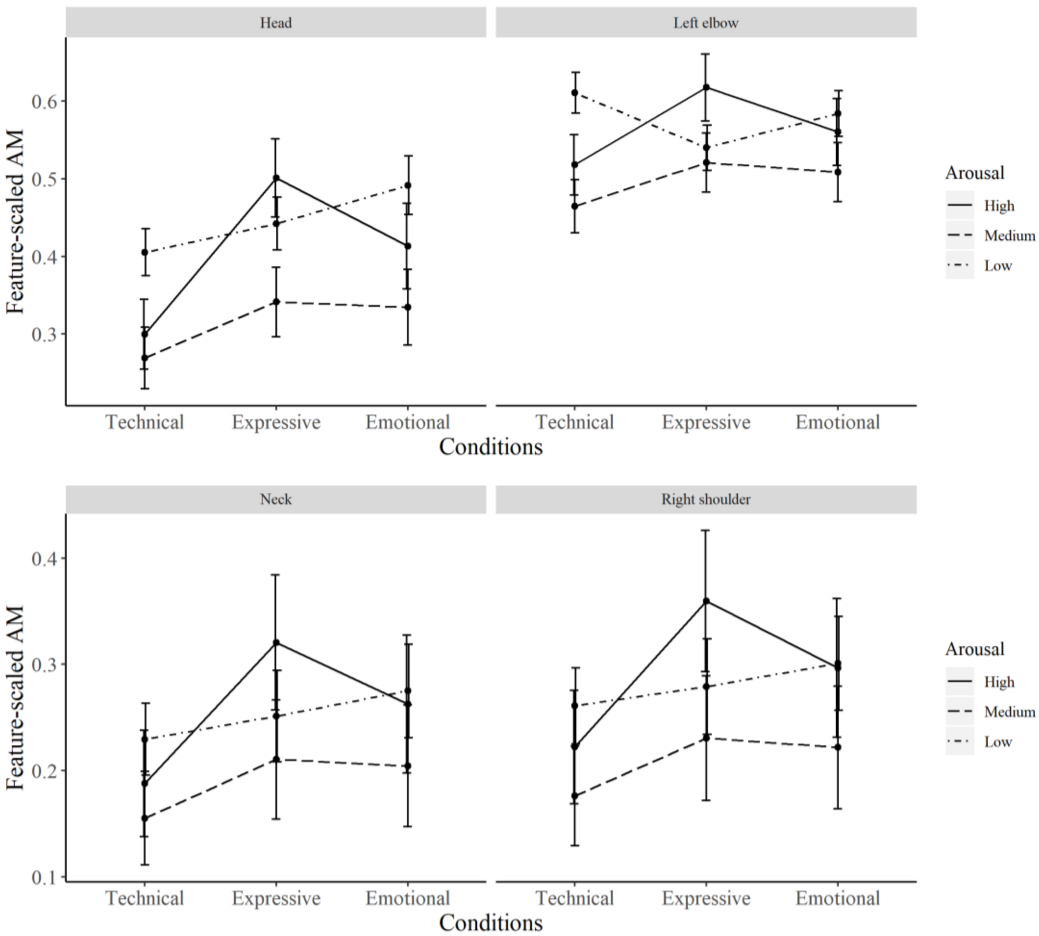


Figure 8. Condition × Arousal interactions for head, neck, right shoulder and left elbow. The graph shows mean AM (with standard error bars) from piece segments of high, medium, or low Arousal across conditions.

4.4.2 Jerkiness

There was a significant main effect of Condition for the wrists, fingers and additionally for the head, neck, left and right shoulder. There was a significant Condition × Valence interaction for the mid-torso (see Table 18). Separate ANOVAs found significant differences in mid-torso jerkiness in the Expressive condition ($F(2,76) = 3.87$, $p = .03$), but not for the Technical ($p = .30$) or Emotional condition ($p = .25$). There were no other significant interactions.

Table 18. ANOVA results for main Condition effects and Condition × Valence interaction for jerkiness. * $p < .01$, ** $p < .01$, *** $p < .001$.

Marker	Mauchly's test for sphericity	Condition				Condition × Valence			
		df	F	p	η_p^2	df	F	p	η_p^2
Mid-torso	$\chi^2(2)$=14.20***	1.69, 118.04	2.50	.10	.03	3.37 ,118.04	2.87	.03	.08
Left shoulder	$\chi^2(2)$ = 8.07*	1.80, 126.08	4.57	.02	.06	3.60,	1.53	.20	.04
Right shoulder	$\chi^2(2)$ =14.80***	1.68, 117.351	5.69	.01	.08	3.35,	.88	.46	.03
Left elbow	$\chi^2(2)$ =11.87**	1.73, 120.91	4.68	.02	.06	3.45,	1.59	.19	.04
Left wrist	$\chi^2(2)$ =14.17***	1.69, 118.08	7.66	.001	.10	3.37,	2.38	.07	.06
Right wrist	$\chi^2(2)$ =12.43**	1.717, 120.18	5.91	.005	.08	3.43,	.75	.54	.02
Left finger	$\chi^2(2)$ =13.51***	1.70, 118.86	7.03	.002	.09	3.40,	2.47	.06	.07
Right finger	$\chi^2(2)$ =9.83**	1.77, 123.60	6.87	.002	.09	3.53,	1.07	.37	.03

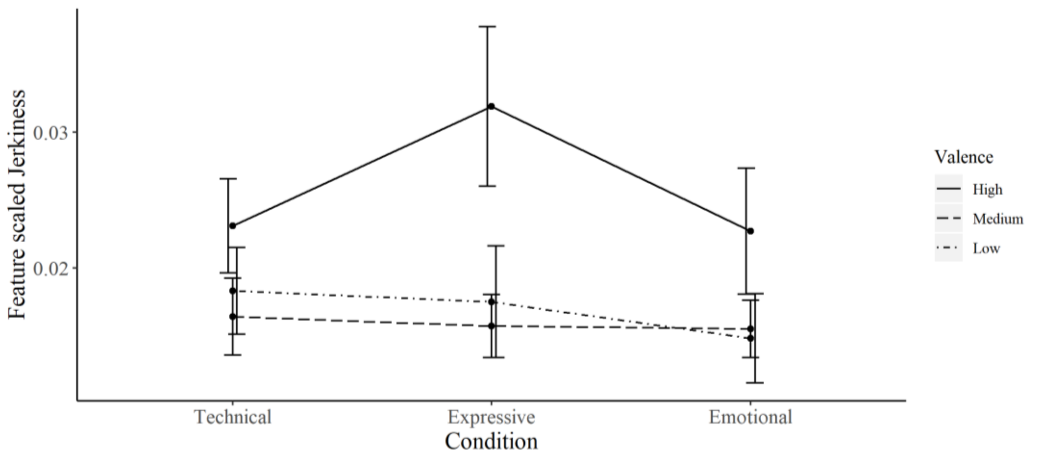


Figure 9. Condition × Valence interactions for jerkiness of mid-torso. The graph shows mean jerk (with standard error bars) from piece segments of high, medium, or low Valence across conditions.

4.4.3 Posture

There was a significant main effect of Condition for mean piano lean, fluctuations of back posture, neck posture, piano lean, head tilts and shoulder hunch. There was a significant Condition × Arousal interactions for mean shoulder hunch (see Table 19.1). Separate ANOVAs revealed shoulder hunch did not change with Arousal in Technical (*p* = .19) or Expressive condition (*p* = .31), but was nearing significance in the Emotional condition (*p* = .08).

Table 19.1: ANOVA results for main Condition effects and Condition × Arousal interaction for postural features. * *p* < .01, ** *p* < .01, *** *p* < .001.

Marker	Mauchly's test for sphericity	Condition				Condition × Arousal			
		df	F	p	η_p^2	df	F	p	η_p^2
Back posture (fl)	$\chi^2(2) = 1.97$	2, 140	12.97	.00	.16	4, 140	1.41	.24	.04
Neck posture (fl)	$\chi^2(2) = 4.70$	2, 140	15.38	.00	.18	4, 140	.97	.10	.05
Head tilt left	$\chi^2(2) = 6.62$*	1.83 128.16	10.91	.00	.14	3.66, 128.16	2.42	.05	.07
Head tilt right	$\chi^2(2) = .54$	2, 140	3.16	.05	.043	4, 140	2.18	.07	.06
Shoulder hunch	$\chi^2(2) = .42$	2, 140	8.42	.00	.107	4, 140	2.77	.03	.07
Head tilt left (fl)	$\chi^2(2) = 12.47$**	1.72, 120.14	21.53	.00	.235	3.43, 120.14	.97	.42	.03
Head tilt right (fl)	$\chi^2(2) = 5.38$	2, 140	18.95	.00	.213	4, 140	.35	.84	.01
Shoulder hunch (fl)	$\chi^2(2) = 5.72$	2, 140	19.02	.00	.214	4, 140	1.86	.12	.05

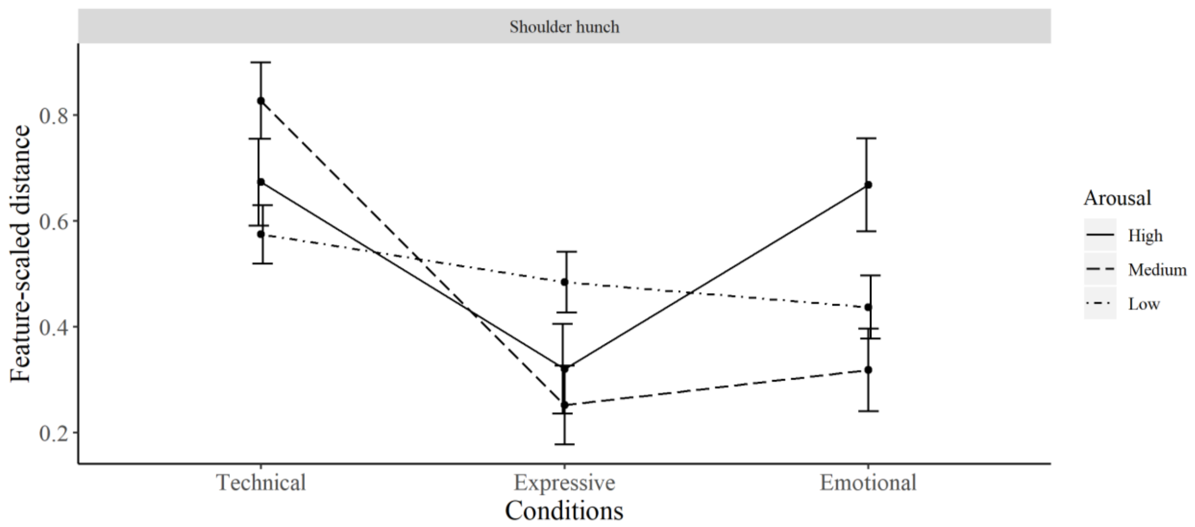


Figure 10.1. Condition × Arousal interactions for shoulder hunch

There were significant Condition × Valence interactions for mean head tilt left and shoulder hunch (see Table 19.2). Separate ANOVAs revealed shoulder hunch did not significantly differ depending on Valence values in the Technical condition (p = .11), just missed significance for the Emotional condition (p = .08), but significant differences in shoulder hunch appeared in the Expressive condition (p = .01), suggesting that shoulder hunch differed depending on Valence only in the Expressive condition. A separate one-way ANOVA revealed no significant differences between any conditions for the head tilt left. Figure 10.2 (where a lower value represents a smaller distance between the head and the shoulder, thus a greater head tilt) shows that high and low valence had greater mean head tilt.

There was a significant Condition × Arousal × Valence for shoulder hunch fluctuation (see Table 19.2). Separate ANOVAs revealed no further significant differences. Figure 10.3 shows that in medium and low Arousal and Valence, fluctuation of shoulder hunch was low in Technical and increased in the Expressive Condition, then fell slightly in the Emotional condition (dashed and dot-dashed lines in far left and middle graph). However in high Arousal and high Valence, there were greater changes of shoulder hunch fluctuation throughout conditions, highest in the Expressive condition. It should also be noted that mixed high and low Arousal / Valence elicited also more shoulder hunch fluctuation. In high Valence and low Arousal, Expressive condition yielded the most differences between fluctuation of shoulder hunch between piece-segments high (most fluctuation), medium (least fluctuation). In high

Arousal and low Valence there were greater changes of shoulder hunch fluctuation throughout conditions, highest in the Emotional condition.

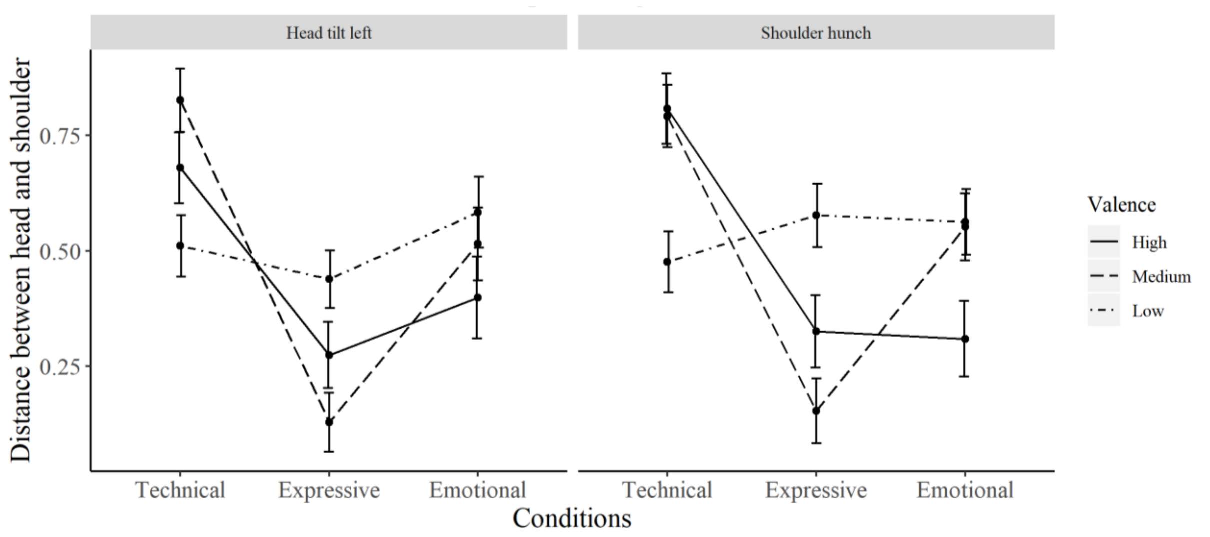


Figure 110.2. Condition × Valence interactions for shoulder hunch and head tilt left. The graph shows mean shoulder hunch and head tilt left (with standard error bars) from piece segments of high, medium, or low Valence across conditions.

Table 19.2: ANOVA results for Condition × Piece Arousal and Condition × Arousal and Condition × Arousal × Valence interactions for postural features. * $p < .01$, ** $p < .01$, *** $p < .001$.

Marker	Mauchly's test for sphericity	Condition × Valence				Condition × Arousal × Valence			
		df	F	p	η_p^2	df	F	p	η_p^2
Head tilt left	$\chi^2(2) = 6.62$*	3.67, 128.16	3.51	.01	.09	7.32, 128.16	1.36	.23	.07
Head tilt right	$\chi^2(2) = .54$	4, 140	.63	.65	.02	8, 140	.74	.66	.04
Shoulder hunch	$\chi^2(2) = .42$	4, 140	4.83	.001	.12	8, 140	1.82	.08	.09
Piano lean	$\chi^2(2) = .01$	4, 140	1.79	.13	.05	8, 140	1.92	.06	.10
Head tilt left (fl)	$\chi^2(2) = 12.47$**	3.43, 120.14	.69	.58	.02	6.87, 120.14	1.62	.14	.09
Head tilt right (fl)	$\chi^2(2) = 5.38$	4, 140	.29	.89	.01	8, 140	1.53	.15	.08
Shoulder hunch (fl)	$\chi^2(2) = 5.72$	4, 140	1.18	.32	.03	8, 140	2.11	.04	.11
Piano lean (fl)	$\chi^2(2) = .01$	4, 140	1.07	.37	.03	8, 140	1.17	.32	.06

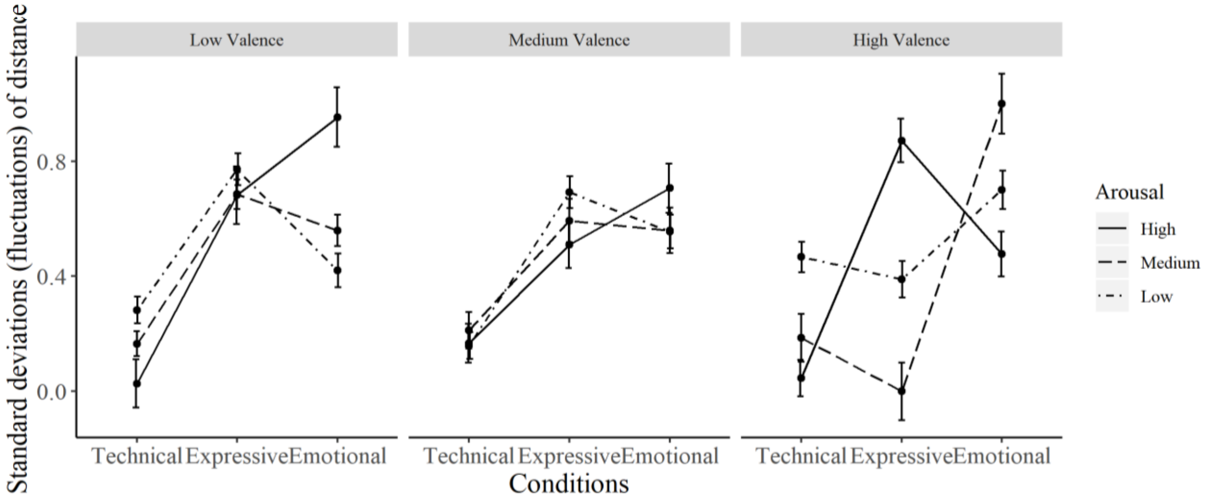


Figure 12. Condition × Arousal × Valence interactions for shoulder hunch fluctuations. The graph shows mean AM (with standard error bars) from piece-segments of high, medium, or low Arousal across conditions and across low, medium and high Valence.

In summary, statistical tests revealed significant Condition × Arousal interactions for AM of head, neck, right shoulder and left elbow, where either high or low arousal elicited more AM compared to the neutral Arousal. As expected, high Arousal elicited the most AM in the Expressive condition. However, significant differences between Arousal levels occurred in the Technical and Emotional condition, where – surprisingly – low Arousal elicited more AM compared to medium and high Arousal. There was only one significant result for jerkiness, where high Arousal elicited significantly more jerkiness in the Expressive (compared to Technical and Emotional) condition for the mid-torso. Modulation of the music's emotion on the influence of emotional engagement for postural features was more complicated, but generally mean head tilt and shoulder hunch were modulated by Arousal or Valence level, especially in the Expressive and Emotional conditions. Fluctuations of shoulder hunch was modulated by *both,* Arousal and Valence, with the high Arousal and high Valence piece-segments increasing fluctuations of shoulder hunch significantly more in the Expressive and Emotional conditions. Mixed high and low Arousal/Valence elicited the most shoulder hunch fluctuations.

4.5 Group differences

Additional ANOVA and independent sample *t*-tests were run with certain movement features to check for some possible uncontrolled variables, namely playing standard (amateur, semi-professional or professional) and whether participants played off-by-heart or from the score. Results revealed differences between jerkiness of shoulder and elbows differed between professionals and non-professionals, and a more bent neck posture occurred in those who performed without the score compared to those who performed with music scores. However, once the p value threshold was lowered to account for the multiple *t*-tests (with the Holm method) no significant results remained. Although statistically speaking this means that there are no significant differences, the previously significant results suggest certain trends that may be nonetheless worth considering (especially for future research). Results and discussion of the previously significant results are presented in Appendix C.

4.6 Interviews

Most of the participants thought that their recording for the Emotional condition was the best and the most natural (see Table 20). The answers to the question "Whether, in their own words, they could describe the emotions they felt in that performance" were coded and counted based on the categories as seen in Section 3.6.6 and in Table 21.

Table 20. Best recording and most natural performances as chosen by participants

	Best Recording	Most natural
Technical	0	2
Expressive	2	1
Emotional	8	7

Much of the interview data supports the results found in the statistical tests and provides further ideas for better interpretation of the data. The Technical condition evoked the most negative emotions, whereas the Emotional one seemed to evoke the most positive emotions, which was also confirmed by repeated-measures ANOVAs (mixed design, Condition as the repeated measure, Piece Valence as the between-subjects factor) for both positive ($F(2, 16) = 6.08$, $p = .01$, $\eta_p^2 = .43$) and negative emotions ($F(2, 16) = 3.81$, $p = .004$, $\eta_p^2 = .03$). No significant differences were observed depending on whether the general Piece Valence was positive or negative (no significant Condition × Piece Valence interaction). The Expressive condition had a mix of both positive and negative performance-related felt emotion. This may have been linked to the idea that the players felt frustrated when they could not express the music the way that they wanted to, due to lack of good technique or enough practice ("my feelings are like, err, why haven't I practiced more"). However, in the Emotional condition they could express themselves more easily ("it was easier to express when you play it more... Hmm more emotional").

Table 21. Different types of emotion as felt by the participants in each condition. Number represent total amount of times the type of emotion was mentioned across all participants.

		Felt Emotion			
		Music-related		Performance-related	
Condition	Perceived Emotion	Aesthetic	Mirroring	Positive	Negative
Technical	3	3	0	6	16
Expressive	1	2	1	21	15
Emotional	5	3	5	26	3

5 DISCUSSION

This thesis studied the influence of different kinds of - and different combinations of - emotion on movement during piano performances. The main research questions were: 1) how do positive and negative felt emotions influence movement features in a performance, 2) how does emotional engagement influence movement features in a music performance, and 3) how does engaging with the emotion of the music influence movement features depending on the emotion of the music? Participants played a piece with which they had an emotional connection in the following conditions: Technical (focusing of technical aspects), Expressive (expressing the piece) and Emotional (*feeling* the emotion). Thirty-six movement features (amount of movement (AM), jerkiness of movement and postural features) were extracted from MoCap data, broadly operationalized into expressive or technical features and were compared between positive and negative felt emotions (first research question) and between experimental conditions (second research question). To observe if influence of conditions on movement features were modulated by the arousal or valence of the music (i.e. how interactions of perceived and felt emotions may manifest themselves in movements), pieces were segmented and rated according to arousal and valence. Movement features extracted from these piece-segments were compared across arousal and valence levels as well as across conditions (third research question).

The results of the current study support the hypothesis that performer movement is influenced by separate kinds of - as well as a mixture of - emotions. Positive emotions during a performance were related to expressive movement. *Performance*-related negative emotions led to jerkiness of wrists whereas *music*-related negative emotions were linked to postural features. The Expressive condition elicited the most expressive movement. The Emotional condition elicited the most fluctuations of head tilt and reduced jerkiness of technical movements. Analysis of movement differences between perceived emotions across conditions showed that playing high Arousal music elicited the most AM in the Expressive condition. Surprisingly, low Arousal elicited the most amount of movement in the Technical condition (perhaps due to cognition load) and the Emotional condition (perhaps due to the interaction between felt and perceived emotions). Results also suggest that there are differences in jerkiness and postural features when *expressing* compared to *feeling* emotion in a performance, especially in music with more extreme arousal and valence values as well as more nuanced mixed emotions (e.g.

nostalgia). Interviews indicated that participants enjoyed the Emotional condition the most and were able to express themselves best in this condition.

5.1 Effect of positive and negative Affect on movement features

Correlations and regression analyses were run with the Positive Affect and Negative Affect Schedule (PANAS) scores that were taken before and after each performance condition. As expected, positive felt affect correlated with more expressive movement, i.e. higher amount of movement in the body locations associated with expressive movement, such as the head, shoulder and elbows (Castellano et al., 2008; Davidson, 2007; Thompson, 2007; Thompson & Luck, 2012) as well as posture fluctuations (Camurri et al., 2004; Clarke, 1993; Davidson, 2002; Wanderley et al., 2005).

Negative affect, on the other hand, elicited less expressive movement (e.g. AM in hip), more jerky movement in wrists and a more stable posture. Further investigation with stepwise multiple regression of movement features within conditions suggested that movement related to negative felt affect is exhibited differently depending on whether it is *music*-related or *performance*-related. In the Technical condition, the instruction was to play the piece as accurately as possible, therefore it is assumed that the pianists' negative affect scores reflected performance-related emotions. Indeed, in the post-Technical condition interviews, many participants said they felt negative performance-related emotions (such as "I was pretty nervous"). On the other hand, instruction for the Emotional condition was to become as absorbed in the music as possible, thus it is assumed that the negative affect scores in the Emotional condition reflected music-related emotions. This was reflected by post-Emotional condition interviews, e.g. "I did feel compassionate and I felt a bit sad." This highlights the difference between music-related and performance-related emotions in negative felt emotions: performance-related negative felt affect (such as nervousness) was associated with jerkiness of wrists, whereas music-related negative felt affect (feeling the sadness of the music) was associated with a more stable posture (less leaning towards and away from the piano) and more fluctuations in shoulder hunching. This supports the idea that negative performance-related movements are evoked in performance (Kwan, 2016) and that music-related emotions of feeling the emotion of the music changes postural features (Van Zijl & Luck, 2013). In terms of negative affect and jerkiness in wrists, an increase of jerkiness was associated with more negative emotion only in the left wrist, with the opposite effect in the right wrist. This may have been due to the fact that the melody was usually in the right hand[8] and therefore given more attention. As the left hand tends to be less dominant and has less dominant lines, it may have received less attention in practice and therefore may not have been as stable in a performance compared to the right hand.

5.2 Influence of emotional engagement on movement features

The second research question further investigated how feeling the emotion of the music (mirroring music-related emotion) influences movement features. In support of the second hypothesis, increased emotional engagement with the music evoked more typically expressive movement, namely AM in typically expressive locations (the head, neck, mid-torso, left shoulder, right shoulder, right elbow and hip) and fluctuations of postural features (back posture, head tilting and leaning towards and away from the piano). This supports previous studies that also found that expressivity in performance is conveyed by amount of movement in locations that were further away from the keyboard (i.e. higher degrees of freedom) and not directly related to producing sound such as the torso, the shoulder and the head of pianists (Davidson, 1991; Thompson & Luck, 2012). Fluctuation in leaning towards and away from the piano also increased in the Expressive and Emotional condition, supporting the idea that swaying to and from the piano may express increase and decrease of tension in a music performance (Camurri, Mazzarino, Ricchetti et al. 2004) and emotional expression (Chang et al., 2019).

Although this expressive movement increased in the Expressive and Emotion conditions compared to the Technical condition, it should also be noted that most of these movements (AM of head, neck, mid-torso, shoulders elbows and hip; fluctuation of torso posture, shoulder hunch and piano lean) decreased slightly (but not significantly) in the Emotional condition. This could be explained in three ways. Firstly, the fact that the instruction was to "feel the emotion and play the piece as if for themselves." In this case, it could be that when the participants were performing, they still needed the expressive movement to express themselves to a certain extent,

[8] Although possibly a generalisation, from looking at the scores, this held true for most of the pieces throughout the entirety of the pieces with some exceptions, namely Debussy's *L'isle* at some of the central sections and also Sibelius's *Romance* near the beginning.

but did not need to exaggerate their movements to a perceived audience. It could also be that the participants were able to concentrate a little more on the sound, and exaggerating expressive movement too much may have hindered producing a good sound (Allingham, 2018). Secondly, because the pieces were already well-rehearsed and in the pianist's repertoire, thus an expressive performance for the pianists may already be an emotional performance. Thirdly, although care was taken to induce the participants with the emotion of the piece as much as possible (in the most ecologically valid and ethically appropriate way possible), it could nonetheless be argued that pianists were not fully feeling the emotion. Indeed, the PANAS showed the greatest difference only between the Technical and Expressive, rather than the Expressive and Emotional. The interview data and general behaviour of some pianists (e.g. getting teary after the Emotional performance) suggested that the emotional induction had been effective for some of the pianists, but perhaps less so for others. This depended on the emotion of the music itself as well as the pianists' personal associations with the music (such as memories or connotations, see Table 7). Although the emotion induction may have not been as strong as in some other studies, it is believed that this was the most ecologically valid way to induce emotions in a way that pianists may actually do in an actual performance. Thus, it is stipulated that in order to express music appropriately, pianists may have used some of the same expressive movement as if they were also feeling the emotion music.

While some of the expressive movement remained similar for Expressive and Emotional conditions, some more subtle movement features significantly differed between these two conditions. The fluctuations of neck posture, head tilts (to the right and to the left) were the highest in the Emotional condition. This supports the findings that head tilt is used as a device for expressing emotions in acting (Dael, Mortillaro, & Scherer, 2012) and music performance (Davidson, 1991; 2012; Delalande, 1995). The fact that it represents *felt* emotion rather than being just an expressive device is a novel finding. This result could be explained by the idea that head tilting is considered more "human" and "natural." In studies exploring human-robot interaction, humans rated robots with increased lateral head tilt with higher "naturalness" (Liu, Ishi, Ishiguro, & Hagita, 2012). Results of this study, therefore, suggest that head tilt may reflect a more genuine emotion, rather than just "expressing" it. The reason behind this may come from body language psychology. Tilting the head to the side exposes the neck - a sign of vulnerability - which shows another person that they are trusted and being more intently listened to (Reiman, 2007). Adding to this interpretation, it could be that the participants had a greater fluctuation of the head tilt as they were focusing more intently on the music. It should be noted that greater *fluctuation* of head tilt, rather than the mean head tilt was found to differ between conditions. This means that the participants did not necessarily have a constant increased head tilt but would often change their head tilt position. Although there seems to be no research in the *fluctuation* of head tilt, the interpretation that the head tilt might represent more natural emotion and a closer absorption in the music could nonetheless be considered compatible with the results.

Engaging with the emotion of music also seemed to change technical movement in the piano performances. With increased emotional engagement there was reduced amount of jerkiness in wrists and fingers. This supports the idea that when pianists focused on affective (rather than cognitive) aspects of the music, their performance was smoother and more legato in the acoustic domain (Higuchi, Junior, & Leite, 2009). Shakiness (which could also be measured by jerkiness) is linked to nervousness (Van Zijl & Sloboda, 2013) or associated with less instrumental expertise (Nusseck & Wanderley, 2009), whereas smoothness represents fluency and proficiency of skill (Gonzalez-Sanchez et al., 2019). The current results therefore suggest that engaging with the music's emotion may result in more fluid playing, providing a less stressful (or at least a less visibly stressful) performance. They also suggest that feeling induced with emotion of the music could lead to smoother movements despite mistakes occurring in a performance. Considering the research by Waddell & Williamon (2017), who found an audience's overall judgement score was lower when they heard a mistake followed by a visual movement reflecting the mistake (negative facial reaction) compared to the same performance mistake with no visual cue reflecting the mistake, this study further proposes that performances with higher emotional engagement could also provide a more convincing performance, even with mistakes (though this would need to be assessed with a perceptual study, see Section 5.6).

It is possible that a reduction in jerkiness in the Emotional condition may have been due to the order of conditions. Participants always performed in the same order: Technical, Expressive and Emotional.[9] Although such reductions in jerkiness could have been due to the pianists becoming more relaxed during the experiment as well as more used to the piano and playing in the motion capture suit, I still believe the reduction was a direct result of the emotional

[9] Alternating condition order was considered, but decided against as it could be difficult to go from feeling emotionally engaged to the music, and then perform with reduced emotional engagement.

engagement for three reasons. Firstly, if participants indeed were getting used to the experiment, there would perhaps be a significant difference from the first to the second condition (Technical to Expressive) which would plateau for the Emotional condition. However, significant differences were only found between the Expressive (second) and the Emotional (third) condition. Secondly, participants described (in the interviews) how they felt "freer" and as if "mistakes did not matter" in the Emotional condition. This suggests that although participants were aware of the mistakes, they felt mistakes were less important in the Emotional condition, which was reflected in the reduction of jerkiness. This is further supported by the idea that music-related thoughts are used as a strategy for mistake recovery in a performance (Oudejans et al., 2016). Thirdly, our findings that reduced jerkiness occurred after focusing on the music's emotion, are perhaps in line with studies where heart rate variability was reduced with emotional induction (Glowinsky et al., 2008). Together, the results suggest that engaging with the emotion could focus the participants' mind, making them calmer while playing with mistakes.

In summary, the result for the second research question, engaging with the emotion of the music (mirroring music-related emotion) increases expressive movement, but does not exaggerate it. Some movement features (AM of head, neck, mid-torso, shoulders elbows and hip; fluctuation of torso posture, shoulder hunch and piano lean) were similar in Expressive and Emotional conditions (but significantly higher compared to the Technical condition). However, some movement features significantly differed between Expressive and Emotional conditions, namely fluctuations of head tilt (providing cues of truly felt emotion, supported by the idea that felt emotion shows one as vulnerable, as does tilting the head) and jerkiness of technical movements. Focusing on technical aspects increased jerkiness of wrist and finger movement, whereas focusing on the emotional musical aspects (music-related emotion) seemed to alleviate any negative emotions (negative performance-related emotions). The results show that music-related emotion can interact with negative performance-related emotion to diminish negative feelings (as discussed by Oudejans, et al., 2016) and this mixed emotional interaction (as suggested by interview where pianists acknowledged a mistake, but coped with it more positively when focusing on the music's emotion) is manifested by the reduced jerkiness of technical sound-producing movements. However, as movement features may change depending on the emotion of the piece, it was important to factor in the music's emotion into the analysis (as discussed below).

5.3 Influence of emotional engagement on movement features moderated by arousal and valence

Previous studies have found movement, tempo, and muscle tension differences when playing in conditions of expressing sadness and happiness, compared to being induced with sadness and elation, respectively (Glowinsky et al., 2008; Van Zijl & Luck, 2013; Van Zijl & Luck, 2013b). The current study extends the findings by comparing movement differences not only between expressed and induced sadness or elation, but when participant induce themselves with the more realistic musical emotions e.g. feelings of patriotism in the Sibelius' *Romance* ('[the emotion] is kind of patriotic in a way'), or feelings of passion mixed with nostalgia in Debussy's *Arabesque* ('maybe sadness in it but more like nostalgia... not so sad'). Instead of being grouped by sadness or happiness, the pieces were segmented and rated in terms of dimensions of low, medium and high arousal and low, medium and high valence. This afforded a greater scope of emotions which are typical in many real musical compositions. Mixed design ANOVA results provided some support for the hypothesis that engaging with emotion changed the movement features depending on the arousal and valence of the piece.

5.3.1 Influence of Arousal on emotional engagement and AM

Firstly, the AM of the head, neck, right shoulder and left elbow changed through conditions depending on whether the music had low, medium or high Arousal. As feelings of low arousal (induced sadness) reduced movement in expressive locations compared to expressing sadness (Van Zijl & Luck, 2013), it was expected that AM would be significantly lower in low Arousal segments compared to high Arousal segments, especially in the Emotional condition. In the current results, AM was highest in high arousal segments in the Expressive condition, supporting the results of several studies showing that conveying high arousal exhibits more movement (Dahl & Friberg, 2004; Wallbott, 1998). However, the results that AM was higher in low arousal segments, compared to medium *and high* arousal segments in the Technical and Emotional conditions contradicted expectations. Two interpretations can be given for this.

Firstly, to discuss why greater AM occurred in low Arousal segments during the Technical condition, the nature of the music itself in different Arousal segments needs to be considered, especially as musical features such as speed and amount of notes were not controlled in this experiment. Indeed, pieces with varying technical difficulties can differently affect movement both a global and local level (see Thompson & Luck, 2012 and Wanderley et al., 2005). Ecologically valid pieces of music with high arousal tend to have faster speeds and more notes, thus requiring a higher cognitive load for the pianists to play technically accurately. The cognitive load of performing technically demanding music means that expressive movement actually hinders the performer from playing the pieces successfully (Allingham, 2018). This idea is supported by some phrases from the interviews, such as 'I felt pretty nervous with the quick [passages]' and 'it was more difficult to play technically, especially when there is a lot that happens'. Low Arousal music tends to be slower and there is more scope for greater movements between sound-producing movements which would facilitate expressivity (Allingham, 2018). Therefore, playing low Arousal music technically accurately still allowed for more expressive movement, whereas playing high-Arousal music technically accurately required a reduction in the expressive movement.

Secondly, the reason why AM in head, neck and shoulder is greater in low Arousal segments compared to medium and high arousal in the Emotional condition, can be explained by the AM as expressing the mixed felt emotions, i.e. the paradoxical feelings of enjoying low arousal (sad and peaceful music). Low arousal music tends to evoke more chills and strong emotions in listeners (Bannister, 2018; Gabrielsson, 2002; Gabrielsson & Lindström, 2003) perhaps due to the aesthetic appreciation or beauty (Vuoskoski & Eerola, 2017; Vuoskoski, Thompson, McIlwain, & Eerola, 2012). An assumption can be made that *playing* music of low arousal when feeling the emotion (mirror- music-related emotion) may also evoke pleasant emotions in performers (aesthetic music-related emotions). The low arousal music may have moved the pianists to move expressively to relish their enjoyment of performing the music. It could also reflect a cathartic experience, where releasing strong emotions involve big body movements (Staunton, 2002). Indeed, the idea that most of the participants enjoyed playing in the Emotional condition the most (according to the interviews) suggests that they were feeling the emotion of the music (mirror music-related emotion), but these were interacting with aesthetic music-related emotion: 'from an emotional point of view […] there are so many short moments that you feel touched [sic]'. This explanation is further supported by the PANAS results (Section 4.1). Although those engaging with generally sad pieces had lower PA and higher NA than those engaging with the generally positively valenced pieces in the Emotional condition, the PANAS scores were not significantly different in this condition, suggesting that the pianists still had some positive feelings in negatively valenced conditions.[10] This may be further supported by the idea that all the participants played pieces that they enjoyed performing. Van Zijl & Luck (2013) found that feeling sadness in music elicits less movement from musicians compared to expressing sadness, which may have been because participants in their study played very short excerpts of pieces that they were given only a week prior to the data collection. The current study asked participants to choose a piece of music they felt emotionally connected to, therefore more ecologically valid emotions would come into play here. Indeed, the results suggests that feeling the sadness of ecologically valid music (music in one's repertoire with complex emotion) can create additional aesthetic emotions of actually enjoying playing the music and enhance the positive performance-related emotions. With this assumption, it can be suggested that low Arousal music may have created aesthetic emotions in the Emotional conditions, and these positive emotions were exhibited through AM of the head, neck, right shoulder and left elbow.

The predicted results were based on studies that used controlled pieces of music, i.e. the same piece of music for different emotional intention (Dahl & Friberg, 2004). Although these results (obtained from realistic musical compositions where the music as well as the performer also conveys the emotion) met expectations in the Expressive condition, they contradicted these expectations in the Technical and Emotional condition (with low Arousal music eliciting the most AM). The current results therefore highlight the importance of testing ecologically valid pieces of music to further understand the movements associated with different emotional intentions.

5.3.2 Influence of Emotion on emotional engagement and jerkiness/postural features

Jerkiness in mid-torso increased significantly in high Valence piece-segments, especially in the Expressive conditions, supporting the idea that high valence is reflected in torso movement such as torso tilts (Burger et al., 2013). Interestingly, the increase in jerkiness in higher valence contradicts previous results that find higher valence is related to smoother movements (Burger et al., 2013) and lower valence is more related to jerky movements (Dahl & Friberg, 2004). Additionally, it seems confusing that only the mid-torso had a significant interaction, especially

[10] This was further supported by the fact that there were no significant correlations between PA and NA – suggesting that pianists may have felt a mixture of positive and negative emotions, rather than one or the other.

considering that the mid-torso does not have high degrees of freedom, and if the torso moves, then the neck and head may move. There were no significant differences for the neck or head. One possible way to interpret differences between arousal levels in the Expressive condition would be due to differences in breathing (given that the lungs are situated in the mid-torso). Indeed, physiological responses are changed with different emotional induction (Carlsson, Lundqvist, Juslin, & Hilmersson, 2009; Kreibig, Wilhelm, Roth, & Gross, 2007) and emotional engagement in music performance (Nakahara, Furuya, Francis, & Kinoshita, 2010; Nakahara et al., 2011). Perhaps expressing highly valenced music may also increase excitement and consequently quicken breathing. However, the interpretation of mid-torso jerkiness as a representation of breathing is a cautious suggestion. In order to fit with our previous results (increased jerkiness of sound-producing gestures in Technical condition, significantly decreased jerkiness of sound-producing gestures in the Emotional condition), mid-torso jerkiness should be highest in the Technical condition to represent nervousness (Homma & Masaoka, 2008) and significantly reduced in the Expressive and Emotional once the participant feel calmer (Glowinsky et al., 2007). Furthermore, it may still be unclear whether the breathing may represent nervousness or whether it represents excitement and enjoyment of playing the music or indeed both. Although support of this interpretation would require further study of physiological patterns in music performance, it is tentatively suggested that interaction of highly valenced music and expressing emotion may influence physiological responses which are manifested in the pianists' movement.

Differences between arousal and valence for postural features had less consistent patterns compared to AM (which had similar patterns across body locations). Nonetheless, some trends could be identified. Generally, high Arousal segments and high Valence had less shoulder hunch and head tilt than the medium and low Arousal and low Valence segments (the greater the value, the greater the distance between head and shoulders), supporting the idea that high arousal and valence music are associated with lifting shoulders (Wallbott, 1998) and more upright posture (Van Zijl & Luck, 2013). Most importantly, mean shoulder hunch across Arousal levels differed the most in the Emotional condition, whereas shoulder hunch and mean head tilt across Valence levels differed the most in the Expressive condition (see Figure 10.1 and 10.2). This supports the hypothesis that expressing emotion is different to feeling the emotion (Van Zijl & Luck, 2013). It should be noted that these are differences of head tilt in varying valence across Conditions compared to the results found for the main effect of

Condition for head tilt (Section 5.2), which was a difference in head tilt *fluctuation*. This suggests that the *occurrence* of head tilt compared to the *degree* of head tilt represents different kinds of emotion. According to the current results, *occurrence* of head tilt may be related more to high emotional engagement of the music, whereas the *degree* of the head tilt is related more to an interaction of heightened (either high or low) valence across expressing or feeling the emotion during a music performance.

Results revealed only one significant three-way Condition × Arousal × Valence interaction for shoulder hunch fluctuation, where high Arousal or high Valence yielded the most differences across conditions. The fluctuations of shoulder hunch changed (depending on emotional engagement) mainly in piece-segments with high arousal or high valence. What can be observed is the potential influences of *mixed* emotional cues in the music had on the shoulder hunch fluctuations. In piece-segments of low Valence and high Arousal, or in piece-segments of low Arousal and high Valence, shoulder hunch fluctuated more, a pattern which occurred mostly in the Emotional condition. Mixed cues in music (e.g. fast minor or slow major music) also elicit mixed emotions (Hunter et al., 2010), which sometimes are the strongest emotions during music listening (Bannister, 2018). It could be assumed that mixed cues in music evoked mixed emotion in the performers most during the Emotional performance (mirroring music-related felt emotion),[11] consequently evoking strong felt emotion (aesthetic music-related felt emotion) which are then manifested in greater shoulder hunch fluctuations. To date, most research into movement expressing emotion is rather two-dimensional, in that mixed emotions are not as thoroughly explored, which further makes the interpretation of these results difficult. Nonetheless, the trend of mixed emotions manifesting differences of shoulder hunch especially in the Emotional condition (indicating mixed mirror and aesthetic *music*-related felt emotions) could provide a direction for further research into the movement correlates of mixed emotion during music performance.

Although these three-way ANOVAs (with two- and three- way significances) suggest that a mixture of emotions interact to become manifested in performer movement, a few things should be noted. Firstly, the fact that patterns for postural features were less clear compared to patterns of AM in the interaction could be due to individual factors (Bella & Palmer, 2011). Although

[11] This is supported by certain post-Emotional interview responses that referring to ‘positive feeling… but maybe sadness in it but more like nostalgia’

expressive movement such as increased head and shoulder movement seems to be a universal expressive device as found in a range of studies (e.g. Castellano, Mortillaro, Camurri, Volpe, & Scherer, 2008; Davidson, 2007; Thompson & Luck, 2012), differences between postural features may be more individual. This individuality may be rooted in participant's musical education, or in playing with or without the musical score. Although postural features are related to expressive intentions (Camurri et al., 2004), it should be noted that they are indirectly also technical features, as good posture is essential for piano playing. Different teachers may variously influence their pupils. One participant related that 'I also had one of those teachers […] who was very kind of like anti-crazy flamboyant movement.' It is very possible that other participants' teacher(s) may have encouraged this movement and did not focus as much on posture technique. Additionally, posture may be different across participants who engaged with Alexander Technique, which can influence the consciousness of gestures in piano performance (Czepiel & Egermann, 2017). As instrumental training or experience in Alexander Technique was not part of this study, further research into posture could well consider individuals' instrumental training, playing techniques and experiences. Furthermore, potential (but not significant) difference between neck postures in those individuals playing with, as opposed to without a score (see Appendix C), could have complicated postural feature results further.

Secondly, the results should be cautiously considered as the effect size is extremely low for Condition, Arousal and Valence interactions, with effect sizes only ranging from $\eta_p^2 = .06$ to $\eta_p^2 = .08$. It should also be mentioned that in some cases separate ANOVA did not result in significant differences which could be due to a Type 1 error (see Section 3.6.7). To overcome this problem, the study could have focused solely on the movement features from piece segments that had the highest Arousal and Valence ratings into the analysis (i.e., removed segments with medium Arousal or Valence to give more clear-cut perceived emotional differences). However, this analysis (results and discussion of which can be found in Appendix B) did not produce any higher effect sizes or more significant results. Thus, these interpretations are relatively tentative and requires replication studies to provide further support and validity of these results.

5.4 Implications

This research may be beneficial for musicians – both in the educational and professional domains – by informing them how felt emotions can be used to create enjoyable and expressive performances. The results showing that expressive and technical movement differs between conditions support the idea mentioned at the beginning that truly feel the music can provide a enhanced visual performance compared to just expressing the music. The Emotional condition created performances with smoother and more nuanced expressive movement, represented by more subtle aspects, such as head tilt. As emotional performances also led to slightly less expressive movement and reduced jerkiness in technical movement, it could be suggested that focusing on the emotion may also prevent extraneous movement (both expressive and technical); with the benefit of preventing exacerbation of physical problems for musicians. The results can have further positive outcomes for those suffering from music performance anxiety, which affects many musicians (Kenny, Davis, & Oates, 2004; Marchant-Haycox & Wilson, 1992; Mor et al., 1995). The results of the current study not only show that focusing on emotion aid negative felt emotion (from interview data, supporting results from Buma, Bakker, & Oudejans, 2015; Glowinsky et al., 2007; Oudejans et al., 2016), but also that it can positively impact on the movement, creating a visually smoother performance.

The results from this study could also be used to partially support the embodiment theory. Expressive movement has been shown to be conveyed in response to expressive intention, but according to the embodiment theory, can also regulate cognitive processes in music performance (Clarke, 1993; Palmer, 1997; Wanderley et al., 2005). The basis of this thesis relies on the embodiment theory: that our emotions and cognitions are intrinsically linked to our body movements. Although the current results do not definitely support it in the way that results from Clarke (1993), Palmer (1997) and Wanderley (2005) do, the way that the results are interpreted may suggest that the movements in the performances facilitated cognitive and emotional processes in the performances. An example from an interview corroborates this suggestion: when focusing on technical aspects, one participant said they felt "stiff", but in the emotional condition they said they could "feel free." It is worth noting that these may reflect "orientation metaphors" (Lakoff & Johnson, 1980), i.e. they represent feelings on a corporeal level. Interview comments suggest that playing with focus on technical aspects made the performance (or the performer's body) stiffer. "Feeling free' also suggests a bodily meaning, especially as it was followed by the phrase that the performer could “move more.” Future studies may examine whether emotions and movement could support the embodiment theory using a paradigm where performers are induced with the emotion of the music, then asked to either play with or without expressive movement. If the non-expressive movement would hinder the performance, this could provide evidence that the movement in music performance can help regulate certain emotions that may positively influence music performance.

5.5 Limitations

Arguably the largest limitation of the study was the fact that participants played different pieces. Although data were transformed into representable values to allow direct comparison between participants (which was done using feature scaling in this study), movement features could have nonetheless been affected by differences in the music itself, for example genre (Huang & Krumhansl, 2011), technical demands, and emotion content. It also meant that it was difficult to assess whether differences of movement features were due to individual differences (as has previously been found in Dalla Bella & Palmer, 2011; Ferrario, Mari, Biggi, Pollice, Sforze, 2007) or due to the selection of the piece. Additionally, some participants played more piece-segments with high arousal (participant 8 and 9) and some played more piece-segments with low arousal (participant 2 and 3), thus differences between movement features of high and low arousal could also be partly driven by the individuals, especially as there was a low sample size. Movement may well vary greatly between performers. As the study had a relatively small sample size, it may not have accounted for a large enough range of playing styles. Further study of a wider range of participants is required to confirm the reliability of our results.

Nonetheless, the decision to choose naturalistic pieces that are in pianists’ current repertoire allowed a more realistic investigation into movement in music performance (Davidson, 2007; Poggi, 2006; Thompson, 2007; Wanderley et al., 2005). I believe it also allowed for strong and genuine felt emotions in the Emotional condition. It also allowed greater control of the movement features more in the sense that repeat performances of pieces that are well-rehearsed in a pianists repertoire differ only slightly on successive playing (Chaffin, Lemieux, & Chen, 2007; Wanderley et al., 2005). Sight-reading or learning a piece prior to the experiment may have meant that the differences in movement between performances were due to differences in the performance itself, rather than on the condition.

While the pieces had high ecological validity, playing in the MoCap Lab space and playing with MoCap suits and finger markers was not naturalistic. Although participants had time to get used to playing in this setting, it nonetheless hindered performance at times (‘I was thinking that it would be easier [to play] without this [suit]’). Future ways of getting quantitative values within a more naturalistic way could consider video recordings and computer vision techniques such as frame differencing, optical flow and kernelized correlation filters (e.g. Alborno, Volpe, Camurri, Clayton, & Keller, 2016; Jakubowski et al., 2017).

Another limitation of the study was the order of conditions. Ideally, the order would have been randomised and counter-balanced among participants. Although this was considered, it was assumed that it would be difficult for participants to go from high emotional engagement to low emotion engagement. It was also important to consider the individual preferences – one participant said that they found the Technical condition the easiest, because their adrenaline levels were highest at the start. If this study were repeated or developed further, the pieces could be played at different sessions (e.g. on the subsequent days) to avoid this problem.

A further limitation was the lack of an appropriate questionnaire or tool to measure emotions felt in music performance that would adequately decipher the distinction between different types of perceived, felt, performance-related or music-related emotions. Although using instruments related to felt emotion, such as the GEMS (Zentner et al., 2008), were seriously considered, these are appropriate only for music-listening. The PANAS was used as it has proved a good tool in previous studies. The disadvantage is for not specifically account for either performance-related or music-related emotions. Additionally, previous testing of the PANAS was more related to mood over a long time frame (up to 2-months; Watson, Clark, & Tellegen, 1988). Therefore, the results in relation to the first research question - and the interpretation of differences between performance-related and music-related NA - may be rather speculative. The study highlights the need for an instrument that measures felt emotions in a music performance as well as one that specifically distinguishes between music-related and performance-related emotions, in order to more systematically confirm the results found in this study.

The fact that the features extracted were low-level features may also be considered a limitation. Future studies could extract a wider range of movement features as well as using feature reduction techniques such as principle component analysis (Burger et al., 2013) or sequential backward elimination with variance inflation factor selection (see Saarikallio et al., 2013) to explore how higher level features may be related to felt emotion. This may provide results more representative of the movement and be to a greater degree similar to potential human perception of movement (Niewiadomski et al., 2019). This grouping of movement features then could give even more meaningful results, as gestures rarely are separate components and blend into each other to provide meaningful movement.

Statically speaking, ANOVA tests were still used for the repeated measures and to assess interactions. Although ANOVAs can be robust against non-normal data (e.g. Schmider et al., 2010), the use of these tests may have increased the chance of Type 1 error (Oberfeld & Franke, 2012). Therefore, results from the current study, especially the results with interaction which have low effect sizes (in most cases less than .01) should all be seen as only trends. The non-normality may have been due to the small sample size which might have skewed the data. One way in which this could have been avoided was to transform the data once more. This was actually done at the analysis stage of this thesis, however it proved to be more difficult to appropriately interpret the results from the transformed data. For future analysis, different methods could prove to be more effective against non-normal data, such as robust means modelling (Fan & Hancock, 2011) or ANOVA-type statistic (for a review see Erceg-Hurn & Mirosevich, 2008).

5.6 Further directions

Within the collected data, there is much that could still be further explored. The study also collected video recordings, which are yet to be analysed. These could provide further insights into details such as facial expression (Davidson 1991), which are an additional indicator of emotional expression (Ekman, 1992; Waddell & Williamon, 2017). This study extracted only a small range of possible movement features (mainly just one value to represent one performance). As Motion Capture data allow very high temporal and spatial resolution, future analysis will consider time-series and time-warping analysis (Thompson, 2012; Wanderley et al., 2005) to try and link the movement features to corresponding points in the music. This may provide further nuanced details and explanation into specific moments of movement (e.g. when exactly head tilts and shoulder hunches occur). Further analysis of the current data set would be fruitful by further investigating, for example, how the differing emotions could influence movement features at structural moments and/or phrase boundaries (Clarke, 1993) or for at moments that allow for *rubato* (Thompson & Luck, 2012; Wanderley et al. 2005).

There could be much more analysis of the interview data, which was only analysed using the basic categories outlined in the literature. A thorough analysis of the interview material is planned in order to gain further insight into the way emotions can aid performance; it could potentially help to understand where performance anxiety comes from (by exploring the interviews from the Technical condition) and how focusing on specific elements of the emotion of the piece may counteract anxiety (analysing the interviews from the Emotional condition).

The correlation between different movement of perceived and felt emotion of the performer and the perceptions of an audience could also be explored (Davidson, 1993; Huang & Krumhansl, 2011; Tsay, 2013; Vuoskoski, Thompson, Clarke, & Spence, 2014). A perceptual study is planned, where different visual and audio stimuli will be presented to participants who would rate performances in terms of communicated emotion, perception of professionality and expressiveness. This would more clearly support the idea that expressive movement differed between conditions, and also that the reduction in jerkiness would increase the perception of a more fluid and skilful performance.

Outside of the data collected for this study, its findings have generated several further questions yet to be explored. Future study should attempt to find other movement correlates of felt emotion during music performance (in particular focusing on postural features, the results of which remain rather inconclusive in the current study). Although research in music listening has begun to explore the sensation of mixed emotion, studies in music performance have thus far focused mainly on how one emotion may be exhibited through movement. Therefore, the research direction of mixed emotion in music listening should be transferred to music performance research. However, this would only be possible if research was also conducted to create a questionnaire or scale that adequately measures the different types of - as well as a mixture of - emotions felt in music performance. Although a few studies have observed physiological measures during music performance (Glowinsky et al., 2008; Nakahara et al., 2010, 2011), further research is required to more precisely decipher which *type* of these may represent emotions experienced by the performer, rather than showing a *difference* in emotion.

6 CONCLUSIONS

The results of this study establish that different types of - and combinations of - felt emotion during a performance influence movement features in pianists. Positive emotions during a performance were linked to expressive movements. Negative *performance*-related emotions were related to jerkiness of wrists whereas negative *music*-related emotions related to postural features. Expressive movements (operationalised as amount of movement in head, shoulders, and elbows as well as leaning towards and away from the piano) occurred in both expressing as well as feeling emotion of the music. The Emotional condition had higher head tilt fluctuations and reduced jerkiness in technical movements compared to both Expressive and Technical performances. Feeling the emotion of music significantly increased fluctuations of head tilt (compared to playing accurately or expressing the music), providing further cues of truly felt emotion. This is supported by the idea that felt emotion shows one as being vulnerable, as does tilting of the head. Feeling the emotion of music also reduced jerkiness in technical movements, suggesting that focussing on music-related emotion can reduce negative performance-related emotion which in turn improves smoothness of technical sound-producing movements. A further novel finding suggests that interactions of perceived, music-related and performance-related felt emotions during performance may be reflected in movement. The most surprising result was that some expressive movements were significantly higher in the low arousal music compared to high arousal music when 1) focusing on playing technically accurately and 2) when feeling the emotion of the music. The former may be explained by the fact that expressive movement is likely to facilitate the sound-production of the slow notes of low arousal music, but hinder execution of fast music typical in high arousal music. The latter may be the case because expressive movements may reflect an interaction of perceived emotion (e.g. sadness in the music), with aesthetic music-related emotion and positive performance-related emotion (e.g. enjoying the beauty of the music). Patterns of jerkiness and postural features across differing levels of emotional engagement, arousal and valence were less consistent. Nonetheless, the results suggest that movements differentiate when pianists are *expressing* the emotion compared to when they are *feeling* the music's emotion, especially in high valence music (jerkiness, mean head tilt and shoulder hunch) and higher extremes of valence and arousal (for fluctuation of shoulder hunch). The results also imply that mixed emotions within the music itself (high arousal and low valence /low arousal and high valence, e.g. nostalgia) may be reflected in movement features, especially when pianists are feeling these emotions. However, the effect sizes of these interactions are relatively small, perhaps due to small sample size, analysis of low-level features, or use of questionnaires that do not differentiate between music-related and performance-related emotions. Overall, however, the current study reveals trends that could inspire further research to disentangle what kind of emotions performer movements may actually reflect and how the movement features covered in this research may be perceived by an audience.

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8 APPENDIX A

PANAS Questionnaire

This scale consists of a number of words that describe different feelings and emotions. Read each item. Indicate to what extent you feel right now (that is, at the present moment) from 1 (only very slightly felt this emotion) to 5 (felt this emotion extremely).

1	2	3	4	5
Very Slightly or Not at All	A Little	Moderately	Quite a Bit	Extremely

__________ 1. Interested	__________ 8. Hostile	__________15. Nervous
__________ 2. Distressed	__________ 9. Enthusiastic	__________ 16. Determined
__________3. Excited	__________ 10. Proud	__________ 17. Attentive
__________ 4. Upset	__________ 11. Irritable	__________ 18. Jittery
__________ 5. Strong	__________ 12. Alert	__________ 19. Active
__________6. Guilty	__________13. Ashamed	__________ 20. Afraid
__________ 7. Scared	__________14. Inspired	

9 APPENDIX B

From the 79 piece-segments, segments with extreme values (that were rated either as 1 or 5, getting rid of any medium values) formed a third data set of 44 segments with extreme emotion.

Piece and piece segments	Movement Features
10 whole pieces	10 × 3 Conditions × 36 movement features =1080
79 segments of different perceived emotion	79 × 3 Conditions × 36 movement features =8532
44 segments of extreme perceived emotion	44 × 3 Conditions × 36 movement features = 4752

Mixed design ANOVAs tests with the third data set revealed a significant interaction Condition × Arousal for the AM of left elbow ($F(2, 80)= 3.58$, $p = .032$, $\eta_p^2= 0.08$). Separate ANOVAs found that there was significant difference of left elbow AM in the Technical condition ($F(1, 42) = 11.17$, $p = .002$) but not for the Expressive ($p = .94$) or Emotional ($p = .157$). There was a significant Condition × Arousal × Valence interaction for the head ($F(1.98, 79.35) = 3.219$, $p =.046$, $\eta_p^2=.07$) and left elbow ($F(2, 80)= 3.67$, $p = .03$, $\eta_p^2=.08$). Separate ANOVAs found that AM for head significantly differed for Arousal groups in the Technical condition ($F(1, 42)= 6.260$, $p = .016$) and the Emotional Condition ($F(1,42) = 4.59$, $p = .038$), but did not differ significantly for the Valence. AM in the left elbow did not differ significantly for Arousal groups between conditions. There were no significant interactions for jerkiness. ANOVAs further revealed a significant of Condition × Arousal × Valence interactions for the fluctuations head tilt right ($F(1.71, 68.50) = 3.52$, $p = .04$, $\eta_p^2 = .08$). Separate ANOVA found no further significant differences.

Extreme values yielded three way interactions of Arousal and Valence for the AM of head, left elbow, neck and right shoulder, and head tilt. This suggests that the more extreme the emotion, the more clearly the movement fits into two-dimensional emotional space, rather than either just a one-dimensional emotional scale or in a category. However, these statistics had an extremely small effect size (e.g. $\eta_p^2= 0.08$). Additionally, results did not replicate the findings that when participants felt sadness (low valence, low arousal), statistics did show there was less movement and more hunched posture.

10 APPENDIX C

Additional ANOVA and *t*-tests were run with certain movement features to check for some possible uncontrolled variables of group differences, namely playing experience and whether participants played off by heart or from the score. As multiple t-tests were run, *p* value threshold were lowered to account for the many tests that were run and to avoid a Type 1 error. The Holm method[12] was used and gave a *p* threshold of .001.

10.1 Professional

Many studies on expressive movement in performance studies have reported differences in playing experience i.e. whether professional or not (e.g. Ferrario, Mari, Biggi, Pollice, & Sforze, 2007; Furuya & Kinoshita, 2008; Van Zijl & Luck, 2013). Participant reported whether they were amateur (2 participants), semi-professional (3 participants), or professional (5 participants). A one-way ANOVA the movement features in each Condition with the between-subjects factor Experience (three levels: amateur/semi-professional/professional) revealed a significant main effect on jerkiness only, and specifically jerkiness of the left shoulder, right shoulder, left elbow, right elbow, and jerkiness of right finger. Amateurs tended to have more jerkiness in shoulders and elbows, whereas semi-professional and professionals had smoother movement in these locations.

Table 22. Movement differences between professional, semi-professional and amateur pianists.

Mean Jerkiness in Technical condition	F statistics	*p* (before Holm correction)
Left shoulder	$F(2,7) = 10.00$	.009
Right shoulder	$F(2,7) = 12.31$	.005
Left elbow	$F(2,7) = 12.68$	.005
Right elbow	$F(2,7) = 11.67$	.006
Right finger	$F(2,7) = 8.77$	.012

[12] Using the `p.adjust` function in R+

Amateurs had more jerkiness in shoulder and elbows movement compared to semi-professionals and professionals, supporting the finding that players with more experience utilise muscles in the other parts of their body (e.g. elbows) to support the wrists and fingers that are involved with directly making the sounds (Furuya, Altenmüller, Katayose, & Kinoshita, 2010; Furuya, Altenmüller, 2013). It also supports the idea that increased smoothness in music performance increases ratings of skill (Nusseck & Wanderley, 2009). It should also be further noted then, that decreased proficiency of the technical movement also decreased the level of expressivity and their level of emotional engagement, as one participants stated in the interviews after the Emotional condition performance: "It's so hard for me to play wrong, that's why err, it's changed my emotions if I play it wrong." This also shows that more realistic factors as technical proficiency is vital in creating expressive and emotional movement.

10.2 Score

Another uncontrolled factor was whether participants played from memory or from the score. Some participants arrived with no score (4 participants), whereas some played from their music (6 participants). Because this may have affected where they were looking (e.g. looking onto score and then onto the keyboard), it could have affected head movement. Independent *t*-tests were run to see if there was a difference of movement with and without score. There were differences in both technical and expressive movement in different conditions. In the Technical condition, participants who played off by heart had a more negative neck posture value, suggesting that their neck posture was bent more forwards (and looking more at their fingers) compared to those who had music, whose results suggest a more upright neck posture (and probably looking more towards the music). In the Emotional condition, those used scores in their performances had less jerkiness of the right finger in the Emotional condition.

Table 23. Movement differences between pianists playing with and without a score

Movement features between conditions	*t*-test	*p* values (before Holm correction)
Neck posture (Technical)	(8)=3.13	.026
Jerk in right finger (Emotional)	(8)=-3.17	.026

The reason why those without the score had higher jerkiness of fingers compared to those who played with the score could be explained by the idea that playing off by heart requires more muscle memory (Ginsbourg, 2004), which at times if uncertain may have resulted in less smooth movements. This suggests that movement in music performance depend on whether the musician read from the score or play music off by heart and perhaps should be considered in all future research that explores expressive and technical movement.

The fact that the study did not control for playing from memory versus playing from the score was a limitation. The *t*-test for whether participants played with or without showed significant differences for neck posture and jerkiness of right finger. When playing with the score, neck posture was less bent more forwards, suggesting that the participants were looking upwards towards the music compared to participants who played without the score (posture bent towards the direction of the keyboard). What was interesting is that neck posture of those who played *with* the score became more negative in the Expressive (m = -0.38) and Emotional (m = -0.39) condition compared to the Technical condition (m = -.034), suggesting that engaging with the emotion also means that participants were less dependent on the music. Playing with and without scores also meant that participants had different versions of the 'Technically' accurate conditions. Scores contain markings, and in the Technical condition, participant who played with the scores had only their memory to serve them, whilst those with scores looked more intently at the music, with one participant saying ("I remember noticing some slurs that I didn't notice before.") Therefore, controlling the focus away from the emotion (low emotional engagement) differed between participants with and without the score in the Technical condition. Although results were not significant after Holm correction, these results suggest that future studies should take playing with/without scores into account when controlling (or comparing) experimental factors.