Mental Imagery Rehearsal Strategies for Expert Pianists

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Declaration

I hereby declare that this thesis, submitted in candidature for the degree of Doctor of Philosophy at the University of Edinburgh, and the research contained herein is of my own composition, except where explicitly stated in the text, and was not previously submitted for the award of any other degree or professional qualification at this or any other university.

Kirsteen Davidson-Kelly, 27 August 2014

Abstract

For pianists working within the western art music tradition, the ability to perform a large and complex repertoire from memory is almost a prerequisite for a successful career. Memorising and maintaining this repertoire requires considerable practice and can lead to physical overuse syndromes. Additionally, automated motor memory developed via physical practice is not always sufficient for secure recall, often leading to performance anxiety. It is important therefore for professionals to identify optimal practice strategies, and mental rehearsal has been widely advocated as a potential means of enhancing memorisation and performance fluency while at the same time avoiding physical overuse. The results of three studies that examined mental imagery rehearsal by expert pianists, adopting a mixed methods approach, are presented in this thesis. The first was a participant observation study of a course at which eleven advanced pianists learned to use a memorisation technique incorporating deliberate imagery; the study aimed to describe the teaching and learning of specific imagery techniques and to examine the potential advantages and drawbacks of this approach. The second study was an online questionnaire survey of thirty six piano students at UK conservatoires designed to investigate the teaching and implementation of mental rehearsal techniques at advanced training levels; the survey found that despite a widespread awareness of imagery rehearsal as a potentially effective strategy, training in specific techniques was not consistently available, and recommended mental practice strategies were adopted much less consistently than strategies involving physical practice. Finally, an fMRI study of fourteen expert pianists aimed to determine the neural correlates of imagery rehearsal and simulated piano playing. Differences observed in brain activation between tasks suggested increased involvement of working memory processes during mental imagery. The thesis concludes that mental imagery rehearsal techniques are acquired skills that can be taught and improved over time and which have specific advantages over motor learning, but that more pedagogical training is needed in order for these techniques to become fully effective and widely adopted.

Preface

> *The fingers are the servitors of the brain, they perform the action the brain commands. If, therefore, by means of a well-trained ear, it is clear to the brain how to execute correctly, the fingers will do their work correctly. (Gieseking & Leimer, 1932: 20)*

A personal experience of a practical teaching method that incorporates mental imagery techniques (in the tradition of Gieseking and Leimer), which radically enhanced my own and other pianists' playing and memorisation techniques, inspired this research. For professional pianists in the western art music tradition, the ability to perform a large repertoire from memory is almost a prerequisite for a successful career. As a performer and teacher I am interested in how musicians learn and how musical memory is effectively established. This thesis arose largely from my own studies with an eminent teacher of piano and Alexander Technique, Nelly Ben-Or, and examines how the deliberate use of mental imagery may, as she suggests, enhance memorisation and performance fluency. This research is very specific to the domain of western art music in which pre-composed texts dominate the performance tradition, but although these studies focus on advanced pianists, the outcomes may be of benefit to a range of instrumentalists at various stages of training.

An introduction to Nelly Ben-Or

Nelly Ben-Or is a concert pianist and senior teacher of Alexander Technique. A Holocaust survivor from Poland, she completed her musical studies in Israel after the end of World War II and came to England in 1960. In 1963 she was the first pianist to qualify as an Alexander Technique teacher and she has taught at the Guildhall School of Music and Drama in London since 1975. She gives masterclasses around the world on the application of Alexander Technique to piano playing, and I first encountered her work in July 2001 when she gave a brief demonstration at a conference of the European Piano

Teachers Association UK. I enrolled for a three-day course in January 2002 and began to adopt some of her techniques in my own work, subsequently attending another course and five private lessons between 2002 and 2005. My PhD began in 2006 primarily as a result of NBO's teaching. Pianists who have studied with her (myself included) believe that her mental imagery and physical awareness techniques help to improve memorisation and to enhance playing.

Imagery rehearsal, however, is not necessarily an easy, or a popular approach. It often feels more difficult than physical practice - although it makes physical practice feel easier once it has been done well. Moreover, and very importantly, musicians love to make sound: the physical act of playing and the effects of sound on the body and mind motivate us to make music. Separating musical thinking from the physical act of playing by using mental imagery is thus not necessarily an obvious route for enhancing learning. The aim of this thesis is to explore ways in which deliberate mental imagery rehearsal might enhance the performance of memorised musical text, compared with physical rehearsal alone.

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I want to start by thanking all the wonderful pianists who have taken part in this research. First and most importantly, Nelly Ben-Or, the most generous of teachers and a true artist of the imagination; thank you for so freely sharing your music and ideas. To those pianists from around the world with whom I spent many hours in Nelly Ben-Or's studio; the Edinburgh University music students who helped to pilot questionnaire materials; the anonymous questionnaire respondents who engaged thoughtfully with the online survey; my colleagues Richard Harris, Katharine Durran, David Appleton and Alex Metcalfe who discussed and tested materials during their development; and the adventurous spirits who contributed such energy and skill to the fMRI study – thank you. My conversations with all of you, real and virtual, have been a delight.

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My great friend Dr. Thomasin Andrews sparked the interest in brain imaging techniques that led me towards this research, and has encouraged me throughout. Thank you for broadening my mind and keeping me sane! My lovely daughters, Eloïse and Zhana, have asked all the best questions and reminded me every day of the power of the imagination, and how to have fun.

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Chapter 1 Introduction

> The music itself is something imagined, first by the composer, then in partnership with the performer, and ultimately communicated in sound. (Hill, 2002: 129)

Pianists are expected to memorise a large and complex musical repertoire, but there is a lack of clear memorisation pedagogy and considerable variation in the amount and type of practice undertaken by experts. Unsystematic approaches may contribute both to inefficient practice and performance anxiety, which in turn contribute to physical and neurological disorders (and consequent stress and reliance on medication) that can affect performing musicians to varying degrees.

Mental imagery rehearsal may support effective memorisation (Rubin-Rabson, 1937, 1941) and help to reduce physical stress (Connolly & Williamon, 2004: 225). Some evidence suggests that certain strategies enhance memory security over particular time periods and that mental imagery rehearsal can effectively reduce the amount of physical rehearsal required for secure memorisation. It is not yet clear, however, to what extent experts use deliberate imagery techniques during learning, which techniques are most effective (Clark & Williamon, 2011) or how they might most effectively be incorporated into musical training (Wöllner & Williamon, 2007).

Recent neuroscientific research points to both overlaps and differences in cognitive processing between mental and physical rehearsal that may help to explain some of the effects of imagery rehearsal. Evidence of cross-modal co-activation in trained musicians suggests that mental imagery can activate auditory and motor neural networks in the absence of perceptual input (e.g. Lotze et al., 2003; Haslinger et al., 2005; Kleber et al., 2007) and may thus have a preparatory effect on performance in the missing modality. Interestingly, some studies have found that imagery recruits frontal regions to a greater extent than performance or perception, possibly reflecting the increased working memory demands of imagery (Kleber, 2007; Schaefer, 2011). Only a small number of studies have examined imagery rehearsal in expert musicians, however, and further research is therefore needed to develop a much fuller account of neural processes during expert imagery.

The first section of this chapter sets out background to the research, defines key terms, discusses the nature of expert musical imagery and summarises imagery rehearsal research (1.1). In the second section, a review of behavioural research studies is structured according to imagery type, and then by examining a number of factors that might influence outcomes (such as the amount and sequence of imagery rehearsal, task difficulty, skill level and attentional focus) (1.2). The third section examines neuroscience literature on imagery in expert musicians and in non-specialist populations (1.3). Research into memorisation processes in musicians is then briefly reviewed and some problems with current practice are outlined (1.4). Finally, research questions are defined (1.5) and the methods used to address them are introduced (1.6).

1.1 Background

1.1.1 Terminology

The term ‘mental imagery rehearsal’ is adopted here, in preference to others such as mental practice or mental rehearsal, to express a vivid sense of the activity as an imaginative and constructive act. It also aims to better encapsulate the notion that mental imagery occurs during performance and that mental and physical processes cannot be entirely separated. As preparation for performance, mental imagery rehearsal can be used for both cognitive and motivational purposes (Connolly & Williamon, 2004; Gregg, Clark, & Hall, 2008); this thesis is concerned with cognitive imagery techniques relating to aspects of musical production. In particular, the focus here is on techniques used to enhance the learning of pre-composed, written musical text, which in the Western art tradition the performer is required to translate into sound (often from memory) during performance (Bailes, 2009) via the retrieval of deliberately encoded mental images.

Mental imagery rehearsal is understood in this context to be multimodal, deliberate, purposeful and (particularly initially) effortful. The key feature of this type of rehearsal is that the musical image in at least one modality is entirely imagined; it can include combinations of auditory, motor, visual, notational, visuo-spatial and structural imagery of the musical text. While terminology in the literature is inconsistent and often unspecific, 'motor imagery' refers here to imagined kinaesthetic experience from the first-person perspective; 'visual imagery' refers to imagery of movement from the third-person perspective, and 'notational imagery' to visualisation of the musical score. 'Visuo-spatial imagery' refers to imagery of note patterns on the keyboard from an external perspective (i.e. non-kinaesthetic). The term 'structural imagery' is used here to refer to a performer's sense of the musical structure as an 'imaginary space' (Holmes, 2005: 228), which may be accessed through a variety of means, including linguistic labels and conceptual associations (although previous research has examined analysis and score study, it is assumed that 'structural imagery' arises from these activities). For the purposes of this thesis, imagery rehearsal is defined as the deliberate internal generation of imagery in the absence of self-generated feedback in the missing modality(ies); imagery rehearsal may therefore occur with or without a score, instrument or auditory model, and in the presence or absence of overt movement.

1.1.2 Musical imagery as memory for performance

Musical imagery is a form of musical thought (Bailes, 2009:41) and the process of memorisation can be understood partly as the process of encoding multiple mental images. Musical imagery can occur 'offline' (in the absence of overt performance) and 'online' during performance (Keller, 2012: 207). In fact, as previous authors have pointed out, performance necessarily includes mental imagery processes (Bernardi et al., 2013: 285; Connolly & Williamon, 2004:225), generated either deliberately or in automatic response to internal or external cues (Keller, 2012:206; Bailes, 2009:41). Conversely, imagery rehearsal may occur entirely in the absence of physical performance (Rubin-Rabson, 1941:102).

For fluent expert performance, with or without a score, multi-dimensional images of the music need to be securely encoded in memory in order to be recalled under performance conditions (see for example Hallam, 1997; Chaffin & Imreh, 2002). Auditory, motor, conceptual, structural, visual and linguistic images may all concurrently contribute to performance (c.f. Williamon & Valentine, 2002; Mishra, 2005: 75; Chaffin, 2009: 354). The manner in which performers attend to different aspects of a musical image is likely to be context-dependent and idiosyncratic. Individual performers report consciously relying on certain mental images more than others; for example, some musicians report vivid visual recall of the score, while others have no conscious access to a visual image of the text (Chaffin, 2009: 356). The ability to imagine in various modalities varies widely, even in experts (Brodsky et al., 2003; Highben & Palmer, 2004; Brown & Palmer, 2012), and the depth of processing of different types of image may vary depending on the performer, the nature of the task and the stage of learning - and potentially irrespective of the degree to which the mental image is consciously accessed by the performer (Chaffin, 2009: 356).

1.1.3 Mental imagery rehearsal

> The material can be visualised as though mentally photographed. The melodic line in both hands can be either imagined or sung when it is adaptable to this purpose. Or both hands can be projected mentally onto a keyboard with or without any overt kinaesthetic behaviour. Finally, all these things may occur together and the tonal, visual, and kinaesthetic factors coalesce, so that, even without any muscular movement, the whole may be rehearsed with nearly the same vividness as exists during actual performance. (Rubin-Rabson, 1941: 102)

There is not yet a substantial body of evidence documenting the extent of deliberate imagery rehearsal amongst musicians (Clark & Williamon, 2011: 354), or variations in its precise content, although a small number of interesting studies have paid detailed attention to various uses of imagery by performers (particularly Holmes, 2005; Bailes, 2009; Bernardi et al., 2013). Experts interviewed by Bailes (2009) emphasised auditory and conceptual, or schematic (structural) imagery as the central features of mental rehearsal. Holmes (2005) interviewed a guitarist and a 'cellist, who reported using auditory and motor imagery, and the guitarist also reported visual imagery of finger patterns (like 'constellations') on the instrument (229). Pianists studied by Bernardi reported using (in order of frequency) auditory, structural, motor and notational imagery, and – least often - visual imagery (2013: 282).

Mental imagery rehearsal has been advocated as a potential means of enhancing memorisation and performance quality (e.g. Gieseking & Leimer, 1932; Holmes, 2005), improving practice efficiency and reducing physical overuse (Freymuth, 1999; Hays, 2002; Connolly & Williamon, 2004). Several studies comparing mental imagery and physical rehearsal have measured the time taken to reach fluent memorised performance, or the number of correct notes memorised in a given period of time (Rubin-Rabson, 1937, 1941; Ross, 1964; Ross, 1985; Coffman, 1990). Findings from some of these studies support the argument that imagery rehearsal can enhance memory encoding compared with physical rehearsal alone (Rubin-Rabson, 1937, 1941; Ross, 1964) and can reduce the amount of physical rehearsal time required to reach memorised performance (Rubin-Rabson, 1937, 1941; Ross, 1964; Ross, 1985; Coffman, 1990).

Some expert musicians (e.g. Gieseking & Leimer, 1932) advocate imagery rehearsal as a means of avoiding excess physical rehearsal, which - as well as being potentially damaging physically – may be undesirable for artistic and motivational reasons. For experts, flexibility of motor movement is essential to the interpretive nature of performance (Palmer, 2006: 50) and thus there may be optimal limits on the amounts of motor rehearsal that is effective (Hill, 2002: 131; Williamon, 2002: 124). Hill, for example, proposes that getting to know the work in detail - by imagining it away from the instrument - enables the performer to memorise the music before playing begins, provides renewed motivation once physical practice has commenced, and frees the performer to focus on musical, rather than technical, goals.

The effects of mental imagery rehearsal on performance quality have been measured by several authors (Nuki, 1984; Mikzsa, 2005; Bernardi et al., 2013), whose findings suggest that performance quality is correlated both with the ability to structure learning according to a schematic framework and with auditory imagery ability. The use of performance quality as a research measure is, however, problematic, as ratings between evaluators can vary considerably, and further work is needed to develop reliable assessment scales for measuring the impact of imagery rehearsal on performance quality (Clark & Williamon, 2011: 356).

1.1.4 Investigating imagery rehearsal effects: overview of experimental methods and findings

Precise definitions of musical imagery rehearsal, and methods for measuring its effects, have varied. Experimental studies have investigated score study (Rubin-Rabson, 1937; Ross, 1964; Rosenthal et al., 1988); auditory imagery elicited by score reading (audiation) (Brodsky et al., 2008); auditory imagery (Rubin-Rabson, 1941; Kraemer, 2005; Leaver et al., 2009; (Herholz et al., 2008; Herholz et al., 2012); auditory imagery during movement observation (Haslinger et al., 2005); auditory imagery during silent piano playing (Bangert et al., 2006; Baumann et al., 2007); auditory and motor imagery (Kristeva et al., 2003; Kleber et al., 2007; Cahn, 2008); auditory versus motor imagery (Highben & Palmer, 2004; Mikzsa, 2005; Brown & Palmer, 2012, 2013); auditory, visual and motor imagery (Ross, 1985); auditory, visual and motor imagery with or without an auditory model (Coffman, 1990; Lim & Lipmann, 1991; Theiler & Lipmann, 1995); auditory/motor/visual/structural imagery in any combination, according to participants' choice (Nuki, 1984; Bernardi et al., 2013); and motor imagery (Langheim et al., 2002; Lotze et al., 2003; Meister et al., 2004). The majority of these studies examined imagery rehearsal in the absence of movement. Three, however, investigated imagery during silent piano playing (Bangert et al., 2006; Baumann et al., 2007; Brown & Palmer, 2013) and four contrasted imagery during silent motor performance with imagery in the absence of motor performance (Ross, 1985; Lotze et al., 2003; Meister et al., 2004; Bernardi et al., 2013). Some authors measured memorised performance outcomes (e.g. Nuki, 1984; Lim & Lipmann, 1991; Bernardi et al., 2013) while others measured performance from a score (e.g. Ross, 1985; Rosenthal et al., 1988; Coffman, 1990). Overall, experimental investigations have found that:

a) Physical rehearsal alone is better than imagery rehearsal alone (e.g. Lim & Lippmann 1991; Coffman, 1990) – although Cahn (2008) found no significant differences.

b) Imagery rehearsal plus physical rehearsal is equal to physical rehearsal alone (Theiler & Lipmman, 1995; Coffmann, 1990; Bernardi et al., 2013).
c) Imagery rehearsal plus physical rehearsal is superior to physical rehearsal alone (Rubin-Rabson, 1937, 1941; Ross, 1985).
d) Imagery and performance activate similar cortical networks (e.g. Kristeva et al., 2003; Lotze et al., 2003; Kleber et al., 2007).

1.2 Behavioural investigations of imagery rehearsal

Score study during the initial stages of learning novel material has been found by some authors to enhance memorisation (Rubin-Rabson, 1937; Ross, 1964), and training in score study skills has been found to improve its effectiveness (Ross, 1964). Score study may improve particular aspects of performance more than others (Rosenthal et al., 1988) and its effectiveness may be modulated by audiation skill (Brodsky et al., 2008). It may be that a general ability to encode structural imagery, accompanied by a high level of audiation skill - rather than formal analytical skill - is responsible for these effects (Nuki, 1984; Bernardi et al., 2013). Auditory imagery skill has repeatedly been implicated in effective memorisation (e.g. Highben & Palmer, 2004; Brown & Palmer, 2012, 2013; Nuki, 1984; Bernardi et al., 2103). Some types of imagery rehearsal may be less effective than others (Nuki, 1984) and may even distract from efficient learning (Bernardi et al., 2013). Documented uses of visuo-spatial imagery do not appear to have been investigated systematically. It has not yet been firmly established whether auditory models aid memorisation, whether there are optimal limits to imagery use, or more or less efficient combinations and sequences of physical and imagery rehearsal. There is some limited evidence that it may be most useful during the initial and mid stages of learning novel material and that its effectiveness may be modulated by task difficulty level, although there is conflicting evidence regarding this point (1.2.11).

1.2.1 Structural imagery

In music pedagogy, analytical strategies have frequently been advocated as a means of securely encoding structural knowledge (see for example Matthay, 1913, 1926; Hughes, 1915; Gieseking & Leimer, 1932) and there is some experimental evidence for the efficacy of this approach. Rubin-Rabson (1937) investigated whether score study prior to physical practice aided recall over time. A within-subjects design was used to measure the time taken by 18 piano students to relearn piano compositions (via rehearsal at the piano), three weeks after having initially memorised the compositions either with or without preliminary score-study. The difference in initial learning times between methods was not significant, but score study during initial learning significantly reduced the time for relearning, compared with physical practice only. Ross (1964) investigated whether training in guided analysis would improve memorisation in a between-groups study of 20 woodwind players. Over six weeks, two experimental groups memorised 20 novel musical examples, with or without verbal guided analysis. At post-test a previously unseen example was memorised, via four minutes of score study, prior to practice on the instrument. Results showed that the treatment (guided analysis) group required significantly fewer learning trials to reach the point of fluent memorised performance than non-treatment or control groups, suggesting that training in analysis techniques reduced the amount of physical rehearsal required during the initial learning and memorisation of novel music.

A later study by Rosenthal and colleagues (1988) used a between-groups design to compare score study, score study plus an auditory model, score study plus singing, and physical practice. 60 band musicians each spent three minutes learning a short piece and then performed it with the score; performances were measured for accuracy on a number of dimensions. The number of correct notes performed did not differ significantly between conditions, although score study with a model produced the highest number of correct notes. Rhythmic accuracy was best following silent score study, but overall it was found that silent score study was less effective than physical practice; this might have been due to unfamiliarity with the mental task, lack of imagery ability and/or the short treatment time. Combined physical practice and score study, which might have improved performance compared with score study only, was not assessed.

1.2.2 Score reading (audiation)

Musicians differ in their ability to imagine how the music sounds based on notation (audiation) (Brodsky et al., 2008). It is likely, therefore, that the effectiveness of score study is modulated not only by the level of analytical skill and training, but also by the level of audiation skill. In the studies by Ross (1964) and Rubin-Rabson (1937), however, the specific contribution of auditory imagery elicited by score reading (audiation) was either not measured (Ross) or the results were inconclusive (Rubin-Rabson). A recent investigation of mental processes during notation reading found that only a third of participants - highly trained expert musicians - were 'proficient enough to hear the temporal, tonal, and harmonic structure of the portrayed visual changes' (Brodsky et al., 2008: 443).

In a series of experiments, Brodsky and colleagues (2003, 2008) asked musicians to read musical scores in which well-known melodies were embedded within a larger melodic context. Participants then listened to excerpts and judged whether they contained the melody embedded within the visual score. Performance was worse if score reading had been accompanied by phonatory interference (i.e. wordless humming of a different melody), rather than by rhythmic interference (tapping a steady beat while hearing an irrelevant rhythm) or if there was no interference. A follow-up experiment again manipulated interference during score reading, and the authors also monitored activity near the larynx with EMG. They found that activity was greater during silent reading of a musical score than during silent reading of printed text or silent working out of mathematical sequences. These results were interpreted as suggesting that when skilled musicians read music notation, it is automatically transformed 'from its inherently visual form into an accurate, covert, aural–temporal stream perceived as kinesthetic phonatory and manual motor imagery' (Brodsky et al., 2008: 443).

1.2.3 Auditory imagery

Music pedagogy emphasises the critical importance of the ability to 'think in sound' (McPherson, 1995) and the central role of auditory imagery as preparation for musical performance (e.g. Matthay, 1913; Gieseking & Leimer, 1932; Suzuki, 1969). Indeed, a great deal of musical training relies on the widely held view that, as Seashore claimed, 'the most outstanding mark of a musical mind is a high capacity for auditory imagery' (Seashore, 1938, cited in Hubbard, 2010: 323). Highben & Palmer (2004) used a within-subjects design to compare mental and physical practice effects on performers' memory, and measured auditory and motor imagery ability for comparison with the mental practice effects. Sixteen adult pianists were asked to practice short excerpts (10 times each), by listening, or playing without feedback, or playing with normal feedback, or via mental practice. Each piece was then performed (four times) from memory with normal feedback, and performances were scored for accuracy. Scores were highest for practice with normal feedback, and lowest for mental practice. Scores on the auditory imagery test correlated with improved performance for mental practice – in other words, effective mental practice relied on auditory imagery skills.

Many musicians would argue, like Seashore, that auditory imagery ability correlates with overall musical ability, although in a review of auditory imagery findings, Hubbard argued that there was insufficient evidence to draw general conclusions about this relationship (Hubbard, 2010: 324). There are, however, some indications that vividness of auditory imagery correlates with experience (Keller & Koch, 2008) and that the effectiveness of imagery rehearsal in the absence of auditory feedback relies on auditory imagery skill (Highben & Palmer, 2004; Brown & Palmer, 2012). Brown and Palmer investigated how auditory-motor learning influenced memory for music using a within-subjects design. Forty eight adult pianists learned right-hand keyboard melodies in each of four conditions (listening, playing a silent keyboard, playing with normal feedback, playing with computer-generated auditory feedback), and then performed a listening recognition task for learned/novel melodies. Recognition scores correlated with auditory and motor imagery scores (assessed via difference-detection tasks). Higher auditory imagery scores also correlated with better recognition following motor-only learning, suggesting that auditory imagery filled in the missing auditory feedback at learning. Auditory recognition of melodies was improved by increases in auditory or motor practice, and performers scored better on recognition following normal auditory-motor learning than following auditory-only learning. The authors suggested that these results indicate that memory for music consists of abstract auditory memory that is further enhanced by motor learning (576).

Experts frequently report particular reliance on auditory imagery (e.g. Lotze et al., 2003: 1827; Holmes, 2005: 225; Bernardi et al., 2013: 284). Aiello (1999) interviewed seven expert pianists, who reported relying on auditory imagery more than on motor imagery, and there is some emerging experimental evidence that experts rely more on auditory imagery than on motor imagery when performing musical sequences from memory (Brown & Palmer, 2013). Two experiments extended the findings described above (Brown & Palmer, 2012) by examining how auditory and motor imagery abilities influenced memory encoding and retrieval. Using within-subjects designs, 24 adult pianists learned short melodies by listening to recordings or by performing on a silent keyboard; they then performed (recalled) each melody four times on a keyboard with normal feedback. During learning or recall, pianists experienced auditory interference, motor interference, or no interference. During recall, the number of correctly performed pitches was measured. Pitch accuracy during recall was significantly higher following auditory learning than following motor learning; participants with high auditory imagery skill showed better pitch accuracy recall than participants with lower auditory imagery skill following either auditory or motor interference at encoding. Furthermore, higher auditory imagery skill predicted higher pitch accuracy following auditory learning with interference, and following motor learning with or without interference. These results suggest that on average, participants relied more on auditory encoding than motor encoding; that auditory imagery abilities aided accurate encoding by protecting against interference; and that memory for performance was more accurately encoded by auditory learning than by motor learning.

1.2.4 Auditory, visual and motor imagery

Ross (1985) used a between-group design to investigate the relative effectiveness of separate or combined physical and mental practice, with and without simulated movement. Thirty trombonists practised a short piece of music three times, and their subsequent performances were scored for accuracy. It was found that combined mental and physical rehearsal produced the highest scores (although these scores were not significantly higher than scores for physical rehearsal alone), and that mental practice was better than no practice, but not significantly so. Mental practice with simulated movement produced slightly higher scores than mental practice without movement, but again the difference was not significant.

In a between-groups study by Coffman (1990), 40 non-specialist piano students were asked to learn a piano piece via either physical practice, mental practice, or combined physical and mental practice. Physical practice was carried out either with or without auditory feedback; mental practice was carried out either with or without a recorded auditory model. After practising the piece six times, participants were asked to perform with the score; performances were measured for duration and accuracy. According to the performance duration results, physical and mental practice combined was as effective as physical practice alone at eliciting shorter performance times, and both these strategies were more effective than mental practice alone. The use of an auditory model did not affect scores. There were no differences between conditions, however, on accuracy scores, which suggests that lack of task familiarity meant that these participants were not able to improve accuracy via any of the practice methods within the short experimental period.

Lim and Lipmann (1991) used a within-subjects design to examine memorised performance of short piano extracts by seven advanced piano students; participants had 10 minutes to memorise an extract via mental or physical rehearsal, or via mental rehearsal while listening to an auditory model. Memorised performances were scored for accuracy; scores were highest for physical practice, and mental practice with listening scored higher than mental practice alone. Theiler and Lipmann (1995) subsequently used a within-subjects design to investigate differences between physical and mental practice, and the potential influence of an auditory model on mental practice. Seven guitar and seven voice students were asked to learn short extracts using physical practice, or combined physical and mental practice, or mental practice with an auditory model, for a total of 12 minutes in each condition. Performances, with the score and then from memory, were assessed for accuracy and musical quality, and for the number of notes memorised. Results showed that performances following combined mental and physical practice were equal to those following physical practice alone, and that mental practice with an auditory model enhanced several performance dimensions (pitch accuracy, tone quality, dynamics and tempo) for vocalists, and enhanced tone quality and memory coding for guitarists.

1.2.5 Participant-selected imagery strategies

Two interesting studies specifically asked participants to use their preferred imagery strategies during learning. Nuki (1984) asked 17 piano students and 13 composition students to memorise a novel piano piece via their preferred method (score reading, acoustic, kinaesthetic, or a mixture – although it is not clear what is meant precisely by these descriptions), for up to a maximum of one hour's learning. The resulting memorised performances were assessed for accuracy, tempo and musical expression. Higher auditory imagery ability and structural knowledge predicted better memorised performance scores. Interestingly, at the group level, composition students performed better than piano students on sightreading and memorised performance, and required less time for memorising. This group spent more time studying the score than the pianist group, suggesting that reliance on audiation, as well as on structural knowledge (which was presumed to be greater in this group compared with the pianist group), was more effective than reliance on establishing motor memory via playing during initial learning. Nuki concluded that a combination of auditory imagery ability and structural knowledge aided memorisation.

Bernardi and colleagues (2013) used a within-subjects design to compare mental and physical rehearsal and to investigate whether certain imagery strategies were more effective than others; 16 pianists were asked to learn one piece using imagery for 30 minutes (followed by 10 minutes of physical rehearsal or continued mental rehearsal), and one piece using physical rehearsal only (40 minutes). Participants used self-selected mode(s) of imagery, which in some cases was accompanied by finger movement and/or by the use of an auditory model. Performances were measured for accuracy and musical quality, and were compared with scores on an auditory ability test and with self-ratings of imagery ability. Results showed that mental practice alone led to effective memorisation, although fewer notes were memorised than when physical practice was added. Mental practice plus physical practice resulted in performances equal to performances following physical practice alone; thus, over a total learning period of 40 minutes, participants were able to replace 30 minutes of physical rehearsal with 30 minutes of mental rehearsal with almost no distinguishable effect. A general reliance on analytical strategies (self-rated) and high scores on the auditory imagery test were associated with the best post-mental practice performance scores, but specific uses of analysis during the mental practice phase of the experiment did not correlate with improved performance scores. There was no association between the use of motor imagery and performance scores, and reliance on visual imagery of movement or use of an auditory model was associated with poorer post-imagery performance scores. Interestingly, some participants used overt behaviours (singing, and/or finger movement) during imagery rehearsal. Finger movement during imagery was found to enhance memorisation for some participants but not for others. This finding might relate to the manner in which attention was focused – either on the movement (which is potentially detrimental), or on the auditory imagery associated with the movement (which is potentially beneficial) - although this question was not examined by the authors. The study found that auditory imagery was essential for effective imagery rehearsal, but while the general ability to form a structural image effectively (possibly semi-consciously) appeared to aid memorisation, detailed formal analysis during the mental rehearsal phase of the experiment did not improve outcomes. Overall, there was no difference in outcomes between use of imagery with movement and use of imagery without movement.

1.2.6 Motor imagery

Musicians describe the use of motor imagery as a rehearsal technique (e.g. (Miklaszewski, 1989; Holmes, 2005), but although motor imagery may at times be the focus of musicians' imagery, it may be impossible for expert musicians to separate auditory and motor imagery entirely. Neuroscientific research has shown that imagery in one modality involves neural systems associated with other modalities. For example, silently watching musical movements (Haslinger et al., 2005) or imagining musical movement (Lotze et al., 2003) has been found to activate auditory areas in musicians, and listening to music can activate the motor system in musicians (Bangert et al., 2006). Behavioural studies that have specifically instructed participants to use motor imagery have generally combined it with auditory and sometimes also visual modes of imagery (Ross, 1985; Coffman, 1990; Lim & Lipmann, 1991; Theiler & Lipmann, 1995: Cahn, 2008), and the effects of motor imagery were not distinguished separately in the results. A study by Miksza (2005) that did attempt to separate motor from two types of auditory imagery did not produce findings that distinguished between the effects of the different modes of imagery. In two studies (Nuki, 1984; Bernardi et al., 2103) participants were instructed to use whichever mode(s) of imagery they chose. Nuki found that focusing on motor imagery during learning was less effective than focusing on other modes of imagery (auditory imagery with or without score study, or mixed modes), while Bernardi did not find any association between the use of motor imagery and performance scores.

Although auditory and motor components may inevitably be co-activated during expert musical imagery, a number of interesting experiments have separated some of the effects of motor and auditory imagery by removing feedback during learning (Highben & Palmer, 2004; Brown & Palmer, 2012). In these studies, higher auditory imagery scores correlated with better recognition following motor-only learning, suggesting that participants with higher auditory imagery ability were able to fill in for the auditory feedback that had been missing at learning. In a subsequent study by Brown & Palmer (2013), both auditory and motor imagery were found to contribute to effective learning. High auditory imagery ability corresponded to the ability to encode and retrieve melodies accurately; motor imagery aided pitch accuracy overall at encoding, but not at retrieval, suggesting that motor imagery ability may have a general, rather than a specific, effect on the memorisation of music.

1.2.7 Visuo-spatial imagery

Musicians have described the use of imagery of the instrument's geography and/or of hand positions on the instrument, and according to Rubin-Rabson *(*1941:102), visuo-spatial imagery and visual imagery of movement may be distinguishable: pianists can imagine both hands 'projected mentally onto a keyboard with or without any overt kinaesthetic behaviour'. In an interview study by Holmes (2005), an expert guitarist described using imagery of the 'shapes in the way you put the fingers down' (229). Mishra (2005) cites proposals by Shinn (1898) that movements covering wide distances on the instrument should be memorised using imagery of hand positions (Mishra, 2005:82). There are studies incorporating visual imagery (see 1.2.4 and 1.2.5), but no experimental investigation appears to have isolated visuo-spatial imagery in musicians.

1.2.8 Auditory models

Evidence for the effectiveness of an auditory model (listening to recordings) during learning is mixed. In comparisons between mental, physical and mixed modes of rehearsal Coffman (1990) found that the use of an auditory model did not affect performance scores. Bernardi (2013) found that listening to a model was associated with poorer performance than the use of other imagery strategies, and Lim & Lippman (1991) found that listening to a model during mental rehearsal produced poorer performances than mental rehearsal alone. Conversely, Theiler & Lipmann (1995) found that mental practice with a model resulted in superior performance on a number of dimensions, compared with mental practice alone, and Rosenthal (1988) found that listening to a model while studying the score produced higher scores than singing from the score, silent analysis or physical rehearsal. The relative success of listening to a model might be partly explained by the extent to which the learner attempts to generate internal imagery during listening as opposed to listening passively.

1.2.9 Optimal amounts of imagery rehearsal

Imagery rehearsal can be difficult and potentially involves more effort than other forms of rehearsal; it is cognitively 'expensive' in that it requires full consciousness (Halpern, 2012: 201). There may be optimal limits on its use as well as more or less efficient combinations of physical and imagery rehearsal. Rubin-Rabson (1941) asked pianists to begin learning short pieces (5-8 bars) of music via pre-study periods of different lengths (3, 6 and 9 minutes), after which they were required to write out the material from memory before continuing learning on the keyboard; two weeks later, participants were retested without pre-study. It was found that the 6 minute period showed substantial gains over the 3 minute period, but that the 9 minute period did not significantly improve on the 6 minute period. Rubin-Rabson concluded that attempting to memorise too much material at one time, without physical rehearsal, was inefficient. This argument was enforced by a meta-analysis of mental practice studies which found that mental practice effects declined with increased duration (Driskell, Copper, & Moran, 1994: 489). Driskell's analysis also found that approximately 20 minutes of mental rehearsal was optimal. A recent perfomers' manual, perhaps as a consequence of these findings, advises musicians to replace 20 minutes of physical practice per day with 20 minutes of mental practice (Rosset I Llobet & Odam, 2007: 13).

1.2.10 Sequences for rehearsal

Rehearsal can be carried out in different sequences of behaviour. In a separate experiment, Rubin-Rabson (1941) investigated different sequences for mental and physical practice by asking nine pianists to analyse short pieces and then to memorise them at the keyboard, adding either a) four minutes of mental rehearsal midway through learning, b) four minutes of mental rehearsal at the end of learning or c) four minutes of physical overlearning after memorisation was complete. On retest two weeks later, it was found that the inclusion of mental rehearsal midway through the learning sequence significantly reduced the amount of physical practice required, but that mental rehearsal at the end of the physical rehearsal period was not as effective as either midway mental rehearsal or extra physical rehearsal. These results suggest that some physical rehearsal might effectively be replaced with mental rehearsal during initial learning and memorisation, in order to reduce the amount of physical practice; but interestingly, on retest seven months later, differences between the three methods were no longer found to be significant, suggesting that over the long term, memorisation can be achieved equally effectively by a number of methods.

Mental imagery rehearsal may have a preparatory effect on the task which improves subsequent physical training (Bernardi et al., 2013: 284). For example, Etnier & Landers (1996) studied the effect of task order on a basketball shooting task and found that mental rehearsal was significantly more effective before, rather than after, physical rehearsal. Pascual-Leone and colleagues (1995) found that when novices practiced a five-finger piano exercise, performance after five days' practice was better following physical practice compared with mental practice, but after only one physical practice session the mental rehearsal group's performance improved to the level of the group using physical practice for five days. This suggests that imagery rehearsal might be employed to reduce physical overuse during the initial stages of learning.

1.2.11 Effectiveness modulated by task difficulty

In Rubin-Rabson's 1941 experiment there were indications that while mental rehearsal midway through the memorisation period (method a) was the most effective method for memorising pieces of an easy and medium difficulty level, increased physical practice (method c) was more effective for more difficult pieces (where difficulty was defined either by the length of the material or the complexity of the harmonic idiom) (1941: 598). More recently, Cahn (2008) investigated how accurately 60 undergraduate jazz musicians performed short memorised sequences, at two levels of difficulty, following study periods that combined different proportions of physical and mental practice. In this study, task differences appeared to consist of differences in harmonic complexity (the number of chord changes per bar) and possibly the number of notes: in the easy task, there was generally one chord per bar, and in the hard task, two chords per bar. In a between-group design, participants rehearsed the material for three minutes using either exclusively physical or exclusively mental practice, or using two combinations of mental and physical practice: a) 66% physical/33% mental and b) 33% physical/66% mental. Results showed that there were interactions between groups and task difficulty; a higher proportion of physical practice to mental practice (a) produced superior performance on the hard task, but a higher proportion of mental to physical practice (b) produced superior performance on the easy task.

Interestingly, and somewhat in contradiction of these findings, there are indications that performers sometimes use mental rehearsal specifically in order to overcome technical difficulties (Connolly & Williamon, 2004: 225). Participants in one fMRI study reported that the most difficult parts of a piece were learnt predominantly through the use of imagery, and that imagery was used more for these parts than for other parts of the piece (Lotze, 2003: 1827). Although findings by Rubin-Rabson and Cahn described above suggest that physical practice may be more effective for difficult tasks than mental practice, their participants had not received specific training in mental practice and it is possible that with training and higher levels of skill they would have been able to improve the more difficult task via mental practice; moreover, it is not clear in either study how task difficulty was controlled and thus it is not possible to draw any general conclusions.

1.2.12 Imagery skill, vividness and task experience

The effectiveness of mental rehearsal is modulated by imagery skill (vividness). In sports research, it has been shown that the more vivid the imagery, the better the training effect of mental practice (Lotze & Halsband, 2006); in musical research, several studies have found that mental rehearsal was most effective for participants with high levels of imagery skill (e.g. Rubin-Rabson, 1941: 597; Highben & Palmer, 2004; Brown & Palmer, 2012). For example, in a recent study by Belardinelli and colleagues (2013), participants with higher auditory imagery skill ratings performed more correct notes from memory after mental rehearsal of a novel piece of music than participants with lower skill ratings. Brown & Palmer (2013) found that auditory imagery ability modulated pianists' encoding and retrieval of short melodies, and that both auditory and motor imagery skills improved pitch accuracy overall.

Targeted training in imagery tasks may increase imagery skill and vividness, and thus increase the effectiveness of mental rehearsal. Professionals in various domains use deliberate imagery techniques to a greater extent than amateurs (Lotze et al., 2003: 1819; Lotze & Halsband, 2006: 389). Auditory and motor imagery abilities do not necessarily correlate with general musical experience (Highben & Palmer, 2004; Brown & Palmer, 2013), suggesting that auditory and motor imagery abilities do not simply reflect greater musical experience. There is, however, evidence that imagery skills can be improved with specific training in the imagery task. Ross (1964), for example, found that training in applying musical analysis to practice improved memorisation, and Clark & Williamon (2011) found that imagery vividness increased after a nine week training programme in mental skills for musicians. In this controlled intervention study, 14 advanced instrumental students received weekly group and individual training sessions that included training in mental rehearsal and imagery. In comparison with a control group, the treatment group's scores on a mental imagery rating scale increased significantly pre- to post-training.

Palmer & Meyer (2000) studied novice and skilled pianists learning short pieces and then playing new pieces with the same or different motor requirements (fingering) and conceptual (melodic) relationships. More experienced pianists showed transfer on both the motor and the conceptual dimensions; the least experienced pianists demonstrated transfer only to sequences with identical motor and conceptual dimensions; thus with increasing skill, mental images of the music to be performed became dissociated from the movements required to produce a musical sequence. At advanced levels, translating musical images from memory or from notation into specific motor sequences may not require conscious attention (Jerde et al., 2006: 88). For real experts, imagery rehearsal may therefore reduce the amount of physical rehearsal required very significantly.

1.2.13 Attention

> When you can hold the sound and pitch of the music clearly in your head. . . performing it accurately becomes easier. Your body has a sense of its goal. (Green & Gallwey, 1986: 75)

Expert musical performance includes multimodal mental imagery (Williamon, 2004: 225; Bernardi et al., 2013: 285) and during performance, imagery and perceptual processes occur simultaneously (Keller, 2012: 208). During such a complex task, the performer must decide which aspect(s) of the task require(s) greatest attention. For optimal performance, attention is ideally diverted away from the process of performing the task (Milton, Small, & Solodkin, 2008; Dietrich, 2008). A review of movement studies showed that for both expert performers and novice learners, paying too much attention to the process of movement, instead of attending to the effects of movement, may decrease the quality of certain well-practiced skills (Wulf & Prinz 2001). In a recent study of 16 music students, Duke and colleagues (2011) tested the extent to which learners performing a simple keyboard passage would be affected by directing their focus of attention to different aspects of their movements. Participants were asked to focus their attention on either their fingers, the piano keys, the piano hammers, or the sound produced, and their performances were measured for evenness of timing and volume; temporal evenness was most accurate when participants focused on the effects their movements produced (i.e. the sound) rather than on the movements themselves, and results showed that the more distal the focus of attention, the more accurate the motor control.

Miksza (2005) studied 20 student trombonists to examine whether it was more beneficial to imagine the physical performance, or the ideal sound, or the sound that the student could actually produce. Using a between-groups design, he asked participants to learn three short pieces of comparable difficulty by interspersing physical and mental practice (1.5 minutes of each). Results showed that there were no significant differences between groups, possibly due to the length of the practice treatment (total 40.5 minutes, over three sessions) which may have been long enough to eliminate differences. There was, however, a significant correlation between scores on a test of auditory imagery skill and performance achievement, measured for accuracy and musical effect.

Interesting recent findings suggest that during imagery rehearsal it may be more effective to attend to certain aspects of the musical image than to others. Bernardi (2013) found that the use of visual imagery of movement detracted from performance scores. In this study, pianists were asked to adopt their own preferred imagery strategies, and two types of imagery use emerged. Some participants showed almost no overt behaviour during imagery rehearsal and tended to focus on analysis rather than motor imagery; others supported internal imagery with finger movement and/or singing, and tended to use motor imagery as well as analysis. Overall there was no difference in performance outcomes; for some participants, however, overt finger movement appeared to detract from imagery effectiveness, while for others it appeared to enhance the encoding process. These differences between participants might relate to how attention was focused during imagery with accompanying movement – in other words, if movement was the focus of attention, imagery might be less effective, but if other aspects of the image were the focus of attention and movement was used as a means of reinforcing audio-motor connections the process might be beneficial.

1.3 Investigations of neural activation during musical imagery

> Musical imagery is assumed to be a multimodal process by which an individual generates the mental experience of auditory features of musical sounds, and/or visual, proprioceptive, kinesthetic, and tactile properties of music-related movements, that are not (or not yet) necessarily present in the physical world. (Keller, 2012: 206)

Recent neuroscientific studies have found evidence that auditory and motor networks are co-activated even in the absence of external feedback, and that musical training increases the extent of this co-activation. In expert musicians, imagery and simulated performance engage similar neural networks; interesting distinctions in cognitive processing during imagery (compared with motor performance or auditory perception) may reflect increased processing demands. Studies of non-specialist populations provide evidence that prefrontal and secondary auditory areas play important roles in auditory imagery, and studies of auditory imagery in non-specialists and expert musicians indicate that activation in these areas may reflect imagery vividness. Prefrontal areas appear to play an increased role in imagery as musical experience increases, presumably due to increased connectivity between auditory and motor processing and to increased imagery vividness.

1.3.1 Auditory-motor co-activation

Comparisons between musicians and non-specialists (e.g. Haslinger et al., 2005; Bangert et al., 2006; Baumann et al., 2007; Herholz et al., 2008) have found evidence that auditory and motor networks are co-activated even in the absence of external feedback, and that musical training increases the extent of co-activation. Haslinger and colleagues (2005) were interested in neural activation during the observation of musical movement. In an fMRI study, they asked 12 expert pianists and 12 non-musicians to watch videos of piano playing, and videos of non-playing finger movements, with or without the sound. When observation of silent piano playing was contrasted with observation of non-playing movements, pianists showed greater activation than non-musicians in prefrontal, premotor, primary and secondary auditory areas, suggesting that this network was involved in auditory imagery elicited when experts observed piano playing.

In an fMRI study of pianists and non-musicians, Bangert and colleagues (2006) compared activations between seven pianists and seven non-musicians who performed a passive listening task and a silent piano key-pressing task in which they were asked to arbitrarily press keys on a mute keyboard. A conjunction analysis showed that prefrontal, secondary auditory and premotor regions were co-activated by both auditory and motor tasks, and the authors proposed that these areas formed a musicianship-specific network involved in auditory-sensorimotor integration. In a similar study, Baumann and colleagues (2007) used fMRI to study the audio–motor coordination network in professional pianists and non-musicians, and to investigate the extent to which auditory and motor interactions occur involuntarily. Seven advanced piano students and seven non-musicians were asked to listen to extracts from a piece by Mozart and to piano scales. The pianists were also asked to perform the stimuli on a silent keyboard, and non-musicians were asked to carry out an internally paced finger movement task. Results showed that secondary auditory areas and motor areas were involved in transmodal activity during both voluntary and involuntary activation, but that voluntary involvement recruited additional prefrontal areas (ventral premotor areas and IFG), suggesting that these regions were mainly involved with top-down aspects of processing.

1.3.2 Auditory and motor networks in musical imagery and performance

A number of fMRI studies specifically comparing neural activation during expert musical imagery and simulated motor performance (Langheim et al.,, 2002; Meister et al, 2004; Lotze et al., 2003), and EEG and fMRI studies comparing overt performance with musical imagery (Kristeva et al., 2003; Kleber et al., 2007) have found evidence that imagery and simulated performance engage similar neural regions (Meister et al, 2004; Lotze et al., 2003). More recent work has identified differences between imagery and performance that are of particular interest here. Kleber and colleagues (2007) were interested in the differences, as well as in the similarities, between overt and imagined singing. Sixteen professional singers underwent fMRI scans while they sang or imagined phrases from an Italian opera aria. Results showed that in line with the findings by Lotze (2003), primary motor areas were activated during imagined performance, but primary auditory areas were not. Secondary auditory areas were activated in both conditions.

Several studies have examined simulated and/or imagined performance. In general, results concerning auditory and primary motor regions have varied. Langheim (2002) investigated whether imagined performance relied on primary motor and sensory areas used in overt performance, or on a distinct network. Six expert musicians (various instruments) were scanned while they imagined performing a recently practised familiar piece, or passively listened to the same piece, or carried out a finger-tapping task. Results showed that prefrontal activations during imagined performance were distinct from those found during finger-tapping or passive listening, and the authors concluded that imagery recruited an associative network independent of primary sensory and auditory activity.

Another study that used a different paradigm did find activation in primary motor cortex during imagery, while activation in primary auditory cortex was observed only when the fingers were moving and not when fingers were still. Lotze (2003) used fMRI to investigate differences between eight professional and eight amateur violinists during simulated and imagined performance of an extract from a piece by Mozart. The amateur group had practised the extract in the week prior to scanning, but the professional group had not (on the basis that they could already play it well). Left hand finger movements were simulated on the participant's body during the movement task, and during the imagined task participants were instructed to imagine finger movements as vividly as possible. Results showed that imagery activated primary and pre-motor areas. Primary auditory cortex was activated when violinists moved their fingers as if playing on an instrument, but not during imagery; and in professionals, the secondary auditory area was activated more by simulated performance than by imagery.

In another fMRI study, Meister (2004) similarly investigated differences between simulated and imagined motor performance. Prior to scanning, 12 advanced student pianists were asked to practise the right hand part of a short Bartok piano piece (selected for its unfamiliarity) until it was 'familiar'; during scanning, they were asked to imagine performing the right hand part, and to perform it on a silent keyboard, in both cases while reading from the musical score. Results showed that imagined and simulated performance activated a similar network of prefrontal and parietal regions, but that there was no activation of the auditory cortex. The primary motor cortex was activated by simulated performance but not by imagery.

In an EEG study comparing actual and imagined performance, Kristeva and colleagues (2003) asked six expert string players to play and imagine a short musical phrase, learnt immediately prior to scanning. EEG results showed that prefrontal and pre-motor regions were activated during imagery, but that auditory areas were not.

1.3.3 Distinct imagery activations

> … imagination of music is a distinct mechanism, and more than a sub-process of (active) perception. (Schaefer, 2011: 107)

There are extensive overlaps in neural activation between musical imagery and perception (see for example Herholz et al., 2012), and between imagery and execution (e.g. Kleber et al., 2007), but there may also be distinctions in cognitive processing during imagery. A recent EEG study found that when non-specialists deliberately imagined or listened to familiar music, imagery elicited higher alpha band activity than perception (Schaefer, 2011: 104). Evidence from fMRI studies comparing musical imagery and performance suggests that some prefrontal areas may be involved to a greater extent during imagery compared with performance. Kleber (2007) studied opera singers imagining and overtly singing phrases from an Italian aria and found that when imagined singing was contrasted with overt singing, activations in prefrontal areas increased. The authors suggested that imagined singing was less automatised than actual singing and that these increases reflected the increased working memory demands of imagery.

In a comparison between imagined and simulated violin performance (i.e. where movement was simulated with no auditory feedback), Lotze (2003) found increases in SMA and parietal areas in professionals, and when the same contrast was performed in amateurs, increases were also found in prefrontal and secondary auditory regions (Lotze et al., 2003: 1825). It is possible that differences in the vividness of particular aspects of each group's imagery might account for some of these differences. The professionals in the study might have been able to imagine finger movements (as instructed) more precisely than the amateurs; and the amateurs might have focused more on a global image of the sound, thus resulting in increased prefrontal and auditory activation in this group compared with the professionals.

1.3.4 Auditory imagery and perception

Investigations of auditory imagery in non-specialist populations (c.f. Zatorre et al., 1996; Leaver et al., 2009; Herholz et al., 2012) have found evidence that prefrontal and secondary auditory areas play important roles in auditory imagery. Zatorre and colleagues used PET imaging to study neural similarities between auditory imagery and perception. Twelve non-specialists were asked to read pairs of words taken from familiar songs, while listening to the songs, and to judge the pitch change between the two sung words. In the imagery task, the same judgment was performed in the absence of sound (i.e. participants had to imagine the melody in order to judge the pitch change). Results showed that both perception and imagery produced similar changes in cerebral blood flow (CBF) in prefrontal and secondary auditory regions.

An fMRI study by Leaver (2009) examined 'anticipatory' auditory imagery for highly familiar music. Twenty non-specialists were asked to listen to the final sections of music tracks from very familiar CD recordings, and to novel music, both interspersed with silence. During silences following familiar music, participants reported experiencing anticipatory auditory imagery (i.e. for the subsequent track on a familiar recording). During anticipatory imagery, significant activations were found in premotor and prefrontal regions, and a novel finding of this study was that the superior frontal gyrus (SFG) was involved in auditory imagery.

In an MEG study (Herholz et al., 2008), only musicians showed an early pre-attentive response, originating in secondary auditory areas, to the mismatched continuation of an imagined tune. In this study, Herholz used magnetoencephalography (MEG) to study differences between musicians and non-musicians during a musical imagery task. Fifteen musicians and 14 non-musicians listened to the first six notes of popular nursery rhymes and songs, and were asked to imagine the six subsequent notes during silence; at the end of the silence, a test tone was presented and participants were asked to judge whether or not it correctly fitted the melody. Results showed that only the musicians showed a pre-attentive brain response to unexpected (incorrect) continuations of the imagined melodies. The authors interpreted the results to mean that in musicians, perception and imagery rely on similar neuronal correlates, and that extensive musical training results in increased imagery ability. In a subsequent fMRI study, Herholz (2012) investigated the neuronal correlates of encoding and recognising perceived and imagined melodies. Ten non-specialists read the lyrics of familiar songs while either listening to, or imagining the song. They were then asked to identify the titles of tunes they had heard or imagined previously. Imagery activated several regions more than perception, including part of the left frontal pole.

Recent evidence suggests that there are common imagery neural networks as well as modality-specific networks. Daselaar and colleagues (2010) investigated imagery and perception in visual and auditory modalities using fMRI. Fifteen participants read words and then imagined or heard a sound or an image associated with the word. The authors identified a 'core' imagery network that included parietal and pre-frontal areas independent of imagery modality. Auditory imagery, but not visual imagery, activated prefrontal and secondary auditory areas that were also activated by auditory perception.

1.3.5 Imagery vividness and musical experience

There is evidence that auditory imagery relies in particular on prefrontal and secondary auditory regions. In an fMRI study of imagery in several modalities, Belardinelli (2009) asked nine female participants to listen to short sentences that each related to one of eight imagery modalities (e.g. visual, auditory, kinaesthetic) and to generate a corresponding mental image. Imagery vividness was assessed using a post-hoc questionnaire, and the functional activations of participants who reported high-vividness were compared with activations of those who reported low-vividness. Higher vividness ratings during auditory imagery correlated with activations in middle frontal gyrus (MFG), inferior frontal gyrus (IFG) and superior temporal gyrus (STG). In two music studies, Leaver (2009: 2481) found a correlation between high ratings of auditory imagery vividness and activation in IFG during anticipatory imagery for familiar music tracks, and Herholz (2012:1388) found correlations between vividness ratings and activation in the frontal pole and superior temporal gyrus (STG) when participants imagined familiar songs.

Differences between expert musicians and less experienced performers or non-musicians further underline the significance of prefrontal and secondary auditory areas during musical imagery and performance. Bangert (2006) found that pianists activated prefrontal and secondary auditory areas more than non-musicians during a silent piano-playing task. In an MEG study (Herholz, 2008), only musicians showed an early pre-attentive response, originating in secondary auditory areas, to the mismatched continuation of an imagined tune. Kleber (2010) carried out a comparative fMRI study of 10 opera singers, 21 vocal students and 18 non-specialists with limited singing experience. Participants were asked to sing phrases from a Mozart aria in the scanner, and results showed that there were positive correlations between the amount of singing practice and activation in prefrontal regions.

1.3.6 Role(s) of prefrontal cortex

During musical imagery tasks, a number of fMRI studies of experienced musicians have found activation in the inferior frontal gyrus (IFG) (Langheim et al., 2002; Lotze et al., 2003; Meister et al., 2004; Kleber et al., 2007) and in the middle frontal gyrus (MFG) (Lotze et al., 2003; Kleber et al., 2007). There is evidence that inferior and middle frontal regions show the greatest differences between adult musicians and non-musicians during musical tasks (Schlaug, 2006: 147). For example, during a silent piano-playing task, when associated sounds were presumably imagined by pianists and not by non-musicians, Bangert (2006) found increased IFG activation in pianists compared with the non-musicians. In addition, parts of the MFG were activated only by the pianists, and not at all by the non-musicians. Haslinger (2005) contrasted silent observation of piano playing with silent observation of a resting hand and found that activation in several parts of the IFG and MFG was greater in pianists than in non-musicians.

The increased processing demands of imagery, compared with performance or perception, appear to be reflected in increased prefrontal activation. Haslinger and colleagues (2005) compared pianists observing piano playing in silence with observation of piano playing with sound, and found that IFG activation during the silent observation task, when sound was (presumably) imagined, was greater than when subjects observed piano playing in conjunction with actual sound. Kleber (2007) compared imagined and overt singing by experts and found that imagining activated areas of the IFG and MFG to a greater extent than overt singing.

Prefrontal activations have thus been observed to increase when experienced musicians imagine the sound associated with observed or executed musical movement (compared with non-musicians), and when expert imagery is compared with performance or perception. Activation in the dorsolateral prefrontal cortex (SFG, MFG) during imagery may relate to memory retrieval, working memory and mental monitoring processes (Leaver et al., 2009: 2482; Herholz et al., 2012: 1394), and increased IFG activation may relate to increased auditory-motor integration demands due to the absence of external feedback. Prefrontal regions may therefore play an increasing role in imagery compared to performance due to increased integration and memory demands during imagery, and may be enhanced by increased musical training (presumably due to increased connectivity between auditory and motor processes and to increased imagery vividness).

1.4 Memorisation processes in musicians

While some research indicates that notation-based practice generally takes place before deliberate memorisation, an alternative model in which memorisation occurs prior to physical rehearsal is believed by some experts to confer benefits. This approach prioritises ‘deep’ content learning as opposed to ‘surface’ (rote) procedural learning. Musicians are known to use both ‘intuitive’ and deliberate strategies for memorising. A limited amount of research into effective practice suggests that multiple strategies should be adopted, that early memorisation is preferable, and that retrieval operations should match encoding conditions (i.e. performance and rehearsal cues should match). Converging evidence also shows that in expert musicians, memory is organised according to formal and/or idiosyncratic conceptions of structural organisation. A lack of strategic training may exacerbate anxiety and overuse issues, but there is not yet enough evidence to support more consistent pedagogy; a variety of approaches can be successful in that they result in memorised performance, but it is not yet clear how strategic memorisation training might enhance performance and reduce known problems.

1.4.1 Learning sequence

Case studies have shown that initial rehearsal is typically carried out while reading from the written score (e.g. Miklaszewski, 1989; Chaffin, 2007). Although some performers may deliberately attempt to play from memory early in the learning process (Ginsborg, 2002), memorisation, if it is deliberately carried out, tends to take place towards the end of the learning process (Hallam, 1997); at this point performers may use deliberate strategies to practise recall, such as gradually removing the score during rehearsal. Mishra explored existing literature to identify four processing strategies - segmented, holistic, serial, and additive - all of which are effective in the sense that they can all result in fluent performance (Mishra, 2005: 80). Her model conceptualises three stages of memorisation: preview (studying notation, listening, or playing through the music to obtain an overview); practice (which includes 'notational practice and conscious memorisation') and overlearning. Although various activities can theoretically occur in any order - or not at all - and in varying amounts, the implication is that notation-based practice generally takes place before 'conscious memorisation practice' (2005: 79).

An alternative approach described by Gieseking & Leimer (1932) and Hill (2002), in which imagery rehearsal occurs prior to physical rehearsal, simultaneously combines the learning and memorisation of musical material. This approach prioritises 'deep' learning at the outset before procedural knowledge is rehearsed. Cantwell & Millard (1994) investigated relationships between strategic behaviours and learning approaches adopted by beginner and intermediate music students. Thirty students were assessed as either 'deep' or 'surface' learners, and six were selected on the basis of extreme assessment scores. These students were asked to read through and then play through three novel short pieces, at three levels of difficulty, and then to describe how they would approach learning each piece. The authors found that, independently of difficulty level, deep learners were more concerned with content and proposed a wider variety of learning strategies, while surface learners were biased towards rote learning techniques. Although the study did not measure relationships between the two learning styles and performance outcomes, the authors argued that musical training should incorporate the development of deeper processing activities alongside technical skill development.

1.4.2 'Intuitive' versus deliberate memorisation

Evidence shows that some experts avoid relying solely on motor memory, which appears to be particularly fallible under performance conditions (Hallam, 1997; Aiello & Williamon, 2002: 175), and use analytic strategies to supplement and consolidate their knowledge (Hallam, 1997; Chaffin & Imreh, 2002; Holmes, 2005). Hallam interviewed 22 professional and 55 student musicians and found that half of the professionals, but none of the students, consciously used analytic strategies during memorisation (1997:96). Other musicians prefer to rely on 'automated' memory, despite being aware of the risks of doing so (Hallam, 1997: 95), or simply find that they can recall a piece once it has been played a number of times without the need for explicit reinforcement strategies (Barry & Hallam, 2002). The effectiveness of this approach appears to be modulated by skill level. A study by Rubin-Rabson (1941) demonstrated that repeated playing of material had an immediate effect – i.e. learning took place - but this did not always lead to secure memorisation over the longer term. Poorer learners in her study were almost back at starting point on retest after two weeks, even though they had learnt the material well enough to play it correctly during the initial test session. More capable learners were able to retain a mental image of the music and to use this for recall, having presumably processed the information more deeply than learners who relied on 'surface' strategies for initial learning.

1.4.3 Multiple strategies and early encoding

Multiple encoding strategies may help to secure memorisation (Hallam, 1995; Ginsborg, 2004) but there may be optimal upper limits on the amount of encoding that is effective (Williamon, 2002: 124). There is some evidence that for memory security, early memorisation is preferable. In summarising her extensive series of experiments investigating memorisation, Rubin-Rabson (1950) recommended that the intention to memorise should exist from the outset. Ginsborg (2002) observed 13 singers memorising a song, and found that faster and more accurate memorisers approached tasks strategically and began memorising early in the learning process (2002: 96). Nevertheless, a variety of approaches may be equally successful (Hallam, 1995), at least over time.

1.4.4 Matching encoding and retrieval

Ericsson & Kintsch (1995: 215) argued that for effective processing, retrieval operations should match encoding conditions. In her interview study of musicians, Hallam (1997: 96) found that mismatches (and therefore retrieval failure) seemed to occur when performers attempted to retrieve material that had been automatically encoded during rehearsal by using 'conscious cognitive codes' in performance, and the choice of memorisation strategy is thus potentially important.

1.4.5 Structuring memory

For effective memorisation of large amounts of material, experts in all domains use existing knowledge structures to encode and retrieve information in and from long-term memory (Jäncke, 2006). Music in the Western art tradition is organised hierarchically and its structural features may be used to organise memory for performance. Williamon & Egner (2004) used behavioural and EEG measures to demonstrate that when six pianists performed a visual recognition task for learned/novel musical material, previously learned structurally significant bars were processed faster, and tended to be processed more accurately, than non-structural bars. These results suggest that the musicians used structural markers to create a 'retrieval architecture' (Williamon & Egner, 2004: 43). Expert musicians appear to organise practice according to structural markers whether or not they are conscious of doing so (Miklaszewski, 1995; Chaffin & Imreh, 2002; Noice et al., 2008). Memory can be organised according to formal and/or idiosyncratic conceptions of structure (Hallam, 1995; Chaffin & Imreh, 1997; Williamon & Valentine, 2002). While formal theoretical analysis may inform memorisation, structural imagery may take a variety of forms. Rink, for example, argues that shape is the main goal of the 'performer's analysis', which he describes as a 'considered study of the score with particular attention to contextual features and means of projecting them' (2002: 36).

1.4.6 Idiosyncratic pedagogy

Evidence of substantial differences in the amounts of practice undertaken by experts (e.g. Ericsson, 1993; Jørgensen, 2002), suggesting that there may be differences in both quality and style of learning, is consistent with evidence for a lack of systematic memorisation pedagogy (Aiello & Williamon, 2002: 176; Ginsborg, 2004). Some teachers expect vast amounts of physical practice from their students, while others advocate a flexible approach to suit individuals, or recommend the use of mental rehearsal to limit the amount of physical rehearsal required (Jørgensen, 2002). There is evidence both that conservatoire students do not always practice effectively (Neilsen, 1999, 2001; Miksza, 2005) and that teachers do not necessarily provide systematic instruction aimed at developing effective practice strategies (Hallam et al., 2012: 672). Furthermore, students do not always integrate theoretical training with instrumental practice, even though this might support effective memorisation (Aiello & Williamon, 2002: 177) - which is perhaps due in part to lack of modeling during instrumental lessons (Hallam et al., 2012: 673). According to Rubin-Rabson (1939: 343), 'haphazard techniques do not seem to improve memorising capacity even when exercised over many years'.

1.4.7 Performance anxiety and physical overuse

Pianists are expected to perform a complex, extensively rehearsed repertoire in front of an audience, and anxiety about being adequately prepared to perform under pressure can lead to overuse through excessive practice. Wilson (2002, cited in Lamont, 2012: 576) identified lack of task mastery as a contributory factor in performance anxiety, and the fear of memory failure is a cause of performance anxiety for both professional and student musicians (Hallam, 1997; Ginsborg, 2004: 123; Kenny, 2011:101, 105). In a survey of 63 conservatoire students, Williamon & Thompson (2006) found that performance anxiety, as well as pain related to excessive practicing, were commonly reported, and the problems of anxiety and overuse are evidently connected (Parncutt, 2007: 12). It is not unusual for advanced students to practise at the instrument for up to 50 hours a week (Barry & Hallam, 2002). Extreme symptoms of overuse can be catastrophic. Altenmüller & Schneider

(2006: 340) have reported that chronic pain due to overuse is implicated in about 20% of focal dystonia cases, a loss of voluntary control over sensorimotor skills that is usually so disabling it ends the musician's professional career. Interventions such as Alexander Technique may help to improve physical use and enhance the quality of musical performance (Valentine, 2004: 191), and by reducing the effects of anxiety and improving self-awareness may facilitate a sense of 'flow' (peak experience) (Riggs, 2006: 184). There is, however, limited experimental evidence for the efficacy of this type of approach.

1.5 Summary and research questions

There is not yet enough detailed evidence to show a) how expert musicians use imagery rehearsal to support memorisation, b) how imagery techniques are taught, or c) how the neural mechanisms that support multimodal musical imagery function. This thesis is based on the hypothesis that strategic uses of imagery during learning can enhance performance. Its aim is to examine imagery rehearsal in more detail in order to develop a more nuanced understanding of memorisation processes in expert musicians - and thus to provide evidence that could support the development of systematic pedagogy aimed at improving learning and at reducing physical and psychological stress in performing musicians.

Although effective and reliable memorisation is a primary concern for performing artists, there is insufficient research comparing the relative effectiveness of different strategies, and musicians adopt differing approaches. The process for encoding images in memory may be more or less 'intuitive and unsystematic', or 'conscious' and deliberate (Rink, 2002: 35). Individual performers may prefer to focus on auditory imagery, motor imagery or visual imagery of the score (Mishra, 2005: 82); may vary in their attitudes towards analytical approaches (Vaughan 2002); and may prefer to memorise 'automatically' or strategically (Hallam, 1997). Previous authors have described the nature of imagery used by some expert musicians as preparation for performance (e.g. Holmes, 2005; Bailes, 2009) but further research is needed to elaborate more fully the nature of imagery as used by expert pianists, and how it can be trained. Memorisation procedures and pedagogy appear to be idiosyncratic, and it is often assumed that it is up to the individual musician to develop memorisation and mental skills strategies (Ginsborg, 2004; Connolly & Williamon, 2004: 242). Certainly there is evidence that neural activation during imagery is more variable than perceptual and/or motor activation (e.g. Schaefer, 2011; Kristeva et al., 2003), which is not surprising in view of the internal and relatively inaccessible nature of imagery processes. But, given that 'the cognitive and neurological systems involved in memory are common to all human beings' (Chaffin, 2009: 361) there is no reason why memorisation and imagery strategies cannot be systematically investigated, understood and taught (Cahn, 2008: 189).

As various authors have pointed out, one of the principle difficulties in measuring the effects of imagery rehearsal is that few participants have extensive experience with, or training in imagery techniques (e.g. Cahn, 2008: 189; Bernardi et al., 2013: 287). Some benefits of imagery rehearsal have been demonstrated through the empirical and qualitative study of elite musicians (Clark, Williamon, & Aksentijevic, 2012), but there is not yet a substantial body of evidence to support specific applications of imagery rehearsal. In particular, there is very little documentation of musical training that explicitly involves the teaching of imagery techniques. In non-musical domains, higher levels of imagery vividness (i.e. imagery skill) have been shown to increase the effectiveness of imagery rehearsal, and training in imagery techniques appears to improve imagery skill. The effectiveness of musical imagery rehearsal is also potentially modulated by skill, imagery vividness and task differences, but the extent to which training may enhance its effectiveness has not yet been widely investigated in musicians (although see Ross, 1964; Clark & Williamon, 2011). A key aim of this thesis is therefore to explore real-world teaching and learning of memorisation and imagery techniques.

Two lines of enquiry are evident in neuroscientific studies of music imagery. From one perspective, musical imagery is defined as the experience of replaying music by imagining it inside the head (Halpern, 2001; 2009) and this experience, which is partly what musicians access during imagery rehearsal (but which is not limited to trained musicians) has been investigated by comparing auditory perception with auditory imagery (e.g. Zatorre, 1996; Herholz, 2012). Another line of enquiry, based on the view that the 'main component of mental rehearsal is motor imagery' (Meister, 2004: 220; Bangert, 2006; 175), has informed a number of investigations into the neural correlates of imagined and executed movement by expert musicians (see for example Langheim, 2002; Lotze, 2003; Meister, 2004). In fact, it is increasingly documented that (at least) for performers, musical imagery is multi-modal and incorporates auditory, motor, visual, structural and emotional components (Holmes, 2005; Chaffin, 2009; Clark, Williamon, & Aksentijevic, 2012). Indeed, neuroscientific research has shown that auditory and motor neural mechanisms are closely coupled in trained musicians, to the extent that it has been suggested that 'the cortical structures providing a musician's audio-motor performing skills are always activated together' (Bangert, 2006: 184). Simulation and observation of musical movements have both been found to activate primary auditory areas (Lotze, 2003; Haslinger, 2005); listening to music can activate motor areas (Bangert, 2006; Baumann, 2007); and auditory imagery can include motor information (Brodsky, 2008; Hubbard, 2013).

While previous fMRI studies of musicians have either explicitly or implicitly assumed that there is an auditory aspect to musicians' imagery, instructions have focused on imagining the motor aspect of musical tasks (Lotze, 2003;

Meister, 2004; Kleber, 2007). For example, in Kleber's study of opera singers (2007), auditory imagery was assessed post-hoc but participants were instructed to 'imagine the physical performance of singing as vividly as possible' (2007: 892). There are two issues with this approach. Firstly, motor imagery is only one feature of musical imagery, and imagery in other modalities may in fact be of similar or greater importance for real-world musical rehearsal (Zatorre and Halpern, 2005; Clark, Williamon, & Aksentijevic, 2012). Secondly, for expert performance it is usually detrimental to focus on motor aspects of the task (Milton et al, 2008; Dietrich, 2008) and there is increasing evidence that attention to movement effects produces is more beneficial than attention to the movement itself (Wulf & Prinz, 2001; Duke et al., 2011).

Another issue is that although four known fMRI studies and one EEG study have directly examined expert musical imagery and motor performance (Langheim, 2002; Lotze, 2003; Kristeva, 2003; Meister, 2004; Kleber, 2007), task design and familiarity with musical stimuli varied across studies and, in some cases, between participants in the same study (c.f. 1.3.2). Imagery instructions have varied and, as already discussed, participants have been asked to focus on imagining aspects of movement. Finally, previous fMRI studies have investigated execution and imagery of only one melodic line, using one-handed tasks (with the exception of one participant in the study by Langheim, 2002). A key aim of this thesis is therefore to examine the neural basis of realistic, expert musical imagery using novel, ecologically valid, bi-manual musical tasks.

The central argument of this thesis is that strategic uses of imagery during learning can enhance performance. Knowing more about how imagery processes work could potentially inform memorisation pedagogy and lead to more specific training techniques (Halpern, 2012: 201). The key objectives of this thesis are therefore to explore how specific imagery techniques are used during learning by expert pianists, how imagery and memorisation techniques are taught, and - by investigating neural mechanisms involved in musical imagery processes - to explain some of the reported benefits of imagery rehearsal.

1.6 Methodology

An iterative mixed methods approach was adopted in order to collect and explain different and detailed accounts of the process, and effects, of imagery rehearsal (Bryman, 2012: 633). Firstly, an exploratory participant observation study of a course for 11 pianists provided descriptions of the teaching and learning of specific imagery techniques. Findings from this study informed two subsequent studies, the first of which was an online questionnaire survey of advanced (conservatoire) piano students. The questionnaire investigated the extent to which memorisation and imagery techniques were taught and implemented at conservatoire level in the UK. Finally, an fMRI study of 14 expert pianists investigated preliminary explanations of imagery rehearsal effects based on inductive analysis of findings from the participant observation study (Bryman, 2012:12). The design of the fMRI study was informed by findings from both the participant observation and questionnaire studies, and fMRI results were in turn used for further interpretation of participant observation findings.

In order to explore real-world teaching and learning of memorisation and imagery techniques, a participant observation study of a course for advanced pianists, during which imagery techniques were explicitly taught by Nelly Ben-Or (NBO), was used to generate descriptions of the teaching and learning of specific imagery techniques. There is no known documentation of NBO's teaching and little published about her work (although see Ben-Or, 1991, 1995; Brandes and Davis, 2007). A study was therefore designed to generate a thorough description of her approach, to define and describe the potential advantages and drawbacks of the method, and to find out how other pianists implemented the techniques.

Building on findings from the participant observation study, an online questionnaire survey of advanced piano students at UK conservatoires examined which memorisation and mental imagery techniques were being advocated, taught, and implemented at advanced training levels. The survey aimed to provide information about current teaching and learning, potentially illustrating variations, developments or gaps in training. The study was also intended to provide a means of revealing whether the findings from the participant observation study were skewed by a number of possible factors, such as participant observer immersion in NBO'S approach, desirability bias, or the extent to which participants in the observation study were self-selecting (for example, members of this group might find learning and memorising disproportionately difficult and seek extra help via NBO's course).

To date, no neuroimaging studies of expert musicians have investigated novel, two-handed musical tasks, or compared tasks at different levels of complexity. Indications of differences in neural activation according to the particular mode of imagery (c.f. Belardinelli, 2009; Daselaar, 2010) suggest that attention to different aspects of imagery engages partially distinct neural mechanisms, and it was therefore hypothesised that by adopting a more ecologically valid tasks and procedures, a fuller account of the neural basis of expert imagery could be developed. An fMRI study was accordingly designed using carefully designed stimuli and training procedures that were informed by findings from the first two studies. Firstly, a guided explanation of the text was used to aid initial learning of the stimuli, prior to physical rehearsal. Secondly, learning was carried out using a combination of mental imagery and physical rehearsal. The key aim of the study was to explore the neural basis of realistic expert musical imagery.

Chapter 2 A Participant Observation Study of a Course for Advanced Pianists Taught by Nelly Ben-Or

This chapter describes a participant observation study of a five-day course for advanced pianists given by Nelly Ben-Or in July 2007. During the course, which took the form of an extended masterclass, eleven advanced pianists were taught to use mental imagery techniques for memorising music and for improving problematic aspects of performance, and to apply principles of Alexander Technique to piano playing. The study aimed to generate an interpretative description of NBO's pedagogy and to explore how course participants implemented her ideas. Findings showed that mental imagery and body awareness strategies are acquired skills that can be taught and improved over time, their effectiveness modulated by skill level and motivation. These techniques helped pianists to focus attention on intended outcomes/distal effects during performance, resulted in an enhanced sense of 'wholeness' or 'flow' and led to reported improvements in technical facility, musical quality and memory security.

2.1 Background and aims

> If … by means of a well-trained ear, it is clear to the brain how to execute correctly, the fingers will do their work correctly. If this is the case and the necessary relaxation is maintained, the fingers in a short time (sometimes immediately, sometimes after a few minutes) will be able to solve the most intricate technical problems ... I have seen the most surprising instances and have obtained in a few months results which otherwise could have been gained only by years of study, if ever. (Gieseking & Leimer, 1932: 21)

Nelly Ben-Or (NBO) is a distinguished pianist and a senior teacher of Alexander Technique (AT) whose own practice and pedagogy can be traced in part to that of earlier pedagogues (see especially Gieseking & Leimer, 1932). Like many pianists, Nelly Ben-Or's approach to learning is idiosyncratic and has been developed and refined through practice; her pedagogy (which she prefers not to think of as a 'method') has not been systematically written down and there is little published about her work (although see (Ben-Or, 1991, 1995; Brandes & Davis, 2007). Her principal aim, as a performer and as a teacher, is to find the simplest and clearest means to express musical intention at the instrument. In order to do this she applies AT principles to piano playing, proposing that 'conscious awareness' of how the body is used facilitates clarity of thought - and equally, that clarity of thought facilitates effective use of the body during piano playing.

NBO teaches a sequence of cognitive strategies for learning new material, a number of cognitive problem-solving strategies for dealing with technical difficulties, physical strategies for avoiding pain and improving technique, and psycho-physical strategies for enhancing performance. Personal experience suggested that her explicit teaching of mental techniques was unusual and had beneficial effects on expert playing, providing rapid means of achieving fluent performance and maintaining physical ease when dealing with complex and challenging material (c.f. Gieseking & Leimer, above). A participant observation study was planned in order to validate and deepen understanding of NBO's work and to investigate how other pianists experienced her approach.

For 25 years NBO has been running courses on 'Piano Playing with Alexander Technique' in various locations; a regular series of 3 - 5 day courses now takes place twice a year in her own home in Northwood (a quiet suburb of North London), typically attracting an international group of between 10 and 15 pianists. Advertisements in international music and music teaching journals (e.g. Piano Professional, Music Teacher), and in leaflets sent out to musical institutions (Figure A.1 in Appendix A), state that NBO

> … works on various aspects of piano playing, such as ways of learning and memorising new scores, deepening the player's understanding and interpretation of the music. She also aims at improving freedom, velocity and fluency in playing … Nelly Ben-Or teaches pianists a way of working which prevents disturbing tensions or possible injuries which can often result from faulty ways of practising. (Course leaflet, 2007)

NBO argues that getting to know the music should be 'the most important aspect, and then the mechanics of playing…(are) the last bit that has to be dealt with.' (NBO, interview). She teaches advanced pianists to learn unfamiliar music away from the instrument, citing the work of Gieseking & Leimer (1932) who described a similar process: the pianist memorises and rehearses the material via score study and mental imagery, only playing the music on the instrument once it can be successfully recalled mentally. Students are initially trained by NBO to memorise short and (relative to their performance ability) simple sections of music. The technique can then be applied to larger and more complex forms. In addition to this memorisation technique, NBO teaches pianists to improve problematic aspects of performance by means of mental imagery rehearsal, and to apply principles of Alexander Technique to their playing. In order to generate an interpretative description of NBO's pedagogy and to explore how other pianists implemented her ideas, the participant observation method was selected on the basis of prior knowledge of her teaching style. During two previously attended courses (2002, 2003) there had been a considerable amount of discussion, observation and commentary around the teaching and learning. It was therefore expected that an active participant would be able take part in this process unobtrusively, in a context where other course participants could act naturally (Bernard, 1994). The aims of the study were to identify the key features of NBO's approach, to explore how other pianists implement her techniques, and to examine the potential advantages and drawbacks of the approach.

2.2 Methods

2.2.1 Rationale

A participant observation method was chosen in order to develop a holistic understanding of the teaching and learning on NBO's course in a manner that was 'as objective and accurate as possible given the limitations of the method' (DeWalt & DeWalt, 2002: 92). I adopted the stance of participant as observer (Gold, 1958, cited in Kawulich, 2005) in which I acted as a member of the group and in which the group was aware of my research activities. I decided to participate for two reasons. Firstly, I wanted to re-immerse myself in the experience of being taught by NBO, in order to understand and experience the teaching as completely as possible (Kawulich, 2005). Secondly, in the context of NBO's courses, which explicitly aim to generate 'a supportive and informal working atmosphere' (course leaflet, July 2007, Figure A.1 in Appendix A), I felt that it was essential to participate as equally as possible, in order to maintain and contribute to the functioning of the group.

Bernard (1994) conceives of observation, natural conversations, interviews of various sorts, checklists, questionnaires and unobtrusive methods as part of the participant observation process. I adopted this approach to the study, choosing methods designed to minimise observer effects, to increase validity, and to elicit explanations of 'behaviors, intentions, situations, and events as understood by one's informants' (deMunck & Sobo, 1998: 43). I knew, however, that the participant observer role would be a demanding one and therefore decided to use a video camera unobtrusively as an extra 'eye', with the video data functioning as an essential aide-mémoire (Bryman, 2012: 457) alongside written notes. Questionnaires (Appendix A, A.1.3 - A.1.5) were designed to be as open and non-intrusive as possible and to function as an extension of the ongoing discussion, as were informal interviews with other participants.

2.2.2 Participants

Table 2.1: Showing participant number (P), sex, age, piano start age, years of piano playing; self-description (professional performer, student, teacher, amateur), main activities [Ensemble Performance (EP), Solo Performance (SP), Piano Tuition (PT), Musicianship Tuition (MT) Piano Study (PS) International Competition (IC), Other classes (O)]; and previous contact with NBO.

P	Sex	Age	Start Age	Years Playing	Self-Description	Main Activities	Previous NBO Contact
1	F	40	6	34	Professional	EP; PT	Yes (courses, lessons)
2	F	36	5	31	Professional	SP; PT	Yes (courses, lessons)
3	F	29	7	22	Professional	EP; MT	Yes (course)
4	M	25	7	18	Professional	SP; PT; IC	No
5	M	30	7	23	Professional	SP; PT	Yes (courses, lessons)
6	F	21	5	16	Student	PS	Yes (course)
7	F	25	5	20	Student	PS; IC	No
8	M	19	7	12	Student	PS; IC	No
9	F	58	10	48	Teacher	O	Yes (course)
10	F	68	9	59	Teacher	PT	Yes (course observer)
11	F	44	8	36	Amateur	PS	No

Eleven pianists (8F, 3M) attended the course in July 2007, including myself as a participant observer (Table 2.1). Of these, five were professional performers and teachers, three were advanced students at music conservatoires, two were teachers and one an amateur player. Several participants already knew NBO while others had never met her before. A few participants had met each other at previous courses. Six of the eleven participants, myself included, had previously taken part in one or more NBO courses, and another had observed a previous course. Three participants had also taken individual lessons with NBO, either privately or at the Guildhall School of Music and Drama in London. Of the five professional musicians, one was a virtuoso pianist who was beginning to perform internationally and to compete at international competition level; I perform contemporary ensemble music internationally; two performed as soloists in their own countries; the fifth performed chamber music locally. Four of the five professional players taught piano (three privately, one in a conservatoire) and the fifth taught theory and musicianship in a junior conservatoire. The conservatoire students, two of whom were beginning to compete at international competition level, were studying in three separate conservatoires across Europe. One of the teachers worked as a private piano teacher and the other ran music sessions for infants. The amateur player worked full time in another profession while continuing piano studies at a conservatoire in North America.

2.2.3 Setting

The course took place in Nelly Ben-Or's home in London, July 2007. Piano sessions took place in a comfortable studio on the ground floor - a back room, extended to create a light and airy studio accommodating 15-20 people, two grand pianos, shelves full of musical scores and books, and pictures, plants and ceramics (Figure 2.6 and Figure 2.7). The course was taught mainly in English, but NBO also spoke to some participants in Polish (her first language) and German (which she speaks easily but not fluently) and then speaks easily but not fluently) and then translated much of what was said into English, or asked participants to translate for each other. Alexander Technique sessions, given by NBO's colleague Peter Ribeaux, were held in a small front room. The atmosphere was informal, relaxed and friendly, but quiet and focused.

2.2.4 Course structure

2.2.4.1 Piano sessions

Throughout the course, participants spent most of their time together with NBO in the studio; each player took part in three or four half-hour sessions at the piano with NBO, working on their own choice of music in front of the whole group. Work typically began at 10.30am and continued until 6.30pm or later, with up to an hour off for lunch and short breaks mid-morning and afternoon. A schedule was read out at the beginning of each day and was loosely adhered to; sessions sometimes over-ran when a point of particular interest was being explored, or when a discussion arose. Participants sat on folding chairs but sometimes preferred to stand in the adjacent hall or to lie on the floor after hours of concentrated listening.

2.2.4.2 Memorisation training sessions

NBO taught three sessions in which she trained the whole group to use her learning and memorisation technique (see 2.3.1.1).

2.2.4.3 Alexander Technique (AT) sessions

Whilst the main piano playing activity took place in the studio, Peter Ribeaux gave every participant a short, separate AT session (c.15 minutes) on each of the first four days of the course. He worked with participants standing, sitting, or lying on a purpose-made couch and sometimes at a small upright piano. On the last day, NBO held an AT session for the whole group in which she 'guided' each participant for up to 10 minutes as they sat, stood and walked.

2.2.5 Materials

Prepared note sheets were used throughout the course to record time points and observations (A.1.7 in Appendix A). An introductory letter, consent form and two questionnaires were administered during the course, and a third questionnaire was sent out nine months later (A.1.1 – A.1.5 in Appendix A). A semi-structured interview script was used for interviewing NBO at the end of the course (A.1.6 in Appendix A). A video camera (Sony DCR-TRV950E) was used to record activity at the piano onto mini DV tapes.

2.2.5.1 Questionnaire design

Three questionnaires were used to collect participants' views, two during the course and one nine months later; these were designed to be optional, simple to understand and exploratory in nature. NBO agreed the content of the first two questionnaires before the start of the course. Each questionnaire began with open questions (concerning musical background, learning methods, and attitudes towards the course) followed by Likert-type pre-coded questions evaluating self-perceptions of skill levels and training, and attitudes to learning (Sommer & Sommer, 2002: 162).

Questionnaire 1 (Q1) aimed to investigate participants' musical backgrounds, their reasons for attending the course, their perceived level of skill with several aspects of musical learning, and the perceived importance of 12 different learning strategies. Questionnaire 2 (Q2) examined participants' experiences of the course and how they felt that their subsequent practice would be influenced by what they had learned. A question from Q1 was replicated in order to examine whether NBO's teaching affected attitudes towards 12 learning strategies. Questionnaire 3 (Q3) was designed after preliminary analysis of Qs 1 and 2 and initial coding had taken place. Q3 aimed to check whether other participants agreed with my analysis of what had been taught, and to investigate how participants had implemented NBO's teaching over time. The 12 strategies listed in Qs 1 and 2 were reduced to seven strategies for Q3.

2.2.5.2 Semi-structured interview (NBO)

A semi-structured interview script for NBO, prepared prior to the course, was designed to explore NBO's formative musical experience and training, the development and implementation of her method, and her learning, memorisation and imagery techniques (A.1.6 in Appendix A).

2.2.6 Data collection

Data collection incorporated observation, participation, handwritten notes, questionnaires, video documentation of piano sessions, photographs, and video documentation of informal and semi-structured interviews (Bernard, 1994). Towards the end of the first day of the course I gave a brief spoken introduction to my research and handed out a letter introducing the project, asking for written consent to video proceedings, and inviting participants to complete the first questionnaire.

2.2.6.1 Notes

On the first day I made detailed and extensive notes, as consent had not yet been obtained for video documentation. Subsequently I was able to video all the activity at the piano and my written notes were sparser, consisting mainly of time points and short jottings. These notes consisted primarily of an event log in which I noted salient teaching points, observations on musical difficulties and how they were treated, and fragments of direct speech (A.1.7 in Appendix A). They contained almost no commentary, with the exception of two short reflections on my own sessions at the piano and a list of themes that emerged during the course.

2.2.6.2 Questionnaires

In order to maximise completion rates, two questionnaires were administered during the course while participants were in NBO's studio. Questionnaire 1 (Q1) was administered at the end of the first day and was completed by all ten participants. Although the responses were not systematically reviewed until after the course, a brief reading provided some insight into the pianists' backgrounds and informed subsequent conversation. Questionnaire 2 (Q2) was administered at the end of the final day and was completed in full by nine participants, and partially by the tenth. Questionnaire 3 (Q3) was sent out by email and post nine months after the course. This was planned before the course but was designed once the initial coding of the observation data had been carried out. It was completed by seven participants. Two participants were asked by email to expand on their answers to Q3 and entered into a brief correspondence.

2.2.6.3 Video

> Where to begin looking depends on the research question, but where to focus or stop action cannot be determined ahead of time (Merriam, 1998: 97).

It was not possible to predict which sections of the course would produce useful material, so prior to the course I arranged with NBO that I would video participants working at the piano with her throughout the week, subject to their agreement. We decided to set up the camera in one area of the studio and to leave it running, in order for it to be as unobtrusive as possible. Assuming that everyone agreed to be videoed this would produce 20+ hours of material for review. At the end of Day 1 every participant gave written consent to the video documentation, and I videoed all subsequent activity at the piano. One participant was initially unsure about working in front of a camera and we agreed that I would switch it off during the first session if requested. In the event it was found to be completely unobtrusive and caused no further concern.

In order to frame most of the pianist's body, the camera was placed in a static position approximately two metres to the left of the keyboard (Figure 2.7). The camera position was adjusted slightly as the week progressed in order to compromise between framing NBO's and the pianist's whole body, and framing the keyboard and hands (Figure 2.2). On the final day the camera was moved to the right of the keyboard, approximately 1 metre behind the pianist, and additional hand-held shots were taken in order to gain a better view of pianists' hands (Figure 2.6).

2.2.6.4 Interviews

NBO agreed in advance to an hour's interview after the course, recorded on video. The interview took place in her studio the day after the course and used a semi-structured script to explore her learning history and views on learning and memorisation (A.1.6 in Appendix A). Three of the pianists on the course also agreed to be informally interviewed on video during breaks throughout the week, allowing me to probe issues arising from the observation and to check my understanding from the perspective of other participants (Colwell, 2006: 295). These discussions took place with other participants present, either over lunch in a café or in NBO's studio.

2.2.7 Data analysis

2.2.7.1 Preliminary treatment of questionnaire data

Firstly, questionnaire data was prepared prior to treatment of the whole dataset. Numerical data generated by Likert-type answers were explored in descriptive terms through tabular analysis. Individual responses and group means were compared between questionnaires. Thematic analysis was used to analyse responses to open questions. These responses were read for themes, categories were developed according to the emergent themes and the responses were tabled by allocation to a category.

2.2.7.2 Thematic analysis of entire dataset

Secondly, thematic analysis was used across the entire dataset, adopting the process advocated by Braun and Clark (2006, outlined by Liamputtong, 2009: 135):

1. Familiarisation: during the initial familiarisation phase I reviewed all the video footage (c. 25 hours). This process served as a means of immersing myself in the data from a different perspective (Bernard, 1994) in order to refine and verify my understanding of the course. I made a new set of handwritten notes, detailing video time points and observations. These video notes were made in a similar style to the course notes but were more detailed and extensive (Figure A.3 in Appendix A shows an example). I also read through the course notes and transcribed handwritten questionnaire responses, recorded interviews, and sections of video dialogue.
2. Writing down initial ideas: I began to develop descriptions, observations and commentary in the form of jottings, charts and more extensive free writing.
3. Initial coding: I made handwritten annotations to video notes, course notes and transcriptions (see point 1 above). I used 'in vivo' terms, based on NBO's and course participants' terminology, in order to maintain 'the meanings of the participants' views and actions' (Liamputtong, 2009). For example, the term 'wholeness', which was used repeatedly by NBO, was used to code several interactions observed on video (A.3 in Appendix A).

4. Preliminary development of themes: preliminary themes based on initial codings were developed from treated questionnaire data (2.2.7.1) and annotated notes (point 3 above). For example, 'wholeness' was now defined as a theme.
5. Revision of themes: I began to generate categories and sub-categories, aiming to identify recurrent themes in the material and using extensive exploratory writing to develop my ideas. All data from questionnaires, interviews, course and video notes were then re-examined, and thematic categories and sub-categories revised and refined. I used exploratory writing, jottings, charts and video clips to group the findings around themes identified.
6. Thematic mapping, definition and naming of themes: as the thematic mapping of the analysis became clear, the analysis was re-worked in the context of the revised categories, and sections of the video data were reviewed. While retaining 'in vivo' terms for sub-categories, I began to define categories in accordance with the literature on music psychology and expert learning.
7. Ongoing refinement and analysis: continuing the writing process in combination with a literature review, I used the analysis of this observation to develop research questions for two subsequent studies (see Chapters 3 and 4).

2.3 Findings part I: Key features of NBO's teaching

Analysis of the entire dataset identified three key, inter-related features of NBO's approach, each of which is discussed in turn in this section:

1. Prior memorisation: meaningful learning and 'total inner' memorisation away from the keyboard, prior to rehearsal on the instrument.
2. Mental imagery techniques: used for learning, memorising, and as a means of enhancing technical facility.
3. Psycho-physical performance enhancement: applying principles of AT to piano playing.

2.3.1 Prior memorisation: 'total inner' memorisation prior to physical rehearsal

> …one has to memorise, not the text as a text on the page, but as a text translated into the happening of the music on the piano. (NBO, interview)

NBO advocates the mental learning and memorisation of musical material prior to physical rehearsal. She teaches pianists to study material away from the piano and to develop a 'total inner memory' via the deliberate rehearsal of multi-modal mental images. She emphasises the need to organise the material into meaningful units, or in other words to identify patterns on various levels. At the formal level this entails identifying structural features (e.g. movements, sections, large-scale repetitions); at the mid–level, phrase groupings are described, and at the most detailed level it involves 'explaining to oneself' the content of the text, bar by bar. The purpose of this 'explanation' is for the pianist to understand the text clearly and thoroughly, before physical memory is encoded and rehearsed. This strategy incorporates the type of analytical pre-study described and tested by Rubin-Rabson (1937): it is relatively simple and does not involve 'the kind of finished theoretical analysis required in advanced analysis classes' (Rubin-Rabson, 1937:16). Instead the description tends to move through the musical text in a successive manner reminiscent of Donald Tovey's method, which attempts to trace the same process in time that the listener experiences (Bent and Drabkin, 1987: 89).

The explanation of the musical text is only the first stage of the work that NBO proposes should take place away from the piano. NBO reports encountering a student who was able to understand and even write out verbatim a piece from memory (presumably using visual, structural and auditory memory of the score), but was subsequently been unable to play the music on the instrument. Thus, alongside the explanation of the material, NBO advocates the use of mental imagery techniques (to which she refers as 'techniques of mental representation'). Using these techniques, but without actually playing on the keyboard, the pianist can create, integrate and manipulate multidimensional mental images of the text and of its performance. Most prominent among these are visual images of the keyboard, visual images of the placement of hands on the keyboard, and auditory image of the music. Interestingly, NBO did not advocate motor imagery of the fingers (i.e. imagining the fingers playing), and stated that she does not think it helpful to memorise the text visually (although she acknowledges that some other musicians do find this useful).

> [Mental imagery rehearsal] has to include a vision of the keyboard. Otherwise I'll come to the keyboard and the vision of the keyboard will confuse me. Because I've got the whole piece inside me … with the experience of playing it … it is the experience of playing it in this octave, and in that octave, and with these keys, and with this arrangement, which demands the fingering that will make it possible. It all comes together somehow. (NBO, interview)

NBO proposes that physical rehearsal should occur only once the material has been explored and understood, and at a point where memorised mental recall is fluent. The mental imagery techniques used during the initial learning phase may also be applied to the rehearsal phase. Table 2.2 shows a summary of NBO's music learning and memorisation sequence.

Table 2.2: Summary of NBO's sequence for learning and memorising novel musical material.

1	Play on the piano, reading from the score, once or twice only
2	'Explain' the piece, in outline and in detail
3	Memorise the piece away from the piano, combining structural knowledge with mental imagery of the sound and of note patterns on the keyboard
4	Once the piece can be recalled fluently from memory, rehearse on piano
5	Refine at the piano and away from it

2.3.1.1 Teaching the technique of 'prior memorisation'

On the first evening, after five hours of individual sessions and some discussion, NBO handed out copies of the opening page of a Haydn sonata (see Figure 2.1). This style of music was extremely familiar to all participants and technically very easy for all of them. NBO asked the pianists to learn the piece without playing on the instrument; they were instructed to 'explain it to yourself. Listen to it inside you'. For a few minutes the participants silently read through the printed music, until NBO began to ask a series of questions relating to its structure. The key, time signature and overall structure were discussed, with the demarcation of sections and sub-sections defined, as appropriate, in terms of the harmonic structure, and rhythmic, melodic and phrase patterns. While NBO talked, the participants followed the score and contribute answers to her questions. They were then asked to learn the piece for the next day, away from the piano, and were instructed not to play it on the instrument at all.

The following day, the pianists were asked to perform the extract on the piano, without the score, in front of the other participants. Four pianists volunteered to play the extract. The first to perform had not heard the piece on the instrument, but subsequent performers listened to one or more performances before they attempted to play it. The first pianist (P6) was an advanced conservatoire student who had attended a course in 2006; she had initially found NBO's learning method extremely challenging, as she had had no previous training in mental practice. Since 2006 she had applied NBO's method to some of her learning. This player reported that she remembered the pieces learnt in this way more effectively than those she had learnt at the piano. During the training session she stated that she achieved a 'clearer picture' in her mind when she learned away from the piano, but that the method was still hard work for her. She played through the extract with a few minor mistakes and one complete memory block, which was not solved when other participants sang the missing note for her. NBO briefly showed her the score and she was able to continue, but when she played the piece a second and third time the same block occurred. NBO pointed out her mistakes and they spent time correcting them; NBO commented on how much progress this pianist had made since the previous year.

Figure 2.1: showing the musical score of the section of a piano piece used for memorisation training (Divertimento in C major by Joseph Haydn, Hob. XVI:1). This work is licensed under the Creative Commons Attribution 3.0 Unported License. To view a copy of this license, visit http://creativecommons.org/licenses/by/3.0/ or send a letter to Creative Commons, 444 Castro Street, Suite 900, Mountain View, California, 94041, USA.

The second pianist (P10) commented that she did not feel confident playing from memory in any situation, but, playing slowly, she remembered some of the piece. She stated that she was effectively ‘reading’ from a score ‘in her head’. When NBO gave her the actual score she was able to play it. The third player, a professional pianist (P2), had already used NBO’s method extensively and played the extract almost fluently and in the appropriate style, despite not having ever played it on a piano before. She commented afterwards that although she had envisaged playing the piece whilst learning 'inside my head, or inside my stomach rather', it was different once she put it onto the piano. The fourth player was a virtuosic professional (P4) who was keen to test himself, although he commented before playing that he was 'afraid'. He played through under speed – almost fluently, but omitting bar 5 (a repetition of bar 4, see Figure 2.1), and reorganising the chord layout of the final bar (while maintaining the harmonic sense). NBO briefly showed him the score and he repeated the final bar correctly. He commented that it felt very strange – while learning the score in his mind he felt that he had been 'playing it', but once at the piano the experience was completely different. He then played the extract extremely fast and almost fluently, still omitting the same bar; NBO stopped him and pointed this out and he was able to continue from that point. He commented during the session that the experience was 'extraordinary'.

2.3.2 Mental imagery techniques: Learning, memorising and enhancing technical facility

In conjunction with the encoding of structural markers, and the bar-by-bar pattern knowledge developed through 'explanation' of the score, NBO uses imagery (mainly auditory and visuo-spatial) to bring the text alive in the pianist's 'inner experience' before the 'external' (physical) aspects of playing are rehearsed. Via the explicit creation and rehearsal of mental images, the pianist is able to encode a multi-dimensional knowledge of the material in memory, to make interpretative decisions and to rehearse recall. NBO states that she does not deliberately imagine the activity of the fingers on the keyboard. Where technical difficulties exist, she only occasionally advocates planning finger sequences and usually prefers visual imagery for technical problem solving (see 2.3.2.2). NBO does not advocate the explicit memorisation of musical notation, although she recognises that some pianists consider this a useful tool.

2.3.2.1 Auditory imagery

> … the most important aspect…in creating the music that you wish to hear, is listening. (NBO, interview)

For fluent performance, extended musical phrases ultimately need to be perceived as whole units. NBO used singing and encouraged mental rehearsal of the auditory image to explore phrasing and intention. The use of singing and mental rehearsal to clarify and shape the auditory image was frequently observed to resolve course participants' performance difficulties without additional physical practice.

2.3.2.2 Visuo-spatial imagery

Although musicians are known to use movement imagery (Holmes, 2005), NBO prefers to focus on visuo-spatial imagery of the key pattern sequences required to execute the piece on the keyboard. In other words, as well as imagining the sound, the pianist is encouraged to visualise the keys going down in the correct sequence - rather than to imagine the movements required to depress the keys.

A 'bird's-eye view' of the keyboard

The pianist is taught to picture the keyboard mentally, as if from above, and to imagine where note patterns will be played on it. The view is of the keyboard as a whole, rather than as individual keys or octave units, and the mental focus is on the sequential movements of note patterns on the keyboard, rather than on the finger and arm movements required to achieve these sequences.

A condensed image of the keyboard

Figure 2.2: Video still showing NBO describing a condensed view of the keyboard.

An imaginary condensed view of the keyboard is advocated, particularly for use in technically challenging passages. See Figure 2.3 for an example in which the right hand must move rapidly from one octave to another and back again within a single phrase. Here the pianist is taught to envisage the circled notes as being next to each other on the keyboard, rather than in different octaves. This might be considered a variation of the 'bird's eye' technique.

Condensing the keyboard in the imagination seems to reduce the perception that the hands must travel across wide distances, which in turn results in a sense of physically encompassing distance with ease. Reducing the perception of difficulty by using this technique was observed to facilitate rapid technical progress amongst NBO's students.

Figure 2.3: Showing bars 135-139 of *Traumes Wirren from Fantasiestücke op. 12,* by Schumann.

2.3.2.3 *Chunking and re-chunking*

> 'When I am at the piano … now it is more mental work than fingers work.' (P6, Q3)

NBO demonstrates how deliberate mental chunking and re-chunking procedures can be used during the initial mental learning phase, and as an adjunct to physical rehearsal, when technical difficulties are anticipated or encountered. Complex material, which might be organised eventually as one chunk, is unpacked into smaller, more manageable sub-units. The sub-units may be organised below the phrase level and therefore do not necessarily make musical sense. Once all sub-units have been clarified, the group of sub-units is re-rehearsed mentally, reconstituted as one whole unit (chunk) and the organisation of the material thereby returns to the meaningful (phrase) level. This technique is used particularly where rapid runs of notes or other technical difficulties cause uneven execution; see Figure 2.4 for an example.

Figure 2.4: Showing bars 1-4 of *Traumes Wirren* by Schumann.

The problem inherent in this passage is that the right hand finger movements (particularly those circled in Figure 2.4) can be difficult to execute reliably at speed and can cause tension in the hand - especially when the 4^{th} finger is used (which, whatever fingering is chosen, is likely to be the case for some or all of the accented notes). NBO proposes removing the focus from the fingering; instead, the pianist can imagine the melody, simplified, as consisting of the accented notes only. Each note is then imagined with an upper mordent, and the last of each group of four semiquavers becomes an acciacciatura leading to the subsequent melody note (see Figure 2.5).

Figure 2.5: Showing a re-imagined version of bars 1-4 of *Traumes Wirren.*

Organising technically challenging material into smaller, or alternative patterns appeared to facilitate rapid technical progress in situations where other practice strategies - for example working slowly, using dotted rhythms, practicing hands separately - had reportedly not produced improvement. NBO's strategy ensures that in complex situations the pianist clarifies auditory and visuo-spatial images in detail and removes the focus from the physical aspects of playing. Throughout the observation pianists were instructed to work mentally to clarify auditory and visuo-spatial aspects of musical events and, by doing so, were able to resolve what might initially have appeared to be physical problems.

2.3.3 Psycho-physical performance enhancement

The third key feature of NBO's approach, the application of AT to piano playing, is discussed here particularly with respect to mental aspects of learning. AT principles inform and are embedded in all NBO's work; she emphasises that AT is about awareness of mind, and that the mind becomes clearer when the body is not engaged in 'unnecessary reactions'. AT proposes that by increasing awareness of body use, one can be trained to stop habitual patterns of misuse (Brandes & Davis, 2007: 33); by learning to avoid unhelpful or damaging unconscious movement habits (i.e. superfluous movements and tensions) the body can be retrained to work more economically and effectively. Practitioners of the technique claim that it enhances musical performance quality and enables musicians to hear what they play more clearly (c.f. Adams, 1995; Brandes & Davis, 2007). NBO advocates a style of playing which involves no excess physical movement. There is no sense of restricting movement, rather of moving as simply as possible in order to produce the required sound.

2.3.3.1 Clarity during initial learning

> … there is no thing that is just physical or just mental. It [AT] improves your psycho-physical state… your mind becomes clear when your body isn't engaged in all these reactions. (NBO, interview)

Underpinning NBO's whole approach is the concept that mental clarity facilitates physical ease, and vice versa. In her view the intelligent preparation of material facilitates ease of playing. By learning in manageable stages and by consciously attending to every aspect of the learning process the pianist may avoid situations in which technical difficulty obscures musical intention. NBO's central proposition is that by mentally learning the music before learning how to play it the pianist can clarify what needs to be done - and many aspects of how to do it - before the body takes over the learning of the material. This is important, she believes, because the body learns more quickly than thought can be organised, at least with complex material:

> …the body can do things very quickly. The brain works in a different tempo to the body… (NBO, interview)

For NBO this means that it is essential to learn how to think about the music and how best to 'organise' it, both in terms of musical intention and physical action, prior to repetitive rehearsal. She aims to ensure that the imagination is trained before the body, in order to avoid unconsciously incorporating tensions and unhelpful habits into the learning. Repetitive physical rehearsal is in NBO's view only useful once the material is clearly understood. The pianist is more able to focus on efficient, healthy use of the body once the material is memorised.

> Clear thinking prevents technical difficulties and mental and physical exhaustion. (P2, Q3)

2.3.3.2 A psycho-physical re-education

> Basically it is about do less, get more music. (P2, Q3)

Figure 2.6: Video still showing NBO 'guiding' a pianist at the piano.

FM Alexander described his approach as a 'psycho-physical re-education' (Alexander, 2001). NBO communicates a sense of what this means by 'guiding' students during their playing. She uses a light touch or tapping motion on the pianist's neck, back, upper chest or hands (Figure 2.6). Bringing the student's awareness to areas of physical tension – which in some cases is very subtle – reminds the student to release tensions or to move less, and to focus on the sound. In NBO's view, any movement that does not directly contribute to the effective depression of the required key is unnecessary and potentially distracting. In order to achieve clarity in playing it is crucial for the pianist to be aware of how the body is moving.

One of the key reasons for pre-learning the musical text is to avoid inadvertently encoding inefficient motor programmes during initial learning.

2.3.3.3 Physical clarity leads to enhanced listening

The purpose of simplifying body movement is not only to reduce potentially damaging tension but equally to increase the focus on sound. NBO believes that the pianist's movement should directly contribute to effective sound production - in order to be able to listen more clearly. She notes that many pianists play with

> … a lot of tension, unnecessary movement, pulling themselves in, all sorts of emotional responses that make the body do extraordinary movements in reaction to the music, which doesn't give the player a simplicity of access to the sound. (NBO, interview)

Working with students, NBO 'guides' them

> …to bring some sort of balance and simplicity into their whole presence in playing, so they don't do all these extraordinary things with themselves in music making, but just do what is necessary to do at the keyboard, this is when they immediately say 'I can listen more.'(NBO, interview)

2.3.3.4 Physical ease affects mental clarity and vice versa: 'Wholeness', integration and flow

> 'Flow' refers to a heightened state of consciousness in which there is a merging of action and a heightening of awareness, a blending of the mental and physical faculties, and achievement of peak experiences through complete attention to and absorption in a clearly defined task. (Riggs, 2006: 178)

In order to achieve economy of movement and greater physical freedom, NBO advocates the following strategies:

- Notice and reduce/avoid physical tension (holding, clenching, locking)
- Focus attention on what the fingers are doing, specifically sensing the contact between the fingertips and the keys

- Separate musical intention from physical reaction: express musical meaning via sound, not via body movements (habitually occurring for example in the face, shoulders, upper back and chest)

One of NBO's central themes is the achievement of a sense of 'wholeness', and she uses AT 'directions' to help pianists develop a sense of what this means. For the performer, this might be experienced as a sense of achieving integration of expressive purpose, physical ease, and emotional engagement with the performance feedback. In other words the performer is in a 'flow' state and there are no physical, mental or emotional blocks to creating the desired sound (Riggs, 2006). NBO's emphasis, derived from the principles of AT, is on clarity and awareness, both physically and mentally. Understanding and knowing musical content at the outset of practice allows the pianist to pay attention to what the body is doing; decreasing extraneous movement allows for greater economy of movement and greater physical ease; physical ease facilitates enhanced listening and a greater sense of connection with musical intention.

Figure 2.7: Video still showing NBO encouraging a pianist to focus on musical content, while other participants observe

2.4 Findings part II: Implementation of NBO's teaching

This section presents findings from three participant questionnaires, interpreted with reference to findings from the entire dataset. Firstly, results from Likert-type ratings are reported. Secondly, analysis of open questions explores how participants implemented NBO's strategies and what factors mediated successful adoption of the approach.

2.4.1 Memorisation: Training and self-perception of skill

In order to explore whether training in memorisation was related to self-perception of skill, Likert-scaled questionnaire ratings of the amount of memorisation training received were compared with self-ratings of memorisation skill at the beginning of the course (Figure 2.8) (c.f. A.1.3, Appendix A). Of the ten pianists who completed both rating scales, two players with high levels of skill (P4, P8) and an amateur player (P11) (none of whom had been trained by NBO) rated their skill levels more highly than the amount of training they had received. One pianist who had been trained previously by NBO (P2) rated skill level below the amount of training received. Five pianists (four of whom had previously been trained by NBO (P3, P5, P6, P9) and one of whom had not (P10)) rated training and skill levels equally (one respondent, P7, did not complete both rating scales).

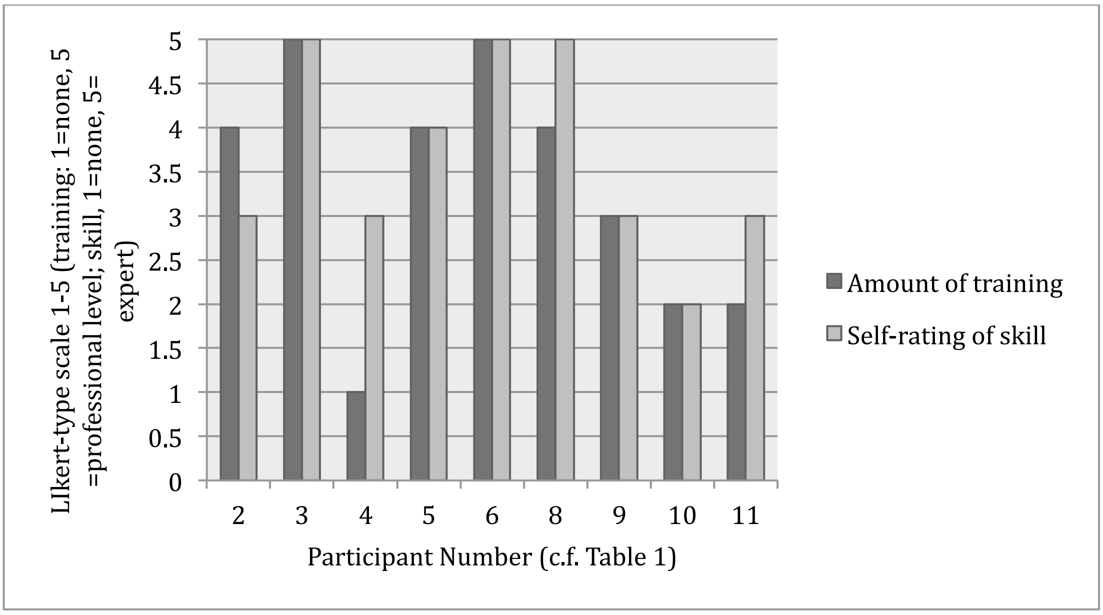
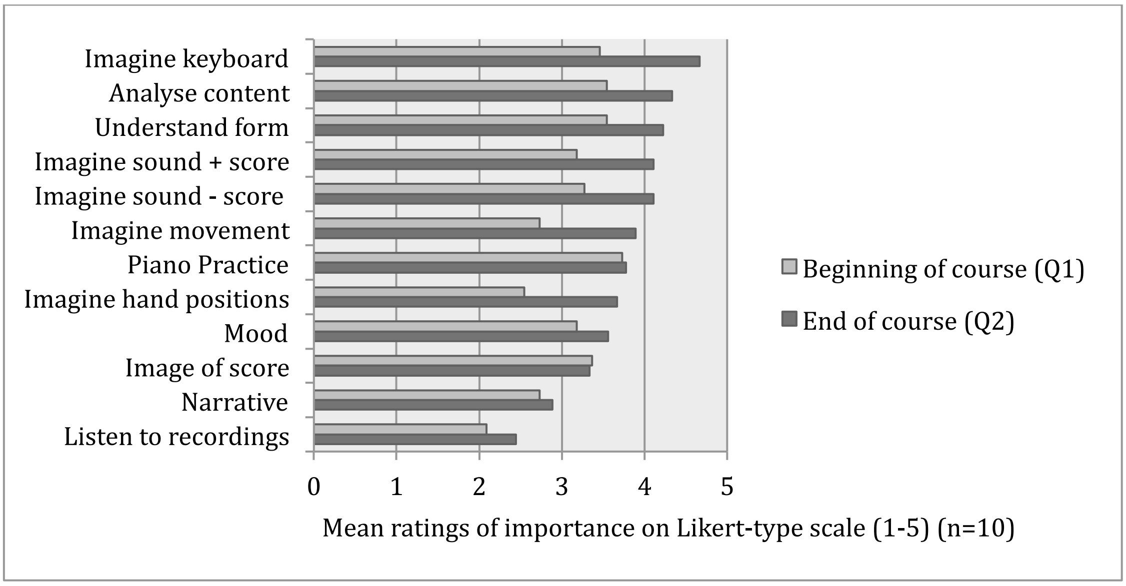


Figure 2.8: Bar chart showing the comparison between individual Likert-scaled ratings of levels of memorisation training received and self-ratings of memorisation skill (scaled 1-5, where for training, 1=none, 5=professional level and for skill, 1=none, 5=expert).

2.4.2 The effect of NBO's teaching on attitudes to practice: Ratings of 12 strategies at the beginning and end of the course

Comparisons of questionnaire ratings at the beginning and end of the course (A.1.3 & A.1.4 in Appendix A) explored how the course had affected attitudes towards different learning strategies (Figure 2.9) and examined which strategies had been most affected (Figure 2.10). Information about individual participants' musical background was used to explain some of the differences in ratings between individuals (Figure 2.11).



Strategy	Mean Q1 rating [SD]	Mean Q2 rating [SD]
Imagine keyboard	3.45 [1.75]	4.67 [0.71]
Analyse content	3.55 [1.81]	4.33 [1.00]
Understand form	3.55 [1.81]	4.22 [1.20]
Imagine sound + score	3.18 [1.78]	4.11 [1.36]
Imagine sound - score	3.27 [1.74]	4.11 [1.27]
Imagine movement	2.73 [1.62]	3.89 [1.45]
Piano practice	3.73 [1.56]	3.78 [0.67]
Imagine hand positions	2.55 [1.75]	3.67 [1.66]
Mood	3.18 [1.78]	3.56 [1.67]
Image of score	3.36 [1.75]	3.33 [1.50]
Narrative	2.73 [1.56]	2.89 [1.45]
Listen to recordings	2.09 [1.30]	2.44 [1.13]

Figure 2.9: Bar chart showing averaged ratings of 12 learning strategies at the beginning (Q1) and end (Q2) of the course, with table to show mean importance ratings [SD] (rated on a 5-point scale where 1 = 'not important' and 5 = 'very important').

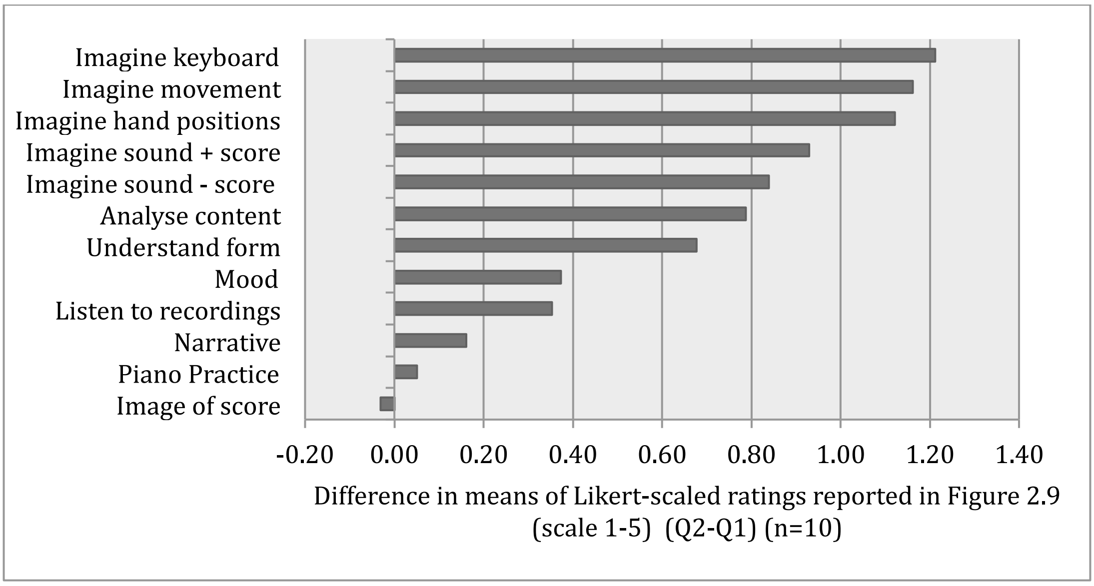


Figure 2.10: Bar chart showing relative changes in mean ratings of 12 learning strategies between beginning (Q1) and end (Q2) of the course (see Figure 2.8 for mean ratings).

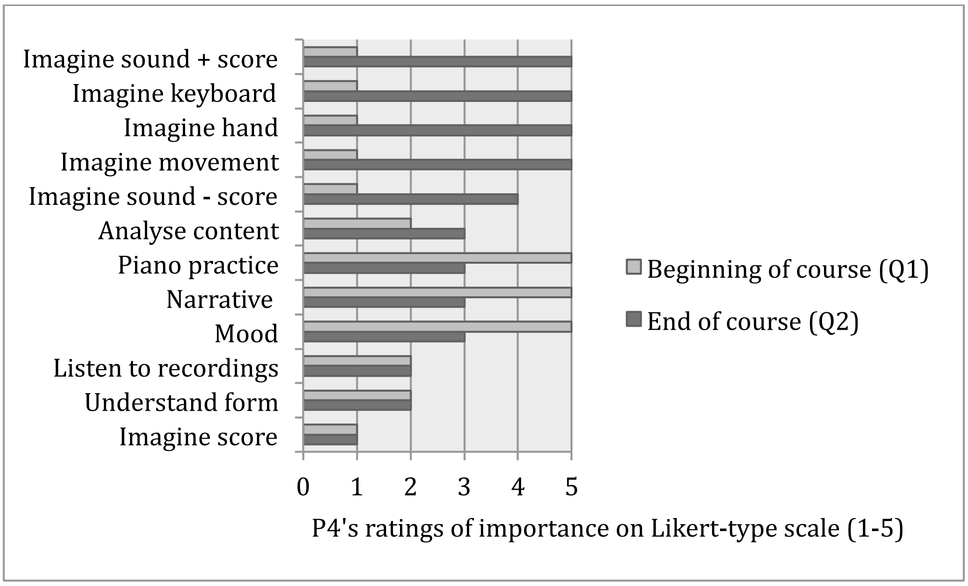


Figure 2.11: Bar chart showing ratings of 12 learning strategies at the beginning and end of the course by one participant who had not previously studied with NBO (P4), whose advanced skills enabled rapid adoption of NBO's strategies.

On average, ratings of all strategies were higher at the end of the course than at the beginning (with the exception of notational imagery). Participants who had not experienced NBO's teaching before, but whose skills were sufficiently advanced for them to be able to adopt her methods relatively quickly, altered their ratings at the beginning and end of the course more than those who had already studied with NBO, or who did not have adequate aural and theoretical skills to be able to adopt all the strategies. As an example, one participant's ratings are shown in Figure 2.11.

At the beginning of the course, practising on the piano was ranked as the most important learning strategy (mean 3.73). At the end of the course, practising on the piano was ranked, on average, seventh in order of importance (but with an increased mean of 3.78). At the end of the course, mental strategies were ranked in the following order: imagery of keyboard (mean 4.67), analysing content (mean 4.33), understanding form (mean 4.22), auditory imagery (mean 4.11), movement imagery (mean 3.89), visual imagery of hand position (mean 3.67), visual imagery of score (mean 3.33). Ratings of all imagery strategies explicitly taught by NBO increased to a greater extent than ratings of strategies not taught during the course (associative imagery of mood or narrative; listening to recordings) or which NBO stated she did not use (visual imagery of score). According to these responses, at the end of the course participants felt that the most important strategies were visuo-spatial imagery, deep learning, and auditory imagery; movement imagery, actual movement and 'mood' were slightly less important; the least important strategies were visual imagery of the score, associated narrative and listening to recordings.

2.4.3 Implementation of seven learning strategies at follow-up

The 12 learning strategies examined in Qs 1 & 2 were reduced to seven strategies for Q3. Two strategies - listening to recordings and deliberately using notational imagery - were removed because NBO had stated that she did not use them, and Qs 1 & 2 found that the course had no impact on participants' use. Four strategies – analysing content, understanding form, thinking about mood and narrative – were merged into the single category 'analyse/explain' in keeping with NBO's training approach.

Ratings from the follow-up questionnaire (A.1.5 in Appendix A) were used to examine whether participants' ongoing use of learning strategies corresponded with predictions derived from the course questionnaires (Qs 1 & 2). Responses showed that in general, participants' ongoing practice had been influenced in ways anticipated at the end of the course, although two respondents had not decreased their physical practice time as expected; there were also discrepancies between predictions and outcomes for two imagery strategies (Table 2.3).

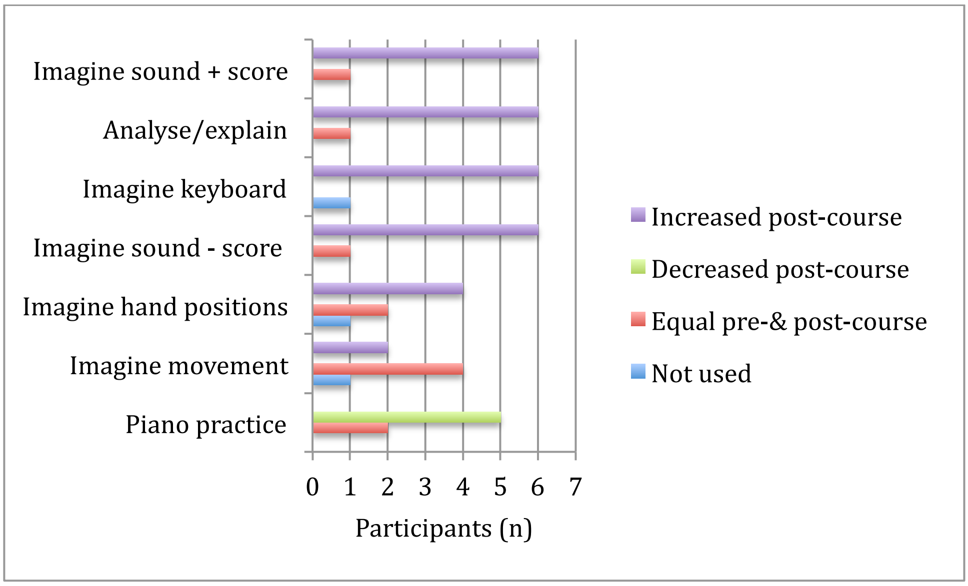


Figure 2.12: Bar chart showing participant reports that allocation of practice time to 7 strategies had increased, decreased or remained the same since beginning studies with NBO, or that strategies were not adopted (Q3) (n=7).

Table 2.3: Showing summary of the comparison between questionnaire Likert-scaled ratings of 7 learning strategies, in which outcomes predicted by a comparison of Q1 and Q2 responses were compared with levels of practice reported in Q3 (n=6).[1]

Strategy	Prediction confirmed (increase)	Prediction confirmed (same)	Prediction confirmed (decrease)	Discrepancies between prediction and outcome
Analysis/explanation	5	1		
Imagine sound + score	5	1		
Imagine keyboard	6			
Imagine hand position	3	3		
Imagine movement	2			4
Imagine sound - score	2	1		3
Play piano			4	2

[1] One respondent did not complete Q2 ratings and could not be included in this analysis.

Nine months after the course, physical practice time had decreased (five respondents) or had been maintained at levels similar to those prior to the course (two respondents) (Figure 2.12). Comparison of Q1 and Q2 responses predicted that six Q3 respondents would reduce their physical practice time, but two had not (Table 2.3). Both were advanced students on demanding courses at the time of questioning (P6, P8). Six out of seven Q3 respondents reported that, since beginning their studies with NBO, they had increased the amount of time they spent analysing or 'explaining' the musical material and imagining sound. The seventh (P8) maintained previous (high) levels of these activities. Six pianists increased their use of keyboard imagery (P2, P4, P5, P6, P8, P11) and four their imagery of hand positions (P2, P4, P6, P8). There were discrepancies at individual level between predictions and outcomes for two strategies. Despite predicting otherwise, four pianists maintained previous levels of movement imagery (three did not increase use (P2, P6, P11) and one did not decrease use (P5)). Three pianists imagined the sound without the score more at follow-up than predicted (P5, P8, P11) (Table 2.3). Two participants, who were less experienced than other players in the group (P10, P11), reported being unable to use some of the mental imagery techniques.

In summary, analysis of scaled questionnaire responses showed that the outcomes of NBO's teaching were reductions (or maintained levels) of physical practice time and increased use of 'explanation'/analysis, aural imagery (with the score) and visual imagery (of the keyboard and of hand positions). The effects of NBO's teaching on the use of movement imagery, and on the use of auditory imagery without the score, were unclear.

2.4.4 Adoption of NBO's prior memorisation approach: An acquired skill

Findings suggest that the 'prior memorisation' technique is an acquired skill that can be taught and improved over time. Course participants had only been taught to learn away from the piano prior to physical rehearsal by NBO, never by other teachers. All course participants believed that the 'prior memorisation' technique was beneficial, but none adopted it entirely. The process of learning away from the instrument was difficult for those with less experience of mental learning (P4, P6, P10), and impossible for an amateur player with little aural and analysis training (P11). The three questionnaire respondents who already had extensive experience of mental learning found it easy: two had several years' experience of using NBO's method (P2, P5), and the other, although new to NBO's training, had extensive experience of using analysis and mental rehearsal during learning, advanced composition and singing training and excellent aural skills (P8).

2.4.4.1 Factors mediating the successful adoption of the 'prior memorisation' approach: Skills, training, motivation, focus, time and preferred learning style

> It is extremely challenging to study and memorise a piece with little familiarity with it beforehand. I have trouble hearing the

> music in my mind when reading the score of a piece that I am not quite familiar with. (P11, Q3)

A variety of factors affected the extent to which participants successfully adopted NBO's method of learning away from the piano. The method was only possible for those with adequate technical, sightreading, aural and theoretical skills, and required the ability to maintain mental focus and the motivation to spend time practising a new method. For all respondents, learning material away from the piano required time, patience and motivation.

> It requires enormous (+ rewarding) time, effort and concentration. (P10, Q3)

> …it is really difficult to change 17 years habit… (P6, Q3)

All respondents to the follow-up questionnaire (Q3) had adopted some of NBO's recommendations, but no-one followed her learning sequence exactly. The majority (5 out of 7) preferred to work in sections rather than to memorise a whole piece prior to playing on the instrument. The only player who reported learning whole pieces from memory before playing had modified what NBO herself reported doing. This respondent (P5) avoided an initial preview at the piano due to poor reading skills, and two others reported that for particularly complex music they also avoided a preview at the piano, preferring to use analysis before any playing took place (P8, P10).

One less experienced player reported not been able to implement all of NBO's techniques because of limited aural and analytical skills. This player preferred to learn initially via physical practice and to reinforce this learning with score study and mental practice at a later stage.

> I find I can get a lot out of studying and memorising from the score after I have some familiarity with the music (from playing it more than a few times). (P11, Q3)

Prior memorisation was experienced as slow and effortful - 'a huge mental effort' (P5, Q3); some pianists reported feeling impatient with mental learning, and others felt the need to carry out certain tasks at the piano, for example learning technically difficult passages, working out fingering, and developing 'muscle memory' for security in performance.

> I think the only aspect that I have really struggled with is the learning solely away form the piano – I find I rely too much on muscle memory to give a secure performance just by studying the score. (P8, Q3)

Under time pressure pianists sometimes felt that learning at the piano was quicker:

> Sometimes when I have a short time to learn a piece I find it more challenging to learn it away from the piano…(P6, Q3)

While all participants reportedly considered all aspects of the 'prior memorisation' approach to be beneficial, not all participants felt that the benefits outweighed the difficulty of applying the method in full and no one had adopted the process exactly. All participants reported having adopted some aspects of NBO's approach, but the majority (five out of seven Q3 respondents) reported learning unfamiliar music in sections, either learning and memorising away from the piano and then playing on the piano, or combining periods of learning and memorising away from the piano with periods of learning and memorising at the piano (NBO, in contrast, reported learning whole pieces prior to physical rehearsal).

NBO began developing her approach as a teenager, and three participants commented that it was difficult to change practice habits once formed. Two participants who had attended previous courses indicated that, although they believed NBO's method to be superior to other working methods, they did not employ it rigorously. One of these pianists felt that she was not using NBO’s techniques as much as she ought to, despite having attended previous courses. Another explained that it took time for NBO’s techniques to become a natural and less effortful part of practice.

> I don’t understand why is so heavy to me [to] change the way I use to memorise … (P3, Q2)

> … no matter how sure we are about the things we know, we have to repeat over and over again until they become part of us and not something we have to try hard to achieve (P6, Q2)

Others commented that applying the method required significant discipline: the physical act of playing is important and enjoyable, and, especially when time is limited, pianists were likely to choose playing in preference to mental practice.

> I have got only 2 hours a day to practise, so I want to play also as I do need playing in order to keep my limbs moveable. (P2, Q3)

> I combine NBO’s approach with work on the piano. I do not learn the whole piece by memory, but small parts and then play these parts on the piano - I am too impatient otherwise. (P2, Q3)

2.5 Findings part III: Advantages and drawbacks of NBO’s approach

This section draws on findings from across the entire dataset and explores participants’ views concerning the advantages and drawbacks of the approach.

2.5.1 Improvements in physical performance

All respondents reported positively on NBO’s approach to the physical aspects of playing and believed that their playing had improved technically as a result of the course. There were numerous references, throughout the observation, to reductions in physical tension and fatigue, and to the benefits of a conscious approach to learning. All participants reported that the concept of 'doing only what is necessary' (P2, Q3) was central to their learning:

> … understanding the difference between doing too much and doing only what is necessary (P2, Q3)
>
> … using only the movement crucial to making the desired sound, much other movement is in many ways wasted effort (P8, Q3)
>
> … paying close attention to what the body is doing (P10, Q3)
>
> The concept of playing with only the necessary physical movements, so that the body is quieter and better listening can occur (P10, Q3)

Participants also reported that NBO's approach helped them to reduce physical tension, to reduce tiredness and to prevent technical difficulties. Understanding and being aware of how the body is moving appeared to lead to greater control and to a reduction in physical effort:

> She made me pay attention to quick ease of muscle tension after making a finger move. In fact it helped me in my deep inner understanding of move and opened the way to the better control. (sic) (P4, Q3)
>
> [I] used to suffer from tendon pain and numbness after long periods of practising. This is now eliminated. (P5, Q3)

2.5.2 Performance enhancement

Participants believed that NBO's approach could enhance performance. NBO argues that as playing becomes physically easier, 'better listening can occur' (NBO, interview). Participants reported that adopting physical aspects of NBO's approach gave them greater freedom to connect with the music and to think more clearly. Interestingly, although pianists were taught to become more aware of how they used their bodies, they reported that NBO's approach helped them to focus their awareness on the sound and the instrument and that their focus on the body's movements actually decreased.

Focusing on sound reportedly enabled pianists to achieve the desired result with minimum physical effort. Focusing on what has to happen to the instrument rather than the body may lead to a greater sense of connection with the sound. Participants all reported that NBO's techniques facilitated ease of playing and enhanced their ability to perform memorised music with 'clarity [both physical and mental] of intention'.

> If I am physically relaxed, and willing this 'imagined' sound strongly enough then more often than not the desired sound is achieved, with minimum physical effort. (P5, Q3)

> When I am at the piano I work with all the aspects from NBO, so now it is more mental work than fingers work. (P6, Q3)

> I have learnt to think more about what has to happen to the instrument rather than what is happening with my limbs (P2, Q3)

> I've altered my thought process in playing to avoid sending 'physical' instructions to my hands, but rather to 'hear' the next sound in my imagination … (P8, Q3)

> [Learning away from the piano promotes] clarity of thought, therefore not getting bad technical habits which are mostly born out of confusion. (P2, Q3)

> It's really taken the focus totally off motor memory… (P5, Q3)

2.5.3 Memory security

During the week's discussions several pianists reported knowing a piece more clearly when it had been thoroughly memorised prior to physical practice and some participants reported enhanced memory security.

> It [prior memorisation] changes the quality of awareness of the piece… (P6, Q3)

> It helps in better learning – helps to see more sharply all nuances … (P4, Q3)

> I am more secure and have less memory mistakes (sic) (P6, Q3)

> These pieces stay in my head and I can refresh my memory very quickly. They are very reliable. (P2, Q3)

Participants at both virtuoso and amateur level who had previously successfully memorised automatically (i.e. via repeated playing) stated at the end of the course that their learning would be enhanced by working away from piano.

2.5.4 Connection with the self

Several participants reported that NBO's approach helped to enhance their connection with the music and, consequently, with the self – in other words, to achieve a sense of 'flow' (Riggs, 2006).

> [I took part in the course] To liberate my playing further and therefore arrive more at myself and my perception of the music [sic] (P2, Q1)

> … get back into the contact with music/piano/myself ... (P10, Q1)

> NBO's approach to music … enables a really profound connection with it (P10, Q2)

2.5.5 Potential drawbacks

Two respondents expressed some reservations about NBO's approach. They worried that too great an economy of physical movement might inhibit expressivity and communication in performance, and that too great an emphasis on the mental aspects of learning might be detrimental to physical technique.

> The technique can mean that one can focus too much on promoting freedom and when trying to channel musical thought elsewhere it can get lost. There ARE may successful and wonderful artists who would be an Alexander teacher's idea of a mess. (P8, Q2)

> … complete cutting of the movement of a pianist body is very risky in the aspect of public performance. Natural charisma of body language should not be disregarded. (P4, Q3)

> The physical aspect i.e. technique is the means by which we make our understanding heard. There are many musicologists who understand music phenomenally but have not the physical means to express it. (P8, Q3)

2.5.6 Summary of participant responses

NBO's approach consists of a number of acquired skills that can be taught and improved over time; high levels of training and motivation are required if it is to be adopted in full. Participants adapted aspects of the training to their own needs, preferences and habits and rarely used the approach in its entirety. No participants had been taught to use the prior memorisation technique except by NBO and in fact, none had been explicitly taught any techniques for memorising music except by NBO. The amount of memorisation training received did not necessarily correspond to self-ratings of memorisation skill. All eleven participants believed that prior memorisation was a useful technique, but its effectiveness was modulated by skill level.

Provided participants had adequate levels of aural and theoretical skill, the imagery strategies advocated by NBO were experienced as beneficial. Participants were more likely to report implementing strategies that had been clearly and explicitly taught, but they did not implement everything they were taught to do, even when they believed that they should. Following the course, participants reported reduced or maintained levels of physical practice and increased use of analysis/explanation and of several imagery strategies. As a result, memory security and performance quality were reportedly enhanced.

The approach generated a sense of 'wholeness'. Technical facility and expressive ability were reportedly enhanced, while physical rehearsal time and physical strain were reportedly reduced. Two participants expressed concern that expressivity and communication in performance might be restricted by the use of NBO's physical strategies (see 2.5.5) but at the same time, all participants reported a variety of benefits. A striking finding was that pianists decreased attention to separate movements (particularly of fingers and arms) but developed an increased, integrated awareness of the whole body. This sense of integration and physical ease resulted in an increased focus on the sound and in a sense of connection with the self that closely resembles the 'flow' state described by Riggs (2006). Deliberate mental strategies combined with increased body awareness were thus associated with a number of positive outcomes.

2.6 Discussion

NBO's approach is discussed in comparison to other approaches reported in the performance research literature and with reference to previous findings concerning musical memorisation strategies; her deliberate imagery techniques are considered with particular relation to the literature on attention to movement.

2.6.1 Intention and execution: Distinguishing 'what' and 'how' during the initial stages of learning

> Knowing is one thing. Being able to do is another thing. (NBO, interview)

NBO's approach, in contrast to the more common practice of initially learning via physical rehearsal, prioritises the encoding of a cognitive schema of the musical material. 'Explaining' the material - identifying patterns and their meaning – is a 'deep' learning approach (Cantwell &

Millard, 1994) and takes place before the specific motor programmes required to perform it are explicitly encoded and rehearsed. Many performers incorporate score study at some stage during the memorisation process (c.f. Hallam, 1997: 90) but NBO argues that study of the written text should take place after only a very brief preview of the material at the keyboard; she advocates playing through the piece from the score to get a sense of how the piece sounds, but only once or twice, so that the pianist does not inadvertently encode a motor memory of the music (and even during preview at the instrument she notes that she is already beginning the 'explanation' process rather than attempting to learn how to perform it).

2.6.2 'Explanation' and deliberate early retrieval practice

Score study may involve some formal analytical skills, particularly when defining large-scale structures, but NBO more vividly describes the technique as an 'explanation' of the material. During this process, the performer builds up a detailed account of the events described in the text; the process may range between analysis at the macro level and micro level descriptions of local detail, moderated by individual preference and task. Analytical and theoretical skills are used to understand, map and learn the information on the page, without the additional tasks of having to implement the required key press sequences on the instrument or monitor feedback.

An important advantage of attempting to think through a piece from memory is that any retrieval failure is easily revealed, as there can be no reliance on automated physical recall. Ginsborg (2002) found that the most successful memorisers in her study of 13 singers began the attempt to memorise very early in their learning and monitored their progress. NBO advocates mental memorisation at the very outset, ensuring that by the time the piece is played on the instrument, encoding and retrieval practice have already occurred. This is a rigourous and demanding method - only one course participant adopted it fully – but because it requires deliberate early encoding and retrieval testing it may be particularly robust. Memory is encoded during the process of practice, meaning that by the time the musician has learnt to play a piece it may have been fully or partly memorised (c.f. Hallam, 1997: 90). In some circumstances (for confident performers, and for the performance of relatively simple material) this will be sufficient to ensure successful performance, but some musicians adopt additional analytic strategies in order minimise retrieval failure (Hallam, 1997: 90). NBO's learning and memorisation sequence begins with the deliberate encoding of retrieval cues via the creation of structural and auditory images. Pianists who successfully used her approach reported that it led to more reliable memory than the opposite strategy of initially learning at the piano (see 2.5.3).

> I've been playing very demanding pieces, some of over 20 pages, piano concertos etc, but I played it only at the piano without really knowing the piece, mentally. I had memory blocks; I was more concerned about the text than the actual performance…(P6, Q3)

2.6.3 Task prioritisation during multiple encoding

The reliable performance of a musical text from memory requires several dimensions of that text to be securely encoded in the pianist's memory: structural, auditory, visuo-spatial and motor images must be accessed via retrieval cues which are secure enough to facilitate fluent recall under performance conditions (c.f. Hallam, 1997: 95; Chaffin & Imreh, 2002). NBO's memorisation technique involves encoding and rehearsing the musical text in multiple dimensions prior to physical rehearsal of the material. This strategy separates out the multiple aspects of the task, and enables the pianist to begin to embody the experience of recreating the music through mental imagery without having the additional cognitive load of executing movement sequences or monitoring physical and auditory feedback. Deep learning, the encoding of retrieval cues, rehearsal and recall of a multi-dimensional mental image of the piece are all carried out prior to physical rehearsal. Motor memory, considered by some experts to be liable to failure under performance conditions (Hallam, 1997: 95), is explicitly encoded during a second stage in the learning process. Removing the focus from motor learning during initial encoding may prime performers to rely less on automated motor programmes than on the structural and auditory cues that are encoded first.

Learning the material away from the piano (without the additional cognitive load of executing movement and monitoring aural and kinaesthetic feedback) appeared to enable the pianist to manage the requisite multiple tasks in stages. Separating mental learning from physical learning may reduce cognitive load during initial learning: by avoiding the potential technical complications of reproducing the text on the instrument the pianist is able to focus exclusively on the content and meaning of the text in the initial study phase.

> Understanding and internalising the music prior to the physical aspect means that you aren't trying to tackle too many things at once. (P8, Q3)
>
> … work out a musical concept before it can be blurred by technical difficulties. (P2, Q3)

Being overloaded by multiple task demands, or distracted by feedback and its effects, may result in a lack of clarity about how technical issues might be effectively addressed:

> when learning at the piano music and emotions connected to the music disturb the attention … (P4, Q3)
>
> …there just seems to be something about the way the brain works when learning at the piano that makes it liable to miss things/ misinterpret things … (P5, Q3)

And as one participant commented, working from memory once at the piano also

> … means you can be totally visually focused on the way the fingers and the note patterns are organised. This will always yield a physically simpler way around the keyboard than you will get if your vision is fixed on the score while your fingers are learning it. (P5, Q3)

2.6.4 Body awareness during playing: Economy, 'wholeness' and flow

Although NBO teaches pianists to become more aware of the way they use their bodies, the point is not to focus on movement but to achieve 'freedom and ease in playing' (Ben-Or, 1995: 92). As movement became more efficient, course participants reported that their attention to sound and to expressive intention increased and that, in fact, attention to movement decreased. This apparent paradox can be explained in terms of the experience referred to by NBO as a state of 'wholeness'. In this state, attention is not over-focused on specific aspects of motor execution (e.g. on finger or arm movements), which might be detrimental to smooth motor performance (see 2.6.6); rather the body is experienced as an integrated whole, moving 'only as necessary' in order to achieve the desired musical effect.

NBO's body awareness strategies, in combination with an explicitly memorised multi-dimensional mental image of the piece, were reported by course participants to facilitate an enhanced sense of connection with the music and with their expressive intention, or 'flow' (Riggs, 2006). By developing a more conscious, and consequently more economical, use of the body, pianists reported that they were able to listen more clearly and to experience a greater sense of control over their performance. At the same time it appeared to be beneficial to shift the focus of attention away from physical action onto the instrument and the sound - both the imagined sound and the sound being produced.

2.6.5 Reducing difficulty via imagery

Reductions in the perception of difficulty can be achieved by, for example, re-imagining distance on the keyboard, or even by re-imagining the geography of the keyboard so that distant notes are imagined as being adjacent to each other. When perceived distances between spatial locations are reduced, execution appears to become easier. NBO explains that

> I have to … put details closer together, so that I get a bird's eye view, so that all the details are there but many many close together, so that when I play it I don't feel that I have to run to get the next thing, they are there waiting for me so to speak … (NBO, interview)

Similarly, the perception of activity in complex or rapid passages can be altered, using imagery to create break the material down into very small chunks in order to learn in detail, then re-imagining it in larger chunks for fluent performance – so that, as NBO puts it

> … you're making actually very slow steps, rather than lots of step after step after step after step. (NBO, interview)

2.6.6 Directing attention to movement effects

Irrespective of the learning approach, more attention is available for focusing on the desired performance outcomes once musical material has been memorised, because the pianist no longer needs to read the notation, decipher meaning, and translate the text into auditory schema and motor programmes. Milton (2008) argues that, for optimal motor performance, attention should be diverted away from the process of its performance. In a review of studies examining attention to movement, Wulf & Prinz (2001) found that paying attention to the external effects of movement, rather than to the movement itself, enhances learning. For musical performance, Highben and Palmer (2004: 64) suggest that performers should focus on the sound, not on the actions that produce the sound. According to common-coding theory (Prinz, 1997), perception and action require a common representational medium. Thus, actions will be more effective if they are planned in terms of their intended outcome or effect, rather than in terms of the specific movement patterns (Wulf & Prinz, 2001: 658). By learning and memorising away from the keyboard, before physical rehearsal, NBO prioritises non-motor aspects of the task. In other words, the initial encoding directs attention towards the results of motor performance: the structured musical intention, the sound, and note patterns on the keyboard. NBO'S students report that by using her approach they reduce their focus on physical action and increase their focus on sound and on the instrument.

> [memorising before playing enables the pianist to be] freer while performing, it decreases the unnecessary body movement, it helps focusing more on the sound, being more connected with the instrument… (P6, Q3)

By reducing movement and tension to the optimal minimum, more attention may be available for performance outcomes (i.e. the expression and manipulation of expressive intention, as embodied in the sound). The effective ('economical') encoding of motor programmes may be enhanced when material is pre-learnt: several aspects of the task have already been automated, thus reducing cognitive load and enabling the performer to focus on minimising movement and on the distal effects of that movement.

2.6.7 Quality of knowing: Freeing the imagination

Participants emphasised that paying clear attention to the musical content and intention, at the outset of learning, enhanced the quality of musical knowledge. Learning the material away from the piano in the initial phase appears to enable the pianist to prioritise the musical concept (intention):

> ... much greater understanding of the piece musically. Very much more so than playing it a lot of times before memorising. You really have to think so much more about the piece and its meaning this way. (P10, Q3)
>
> … changes the quality of awareness of the piece … (P6, Q3)
>
> It helps in better learning – helps to see more sharply all nuances … (P4, Q3)
>
> … pianists [learn] to play only with their fingers, and it actually works somehow but only if you don't come to the point where you see what a big hole it leaves first of all in your perception and most important in your performance… (P6, Q3)
>
> … it promotes being a musician rather than merely a pianist (P8, Q3)

Managing complex tasks in explicit stages appears to lead to an overall sense of integration of intention and action; although tasks are initially separated out, pianists appear to achieve integrated results and course participants reported an enhanced quality of knowing. The sound of a piece can be recreated entirely in the pianist's mind. This facilitates decision making, for example about phrasing and gesture, which can be much more difficult to make freely and imaginatively if the pianist is simultaneously attempting to effect the correct key press sequences, during the initial learning stage, before motor aspects of the task are sufficiently automated. An auditory representation of the piece can also be used to practice recall and then for overlearning and maintenance rehearsal, both before physical rehearsal and after it has begun.

> … it improves the quality of the work at the piano and the quality of the final product … I am freer to create music and experiment while performing because I have the pieces in my mind and that gives you more freedom. (P6, Q3)

2.6.8 Discrepant results

At follow-up, participants appeared to have adopted strategies that had been explicitly demonstrated during the course. There was a lack of clarity in findings concerning two particular strategies that were not explicitly demonstrated and discrepancies at individual level between predictions and reported outcomes for these strategies (2.4.3). At the end of the course, three pianists' ratings predicted that they would reduce their use of auditory imagery without the score, but at follow-up they reported increased use, suggesting that during ongoing practice they may have found that the strategy was an implicit part of the approach. From beginning to end of the course, ratings of the importance of movement imagery increased, but follow-up questioning found that three pianists had not increased use as predicted and one had not decreased use as predicted, possibly indicating that participants were not clear about how to implement this strategy, or that their views of its effectiveness altered over time.

2.7 Summary and future directions

NBO's teaching was already partly familiar and the findings concerning her pedagogy were therefore broadly as expected. By documenting a course for the first time, the study was able firstly to identify three key techniques - a prior memorisation strategy, the explicit teaching of imagery techniques, and psycho-physical performance enhancement through the application of AT to piano playing. Secondly, the study articulated and interpreted features of NBO's approach in relation to other pianists' understanding, which both increased validity and produced some unexpected insights. Finally, findings from the observation were interpreted in relation to the literature on musical memorisation and attention to movement.

Unexpectedly, detailed exploration of NBO's teaching and participant responses found that although pianists were taught to become more aware of how they used their bodies, NBO's approach helped them to increase focus on the sound and the instrument, and focus on movement actually decreased. Interpretative analysis of this finding suggested that the imagery strategies employed helped pianists to focus attention on intended outcomes/distal effects. Overall the approach generated a sense of 'wholeness' or 'flow'. Understanding and being aware of how the body is moving appeared to lead to greater technical control and to a reduction in physical effort, and participants believed that NBO's teaching resulted in improvements in musical quality and memory security.

As anticipated, the technique of prior memorisation, incorporating specific mental imagery strategies, was identified as an acquired skill that can be taught and improved over time. This approach prioritises deep learning, multiple memory encoding and early retrieval practice, all of which have been shown to be features of expert memorisation. While NBO advocates and teaches particular strategies and techniques, she specifically resists the idea that she promotes a 'method'. In keeping with this view, participants chose to adapt aspects of her pedagogy to their own needs and preferences and rarely used the approach in its entirety. In some cases, participants did not feel able to use all the recommended techniques due to lack of aural and theoretical skill. Most pianists preferred, or felt that they needed more physical practice (and at an earlier stage in learning) than NBO proposed. The fact that no participants adopted the approach in its entirety suggests that, although all participants expressed enthusiasm for NBO's techniques, there may also have been some tacit reservations that were not captured by the study; furthermore, two participants were concerned that too great an economy of movement might inhibit expressivity and communication in performance. Participants found mental techniques difficult and challenging (although they appeared to be acquired skills that became less effortful with extended practice), and several participants commented that it was difficult to change practice habits once formed.

In order to investigate whether findings from the observation would generalise to a wider population of pianists, a survey of conservatoire piano students was planned. NBO's approach, seemingly unusually, integrates learning and memorisation and initially separates this process from physical learning; the questionnaire therefore set out to examine students' processes for learning and memorising, and to explore whether their underlying conceptions about learning and memorisation might relate to strategy choices. NBO course participants were more likely to report implementing strategies that had been clearly and explicitly taught, but they did not implement everything they were taught to do, even when they believed that they should. The survey was therefore designed to explore which memorisation and imagery techniques were being taught and implemented at conservatoires in the UK. The observation also found that NBO's training improved memory security and technical confidence, and the survey therefore set out to examine possible relationships between strategy choice and self-perceptions of memorisation skill, confidence and satisfaction.

Chapter 3 Learning and Memorisation Amongst Advanced Piano Students: A Questionnaire Survey

This chapter describes an online questionnaire survey of thirty six piano students at UK conservatoires that was designed to examine advanced piano students' conceptions of learning and memorisation, and their experiences of the process; to identify which strategies and techniques were most commonly recommended and implemented, and to find out where and how students acquired musical skills; and finally to examine how effective students believed their own approach to be. The survey aimed to explore gaps between beliefs and practice habits, and between what students were taught to do, advised to do, said they did and actually did. Results showed that respondents were aware of a variety of imagery and memorisation strategies, but adoption of recommended mental imagery and deliberate memorisation techniques was less consistent than the adoption of recommended physical practice techniques.

3.1 Introduction

According to recent literature, learning and memorisation skills are rarely taught explicitly (Ginsborg, 2004), and mental skills training programmes are not widel y applied within the performing arts (Hays, 2002; Clark and Williamon, 2011). This study therefore set out to explore what advanced piano students in the UK knew about mental (and other) learning and memorisation strategies, including how this knowledge was disseminated, how often students adopted particular strategies, what factors influenced the adoption of particular strategies, and whether strategy choice related to confidence, satisfaction and skill.

Advanced piano students studying at conservatoires were identified as the survey population. These students represented a similar population to that of the NBO participant observation study, as both groups consisted of pianists who had reached at least the level of expertise required to gain entry to advanced training courses. Although it was recognised that the NBO group was more diverse, including professionals as well as advanced students, the survey aimed to provide information about current teaching and learning, potentially illustrating variations, developments or gaps in training, and it was therefore considered appropriate to design a questionnaire survey of students who were still in training and who could provide current information and views on pedagogical approaches.

Drawing on evidence from the participant observation study and from previous literature, the questionnaire aimed to examine five key, interrelated topics, the background to each of which is set out below (3.1.1 - 3.1.5).

1. Conceptions of learning and memorising.
2. Frameworks for the process(es) of learning and memorising.
3. Adoption of recommended techniques.
4. Contexts for knowledge acquisition.
5. Skill, confidence and strategy choice.

3.1.1 Conceptions of learning and memorising

> Learning music is about understanding the printed page. Memorising is about owning the piece, taking it into your body and psyche, and expressing your self through that particular composer's language, discovering the concepts that lie behind the notes. (Fisher, 2006)

A number of possible meanings and apparent inconsistencies in the ways that musicians conceive of 'learning' and 'memorising' were evident from pedagogical literature and from observation. The first objective of the questionnaire was therefore to examine how respondents conceived of learning and memorising, and what they believed characterised each process, as a means of informing analysis of the whole questionnaire and potentially identifying inconsistencies between beliefs and reported practice habits.

Although 'learning' is described by Fisher (above) as the process of developing an understanding of the musical text, in practice musicians often refer to the process of learning to play the material from a score as 'learning' and to the process of learning to play without the score as 'memorising' – and often view the two processes as separate, sequential functions (Rubin-Rabson, 1937: 44). The concept of 'learning' might therefore incorporate either analytical or procedural processes, or both. Mishra (2005) concluded that the memorisation of music comprises three stages: preview, practice, and over-learning. Practice, according to her theoretical model, includes notation-based rehearsal while the pianist is 'learning the technical aspects of a piece' (Mishra, 2005: 79) and during which incidental (automatic) memorisation occurs, followed, where necessary, by conscious memorisation practice. 'Memorising' may therefore be conceived of as an outcome or extension of the learning process (incidentally or deliberately achieving fluent recall of a text without recourse to a score). Alternatively, as Fisher suggests, memorising may be conceived of as qualitatively different from learning, with memorisation experienced as the process of internalising knowledge and resulting in fluent performance that feels as though it is a personal utterance. Learning and memorisation might therefore be conceived of as two separate processes, which may overlap to some extent, or as aspects of an integrated process of internalisation achieved by a number of means.

3.1.2 Frameworks for the process(es) of learning and memorising

The second objective was to examine the sequence of events in respondents' recent practice in the context of three possible frameworks (Figure 3.1), and to find out whether their choice of approach corresponded to their conceptions of the process (3.1.1).

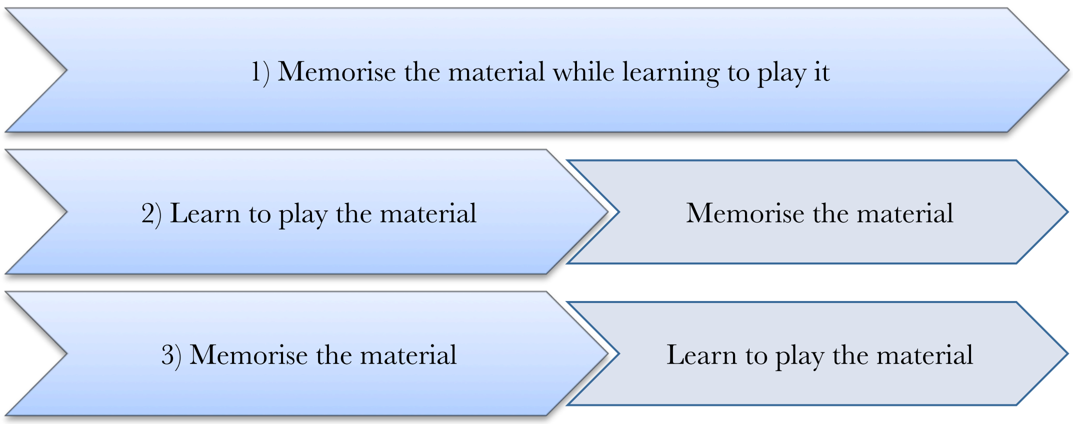


Figure 3.1: Figure to show three frameworks for learning and memorising. 1) an integrated process in which material is memorised as it is learnt, 2) a two-stage process in which the pianist learns to play the material and then memorises it and 3) a 'prior memorisation' process, in which material is memorised before the pianist learns to play it.

However 'learning' and 'memorising' are conceived of, in practice it is difficult to define a point at which 'learning' ends and 'memorising' begins - although for pedagogical purposes, distinguishing between different aspects of the whole process and understanding how different sequences affect outcomes may prove beneficial. NBO's approach offers a potentially useful model of the learning and memorisation process by distinguishing between (i) learning 'about' the material (using analytic strategies – declarative or structural knowledge) while concurrently memorising (using imagery rehearsal) and (ii) learning to play (procedural learning). Within this framework, the memorisation process incorporates and is indistinguishable from learning, the aim from the outset being to memorise a multi-dimensional image of the material. The key distinction here is not between learning and memorising, but between consciously memorising that which is learnt, and learning how to play it.

A key feature of NBO's approach is that memorisation takes place explicitly, before procedural learning. Although other piano pedagogues have suggested similar strategies (see Gieseking & Leimer 1932/1972; Brée, 1969), they may not be widely taught: NBO course participants had not been actively taught to work in this manner by anyone else, nor does the technique appear to have been described in naturalistic studies of instrumentalists (see for example Chaffin, 2002; Chaffin & Logan, 2006; Miklaszewski, 1989). According to Hallam (2006: 97), expert studies suggest that learning to play the musical material usually takes place first, with memorisation taking place towards the end of the learning process when performance of the music is already secure. It should be noted, however, that even when memorisation is not the primary goal some or all memorisation occurs incidentally from very early in the process of learning to play the material (Mishra, 2005).

3.1.3 Adoption of recommended techniques

The third objective of the questionnaire was to examine how frequently students adopted recommended strategies and techniques - in order to find out which techniques were more and less likely to be adopted and, in particular, to assess whether reported adoption of memorisation techniques corresponded with reports concerning recent practice (3.1.2).

Several recent studies of musicians' practice behavior have found that quality, not quantity of practice (for specific pieces) determines performance outcomes at all skill levels (see for example Duke, 2009; McPherson, 2005; Williamon and Valentine, 2000), but although the practice behaviours of individual musicians have been documented (e.g. Chaffin & Logan, 2006; Miklaszewski, 1989), detailed descriptions of mental practice activities are rare (although see Holmes, 2005). In order to examine respondents' strategy choices, an extensive list of learning and memorisation techniques was compiled, based on the analysis of questionnaire responses from NBO's course participants and on the pilot questionnaire responses and discussion. This list was used twice in the questionnaire, firstly to ask how often each of the techniques was implemented, and secondly to ask whether each of the techniques had ever been recommended (irrespective of adoption) (Figure 3.2). Additionally, because reporting might not accurately reflect what actually happened in practice (c.f. Koopman et al., 2007), two different questioning strategies were used to ask about one recent learning experience, to provoke detailed introspection and to minimise desirability bias in the responses.

3.1.4 Contexts for knowledge acquisition

The fourth objective of the questionnaire was to explore how students believed they developed their own methods, by examining a broad range of contexts in which students might have acquired strategies and techniques for learning and memorising music.

A number of researchers have argued that practice skills and strategies need to be explicitly and strategically taught in order for students to adopt them consistently, and that facilitation of learning, which is often underutilised in music teaching, is essential (Hallam, 2006: 166). In a study of music students Lane (2006) found that score study skills did not necessarily transfer from one context to another and consequently advocated an expert modeling approach in which skills are taught in an embedded manner. Koopman and colleagues (2007) studied individual conservatoire instrumental lessons and student practice sessions and found that practice was largely driven by tacit knowledge. Although individual practice generally mirrored what happened during lessons, the majority of the teaching did not result in transparent and consistent forms of practicing, with students gradually departing from teachers' suggestions over the course of a week unless they had received explicit instructions for practising. While these studies acknowledge the potentially influential role of formal teaching in the development of practice skills, Folkestad (2006) has also pointed out the importance of enculturation and hidden transmission in musical development. He argues that musical learning should be considered in a much broader context, with a shift of focus from teacher to learner, and that research must deal with all kinds of musical learning, irrespective of where it takes place. Informal musical learning outside institutional settings, for example, has been shown to contribute to important knowledge.

3.1.5 Skill, confidence and strategy choice

The participant observation study found that NBO's training improved memory security and confidence in performance; a somewhat surprising finding, however, was that training in memorisation skills did not necessarily improve confidence (as measured on self-rating scales). The survey therefore set out to examine possible relationships between strategy choice and self-perceptions of memorisation skill, confidence and satisfaction.

3.2 Methods

3.2.1 Online version

Following discussion with key staff members at two conservatoires, it was decided that an online version of the questionnaire would provide the most effective means of administering the questionnaire, for two reasons. Firstly, the survey could potentially provide access to students at several conservatoires around the UK for a limited cost (£19.99 per month), and the growing use of internet surveys amongst populations with high rates of internet coverage (Bryman, 2012: 674) suggested that this method would be appropriate for a conservatoire student population. Secondly, the online method would be potentially advantageous in eliciting the types of response sought. Open questions provided an important tool for probing respondents' actual practice habits, and a potential advantage of web surveys was that open questions tend to be answered more often, and in more detail, in online (compared with handwritten) versions (Bryman, 2012: 677). Furthermore, in web surveys interviewer effects may be largely avoided, which according to Sudman and Bradburn (2009, cited in Bryman, 2012: 234) can be helpful in avoiding social desirability bias. Both of these factors were important considerations in the design of a survey that aimed to examine differences between what respondents were taught to do, what they thought they ought to do and what they actually did, as well as to examine potentially sensitive issues of confidence in personal skill levels in a competitive environment. Thus an online method was deemed suitable for reducing bias and eliciting honest, detailed responses.

3.2.2 Pilots

Two 'paper and pen' versions of the questionnaire were piloted, on both occasions in the foyer of the Edinburgh University music department, with undergraduate piano students recruited on an ad hoc basis; ten volunteers completed pilot Version 1 and five volunteers completed Version 2. Version 1 contained 16 questions and completion took an average of 9 minutes (range 7 - 15 minutes). Version 2 contained 17 questions and completion took an average of 12 minutes (range 8-20 minutes). I was present throughout and was asked to clarify the meaning of several questions while volunteers were completing their responses. Informal discussion followed, during which handwritten notes were made, and this feedback from volunteers proved informative in shaping subsequent revisions (see below).

3.2.3 Pilot data analysis

Analysis of pilot data was carried out by hand. Numerical data generated by forced-choice and Likert-type answers were analysed at group level, and open responses were read for themes. After each pilot a brief report was compiled and discussed with two supervisors. Analysis of the pilot data, plus the handwritten notes made during pilot discussions, informed two sets of revisions to the questionnaire. The main revisions after Pilot Version 1 entailed refining and expanding definitions of practice strategies, providing scaled (rather than 'yes/no') response categories to two questions, and adding a new question to examine the stage at which memorisation is considered to occur (in relation to learning). The main revisions after Pilot Version 2 were to remove or amalgamate superfluous questions (where responses overlapped) and to revise the question order. The 'knowledge acquisition' section was substantially expanded in order to identify as many factors in the development of pianists' learning as possible. Open questions were added to investigate personal preferences and perceived skill and effectiveness. In addition, 'memorise' was changed to 'learn and memorise' throughout the questionnaire, in order to capture all aspects of a process that appeared to be conceived of differently by different respondents.

3.2.4 Ethics

On completion of the final draft of the questionnaire, a completed ethics checklist was submitted to the University of Edinburgh Arts, Culture and Environment Research and Ethics Committee. Following discussion with conservatoire personnel, it was subsequently decided to offer a prize draw and to administer the survey online, rather than in person or by post as proposed in the original submission. A revised checklist was submitted to the committee and approved.

3.2.5 Recruitment procedure

Seven UK conservatoires were contacted, either in person or in writing, and key personnel (heads of department or senior research staff) at six of these institutions agreed to facilitate recruitment for the study. These contacts, or their administrators, then received a recruitment email, which they forwarded to their student group or, in one case, posted on the college intranet. The recruitment email was sent to 927 students across five colleges. Of these, 377 were identified by four of the colleges as being piano students. The total figure also included all 550 students studying piano at a fifth college, either as a first or second study. A sixth college posted the link via intranet and did not provide a total figure for the number of piano students at their institution. The recruitment email and intranet posting contained a weblink to the questionnaire survey site. As an incentive, the subject-line of the email indicated that respondents could win £20 and that completion of the survey would take 20 minutes. Respondents were not required to supply personal or college details, although email addresses were collected from those who opted in to the prize draw. The survey was online for two months, during which time two follow-up emails (again containing the weblink to the questionnaire) were sent, approximately ten days and three weeks after the initial email invitation.

3.2.6 Full and partial completion of survey

Thirty six respondents completed the entire questionnaire. Sixty six respondents began the survey and completed the first three questions; 27% of these respondents had dropped out by Question 9, and there was a steep dropout of a further 15% of the original group at the open question (Question 10). The questionnaire was thus completed in full by 55% of those who began, and the data from these 36 respondents are reported here. The average time taken to complete the whole questionnaire was 25 minutes (range 11-58 minutes).

3.2.7 Participants

Thirty six piano students from six UK conservatoires completed the questionnaire in full. Of these, 19 were undergraduates (years 1- 4), 16 were postgraduates (years 1-4), and one was a continuing education student. Thirty three respondents were first-study pianists, one a first-study repetiteur, and two studied piano as a second instrument (of these, one was first study brass and one was first study woodwind).

3.2.8 Materials

An online version of the questionnaire was created using Survey Monkey (http://www.surveymonkey.com/). A weblink was included in the body of the recruitment email, meaning that the survey could be accessed directly from any computer without a password. While this meant that respondents could, theoretically, respond to the survey more than once, it was anticipated that in practice the compulsory open question, and the length of the questionnaire, would preclude students from doing so. In order to enter the prize draw respondents had to complete the questionnaire in full.

3.2.9 Survey design

The questionnaire was structured around five key questions (based on the five topics set out in 3.1):

1. How did respondents conceive of learning and memorising?
2. In what order did respondents' most recent learning and memorising occur?
3. How frequently did students adopt recommended strategies and techniques?
4. To what extent were different learning contexts and types of activity perceived to influence the development of personal practice strategies?
5. What was the relationship between strategy choice and self-perception of skill and ease?

Each of the five key questions was probed with mixed question types. Twenty-eight questions were used, consisting of a mixture of 11 Likert-type scales (all required), 8 forced-choice questions (all required) and 9 open questions (2 of which were required, 3 of which were filtered and 4 of which were optional). Of the total 28 questions, 5 were optional, 21 were required for all respondents and a further 2 were required for filtered respondents (Figure 3.2).

3.2.9.1 Validity and aims

The ordering and style of questioning was designed to avoid priming and to minimise social desirability bias (Bryman, 2012: 228) - and thus to explore possible discrepancies between what respondents said they knew, what they said was important, and their actual practice habits. The first section asked respondents to examine their own conceptions of learning and memorisation, and in particular to think about the mental images and procedural knowledge that they believed were required for successful learning and memorisation. The aim was to probe implicit attitudes that might inform responses to subsequent questions and to provoke introspection about the aims of practising. This led into detailed questions about personal strategy use, deliberately asked in a number of ways. Potentially sensitive questions about the effectiveness of strategy choice were placed in the middle and towards the end of the questionnaire, on either side of a substantial section examining a variety of contexts in which knowledge might have been acquired (Figure 3.2).

No.	Question	Type (items)	Details
4	Do you think that there is a difference between learning and memorising?	Forced (Yes/No)	
5	If you answered 'yes' to question 4, how would you describe the difference?	Open	
6	When do you feel that you have *learnt* a piece (or a section of a longer piece)?	3-point scale (8)*	Figure 3.3
7	When do you feel that you have *memorised* a piece (or a section of a longer piece)? * plus optional open description of 'other' ways of knowing	3-point scale (8)*	Figure 3.3
8	Think of the piano piece you most recently memorised from scratch. You must have used a written score to begin with and reached the point where you could play fluently from memory. Which of the following statements best reflects the way you worked?	Forced (3 options)	Figure 3.4
10	Think of the piano piece you most recently memorised from scratch to performance standard. In other words it must be a piece which you had never played before, and you must have learnt it from a written score to a standard where you could play it fluently from memory - in front of someone else, incorporating dynamic and expressive markings, at tempo. Briefly list everything you did to learn and memorise it, showing the order in which you did things.	Open	
9	Which of the following strategies do you use to work on an unfamiliar piano piece?	5-point scale (25)	Table 3.2
11	Have you ever been advised to use the following strategies? (it doesn't matter if you actually use them or not!)	Forced (Yes/No) (25)	Table 3.2
3	Does your college teach memorisation skills?	Forced (Yes/No)	
15	Classes at your music college: how much has each of the following influenced the way you learn and memorise piano music?	5-point scale (9)*	Table B.8
16	Classes before music college (eg at school or junior college): [as above]	5-point scale (9)*	Table B.8
17	Classes outside your college (eg holiday courses or classes provided by another institution): [as above]	5-point scale (9)*	Table B.8
18	Individual piano tuition at college: [as above]	5-point scale (9)*	Table B.8
19	Individual piano tuition before college: [as above]	5-point scale (9)*	Table B.8
20	Group sessions: [as above]	5-point scale (5)*	Table B.8
21	Other musical activities: have your experiences of playing other instruments, singing, or playing different styles of music influenced the way you learn and memorise piano music?	5-point scale (5)*	Table B.8

22	Informal learning: you may have developed your ideas outside classes, either deliberately or without thinking about it. How much has each of the following influenced the way you learn and memorise piano music?	5-point scale (4)*	Table B.8
25	I would be interested to know about your favourite ways of learning and memorising: what do you most enjoy doing?	Open	
26	What do you least enjoy doing?	Open	
27	Who taught you to work as described above, and how did they teach you?	Open	
28	Would you like to add any further comments?	Open	
	* plus option 'I have never done this'		
12	Do you believe that you use the most effective methods for learning and memorising piano music?	Forced (Yes/No)	
13	According to your last answer, you do not believe that you use the most effective methods for learning and memorising piano music. Describe what you think you ought to do differently!	Open	
14	What stops you from working in ways you believe to be more effective?	Open	
23	How effective do you feel you are at memorising piano music? Please try to be as honest as possible, without being modest or boastful (!)	Forced (7 options)	Table 3.6
24	Which of the statements below best describes your attitude to memorising piano music?	Forced (7 options)	Table 3.6
1	Which year are you in?	Forced (9 options)	
2	What instruments/voice do you study? (Main study, second study)	Open	

Colour coded key, showing categorisation of questions around 5 key questions.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

How did respondents conceive of learning and memorising?	To what extent were different learning contexts and types of activity perceived to influence the development of personal practice strategies?
In what order did respondents' most recent learning and memorising occur?	What was the relationship between strategy choice and self-perception of skill and ease?
How frequently did students adopt recommended strategies and techniques?	Participant details.

Figure 3.2: Figure to show survey questions, giving number, content & type, and categorisation around the 5 key research questions.

3.2.9.2 Conceptions of learning and memorising

Four questions were designed to find out about students' own conceptions of learning and memorising (Figure 3.2). A forced-choice question examined whether students conceived of learning and memorising as two distinct processes, or as one integrated process. Students were simply asked to state whether or not they believed that a distinction could be made. Respondents who had stated that there was indeed a difference between learning and memorising were then asked to describe, in their own words, what each process entailed. Two Likert-scaled questions asked all respondents to assess how important eight 'ways of knowing' were for their sense of having learnt, or having memorised, a piece of music.

3.2.9.3 Frameworks for learning and memorising

Two questions examined respondents' most recent learning and memorisation of a previously unknown piece (Figure 3.2). The aim was to characterise the process as either

1. Integrated (memorising and learning takes place concurrently)
2. Two-stage (learning to play the material takes place first and memorising occurs once the material has been learnt)
3. Prior memorisation (the process adopted by NBO, in which material is memorised before learning how to play) (Figure 3.1).

3.2.9.4 Adoption of recommended techniques

Two questions were designed to find out which strategies and techniques students were advised to use and how often each of these was reportedly implemented. In order to find out which techniques were being recommended, students were presented with a list of twenty-five techniques and asked whether they had ever been advised to use each of them. In order to find out how often these techniques were reportedly implemented, students were asked to rate how frequently they adopted each of the listed techniques (Figure 3.2).

3.2.9.5 Contexts for knowledge acquisition

Thirteen questions examined sources of learning. A forced choice question at the start of the questionnaire asked whether memorisation skills were taught at the current college, and towards the end of the questionnaire four open questions were used to collect descriptions about preferred methods of learning and memorising, and how these had been acquired. In a substantial intervening section, eight Likert-scaled questions assessed levels of participation in a variety of formal and informal musical and training activities and examined the extent to which each activity and context was perceived as influential (Figure 3.2).

3.2.9.6 Skill, confidence and strategy choice

Five questions examined ways in which students experienced the learning and memorisation process. A forced choice question asked whether students believed their chosen strategies to be optimal and those who did not were asked for open descriptions of what they thought they should change, and why they did not make these changes. Two Likert-scaled questions examined how effective and effortful respondents considered their own approach to be (Figure 3.2).

3.2.10 Data analysis

The intention of the survey was to explore attitudes and experiences within an elite group of learners and to compare the findings with the participant observation study of a smaller, similar group - not to generalise the findings to a wider population. Thus it was not considered to be a drawback that, in common with many online surveys (Bryman, 2012: 675), a response rate could not be accurately calculated because sample size could not accurately be determined (see 3.2.5 for details). The survey did not measure whether respondents represented particular types of student within the surveyed population, although the range of responses across year-groups, and in answer to questions concerning confidence and skill, suggests that respondents were (at least to some extent) representative of a cross-section of the student body.

3.2.10.1 Quantitative data analysis

Firstly, numerical data generated by forced-choice and Likert-type answers were explored in descriptive terms through tabular analysis (see Figure 3.2 for question content). Answers to forced choice questions were tabled numerically. For comparison of Likert-scaled ratings:

a. Qs 6 & 7 scaled ratings of 'ways of knowing' were categorised as either 'essential' or 'non-essential' The category 'non-essential' combined the responses 'desirable' and 'not necessary'.
b. Q 9 scaled ratings of strategy adoption were categorised as 'frequently adopted' ('always' and 'often' responses) or 'infrequently adopted' ('rarely' and 'never' responses). Analysis at whole-group level was used to make general comparisons between the number of respondents who reported being advised to use each strategy (Q11) with the number of respondents who reported adopting it frequently ('always' or 'often') or infrequently ('rarely' or 'never') (Q9). This analysis did not take into account whether or not each respondent implemented the strategies they had been advised to use, or used strategies that they had reportedly not been advised to use (both of which factors do contribute to the data); rather, it examined, at group level, how frequently each strategy was reportedly adopted in relation to the frequency at which it was reportedly recommended (Table 3.2).
c. Qs 15-22 scaled ratings of influence were categorised as 'strongly influential' ('profoundly' or 'a lot' responses) (Table B.8) or 'less influential' ('moderately', 'a little' or 'not at all' responses).

3.2.10.2 Qualitative data analysis

Open responses provided rich qualitative data about the actual practice habits of the respondents and required treatment before this data could be compared with the quantitative findings. Thematic analysis was used to analyse responses to open questions (see Figure 3.2 for question content). These responses were read for themes, categories were developed according to the themes identified, and the responses were tabled by allocation to a category.

a. Q 5: Thematic analysis was used to develop five categories of learning and four categories of memorising. The responses were then allocated to these categories (Table B.1 and Table B.2 in Appendix B).
b. Q 6 (optional open description of 'other' ways of knowing that contribute to a sense of having learnt music): three categories were developed, and the responses allocated to these categories (Table B.3).
c. Q 7 (optional open description of 'other' ways of knowing that contribute to a sense of having memorised music): two categories were developed, and the responses allocated to these categories (Table B.4).
d. Q 10 responses: Descriptions of mental practice techniques included in the open descriptions of recent learning were tabulated (Table B.5).
e. Q 10 responses: 3 categories were derived from a previous, closed question (Q8). The author and one supervisor independently reviewed the statements given in the open descriptions and coded them according to these three categories. They then compared and discussed their decisions in order to agree on final codings (see Table B.6).
f. Q 27: Open descriptions were read for themes and three categories were developed. Responses were allocated to these categories (Table B.7).
g. Q 13: Three themes were identified in the responses and statements were categorised according to these themes (Table B.9).

h. Q 14: Three themes were identified in the responses and statements were categorised according to these themes (Table B.10).
i. Qs 25 & 26: Responses were categorised and tabulated according to 4 types of activity: physical practice techniques (Table B.11), mental imagery techniques (Table B.12), techniques for understanding and memorising (Table B.13) and general preferences (Table B.14).

3.3 Results

Some respondents clearly distinguished between the processes of learning and memorising while others did not; different respondents' conceptions of the two processes sometimes overlapped. Mental imagery tended to be considered more essential for memorising than for learning, but auditory imagery was considered to be an essential part of both processes (by 89% & 81% respondents respectively). Four frameworks defining the sequence of events in the learning and memorising process were identified (two-stage, automatically integrated, deliberately integrated and prior memorisation), but there was no consistent relationship between the type of process adopted and reported conceptions of learning and memorising; in addition, some respondents appeared to give inconsistent reports about which process they had most recently adopted. Despite demonstrating a widespread awareness of mental imagery and memorisation techniques, students were less likely to adopt them than to adopt recommended physical practice strategies. Memorisation training was not consistently available, and where it did exist was rated as the least influential of all forms of training. Overall, instrument-related learning was much more influential than strategy training, and explicit expert advice was highly valued. There was widespread dislike of effortful memorisation. Respondents who were dissatisfied with the methods they adopted were more likely to rate themselves as below-average memorisers, and to find memorisation more effortful, than peers who were satisfied with their choice of methods.

3.3.1 Conceptions of learning and memorising

> I can't really specifically say at what point I memorise a piece as it tends to happen as I learn. In pieces where the intention is ultimately to perform from memory, the two seem to be inseparably linked.

Twenty nine pianists (81%) stated that learning and memorising were different and seven pianists (19%) stated that there was no difference. Analysis of open responses found that while some respondents clearly distinguished between the two processes, different respondents' conceptions of the two processes sometimes overlapped. In scaled ratings of eight factors that contribute to learning and memorising, auditory imagery was ranked at group level as the most important factor in both processes. For some pianists, memorising (as distinct from learning) was specifically associated with an increased reliance on motor imagery and (less often) on structural and notational imagery.

3.3.1.1 Open descriptions of learning and memorising

Several respondents described learning as an integrated physical and mental process while a similar number (of different respondents) described memorisation as such. Other respondents expressed the view that internalising, 'owning' or achieving emotional connection with the music was integral to one or other process.

Learning

The majority of respondents described learning as the acquisition of procedural knowledge, while others described it as understanding content or as a process combining both these factors (Table 3.1; full responses in Table B.1 & Table B.2 in Appendix B). Twelve pianists (43%) described learning as the developing the ability to play the notes, often with specific reference to reading from the score -

‘being able to play fluently while glancing at the music for frequent reminders’, ‘reading the notes and playing them’. Six pianists (21%) respondents described learning as a process of understanding: ‘understanding what you play, what is behind the notes and how to convey this’, ‘understanding the piece - perhaps through theory’. Five pianists (18%) described learning in general terms such as ‘becoming familiar with the music’. Three pianists (11%) specifically described learning as a process integrating both understanding content and being able to play; interestingly, 2 pianists (7%) described learning as memorising.

Table 3.1: Table to show categories developed from open descriptions of learning (n=28) and memorising (n=27)

Learning is…	**Memorising is…**
Learning to play: procedural knowledge (n12)	Removal of score: a subset of learning (n9)
Understanding content/intention (n6)	Internalising/automating (n8)
General process of familiarisation (n5)	Mental imagery (n5)
Combined mental & physical knowledge (n3)	Combined mental & physical knowledge (n4)
Memorising (n2)	

Memorising

Two distinct, although not necessarily mutually exclusive, views of memorising were apparent. Several respondents described memorising as internalising, or automating, the music, while others expressed rather the opposite view and described a sense that memorisation relied on conscious mental imagery. Memorising was also described as the removal of the score and as a combination of physical and mental knowledge. Nine pianists (35%) described memorising simply as the process of ‘not having to rely on the printed page anymore’, ‘just learning to play the notes without the score‘, ‘the next step’ or ‘a subset of learning’. Eight pianists (30%) described memorisation as internalising the music or automating the process of playing. For example:

> doing it without thinking
>
> put everything into brain and play automatically

> being able to do something without really thinking about it or paying much attention to what you are doing.

> almost becoming the piece itself.

Five pianists (18%), somewhat in contrast, specified that memorisation was about clarity of mental imagery, in particular, auditory and structural imagery:

> Being able to hear the music in your head from start to finish.

> Knowing in your mind, and your ear where your fingers should go, without having to demonstrate by playing.

> Finding a way to know how the piece is built, to have the plan in your head.

> Learning the form and contours of a piece.

Four pianists (15%) emphasised that memorisation required a combination of mental and physical knowledge:

> Knowing the score well enough to be able to review the work in your mind without the score *and* being able to play it at the instrument without the score successfully.

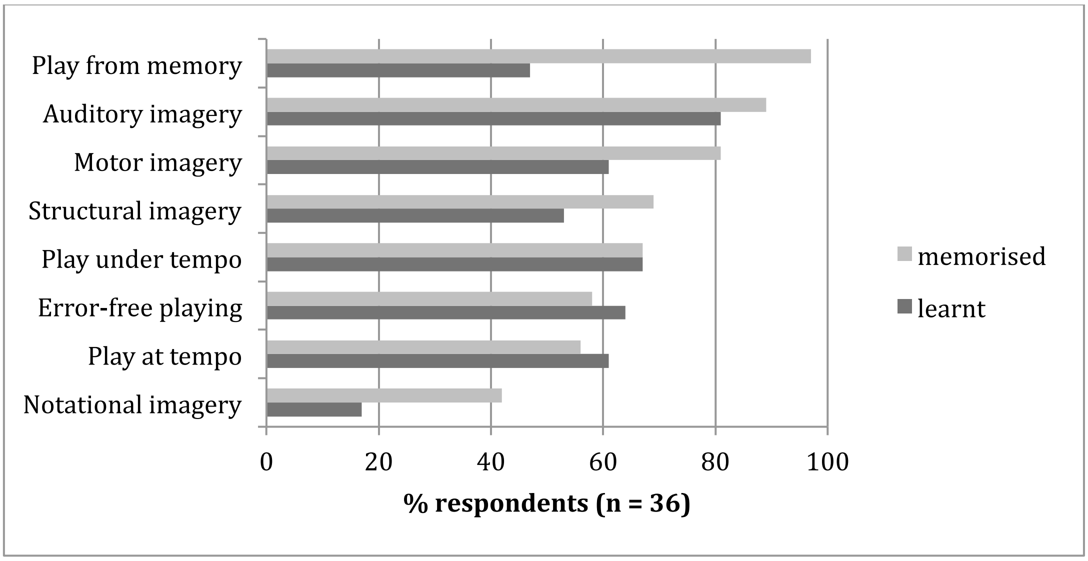
This last group described memorisation in similar terms to those used by other respondents to describe learning.

3.3.1.2 Scaled ratings of eight 'ways of knowing'[1]

The most striking finding was that auditory imagery was the item rated 'essential' for both learning and memorising by the greatest number of respondents (Figure 3.3). Auditory imagery was rated as essential for learning (81%) and for memorising (89%) more often than any other type of imagery, and more often than playing (when the item 'play from memory' was excluded[1]). For memorisation, the four types of imagery listed were

[1] Playing from memory was rated essential for learning by 17 pianists (47%) and as 'essential' for memorising by 35 pianists (97%). This item, however, was considered to be of a more general nature than the other listed items and was excluded from subsequent analysis.

rated ‘essential’ in the following order: auditory imagery (89%), motor imagery (81%), structural imagery (69%), notational imagery (42%).



Way of knowing	Learning rating mean [SD]	Memorising rating mean [SD]
Play from memory	2.36 [0.68]	2.97 [0.17]
Auditory imagery	2.78 [0.48]	2.89 [0.32]
Motor imagery	2.58 [0.55]	2.81 [0.40]
Structural imagery	2.47 [0.61]	2.67 [0.53]
Play under tempo	2.61 [0.60]	2.56 [0.69]
Error-free playing	2.64 [0.49]	2.58 [0.50]
Play at tempo	2.61 [0.49]	2.44 [0.69]
Notational imagery	1.78 [2.17]	2.17 [0.81]

Figure 3.3: Bar chart to show comparison between % respondents who rated 8 ways of knowing as ‘essential’ aspects of memorising with % respondents who rated the same 8 ways of knowing as ‘essential’ aspects of learning, with table to show mean ratings [SD] on a scale of 1-3 (where 1= not necessary, 2=desirable, 3=essential).

The main differences between ‘learning’ and ‘memorising’ were contained in the ratings of imagery items (Figure 3.3). Overall, mental imagery items were rated ‘essential’ for memorising by an average of 25 pianists (69%), and for learning by an average of 19 pianists (53%). For some respondents, memorising was characterised by an increased reliance on motor, structural and visual forms of mental imagery (compared with learning). With the item ‘play from memory’ removed from the analysis, ways of playing were on average rated as essential for learning by 23 pianists (64%) and for memorising by 22 pianists (61%).

3.3.2 Frameworks for learning and memorising

The sequence of events in the learning and memorisation process was assessed within the context of three possible frameworks: a two-stage approach, in which learning to play the notes occurred before the material was memorised; an integrated approach, in which memorisation occurred during learning; and the 'prior memorisation' approach advocated by NBO (see Figure 3.1). Analysis of open responses found that the 'integrated approach' included both deliberate attempts to memorise from the outset and instances where memorisation appeared to occur automatically. Some respondents appearing to give inconsistent reports about which approach they had most recently adopted. Respondents spontaneously reported recent uses of a variety of mental imagery strategies.

3.3.2.1 Forced-choice descriptions of recent memorisation

Twenty-two pianists (61%) selected the statement 'I memorised the music while I learned to play it' (integrated approach), 13 pianists (36%) selected the statement 'I learned to play the music before I memorised it' (2-stage approach) and one pianist (3%) selected the statement 'I memorised the music before I learned to play it' (prior memorisation approach). No consistent connection was observed between these responses and pianists' original statements that learning and memorising constituted two different, or one single, process (3.3.1). Of the 29 pianists who had stated that the two processes were different, 11 (38%) reported adopting a two-stage approach, 17 (59%) an integrated approach and one (3%) a prior memorisation approach. Of the seven who had stated that there was no difference between learning and memorising, three (43%) adopted a two-stage approach and four (57%) an integrated approach.

3.3.2.2 Open descriptions of recent memorisation

According to coded analysis of open descriptions, 22 pianists (61%) had adopted a 2-stage approach, 13 pianists (36%) an integrated approach, and one pianist (3%) a prior memorisation approach. There was no observable link between respondents' original statements that learning and memorising constituted two different, or one single, process (3.3.1) and these results. According to this analysis, of the 29 pianists who had stated that the two processes were different, 17 (59%) reported adopting a two-stage approach, 11 (38%) an integrated approach and one (3%) a prior memorisation approach. Of the seven who had stated that there was no difference between learning and memorising, five (71%) adopted a two-stage approach and two (29%) an integrated approach).

Open descriptions coded as 'two-stage'

Twenty-two pianists (61%) adopted a two-stage approach, in which learning to play the material came first and memorisation was a second discrete stage; here, irrespective of the extent to which memorising had occurred incidentally during the learning process, learning to play was described as one phase and memorising was specifically described as a second phase.

> I learnt the whole piece first. I then played a line at a time without using the music and when I had memorised that line I went onto the next line. I continued this until I learned the whole piece.
>
> (for further examples see Table B.6 in Appendix B)

Open descriptions coded as 'integrated'

Thirteen pianists (36%) described learning and memorising in an integrated manner – in other words, material was memorised as it was learned. In some cases this involved a deliberate attempt to memorise from the outset:

> I listened to a recording first to get a general idea of the piece. I then learnt the score at the piano, memorising fragments as soon as I started to play them. Once the notes memorised [sic] I could only play it at a slow tempo so I worked through the piece, increasing the tempo and beginning to incorporate dynamics and expressive markings …
>
> (for further examples see Table B.6 in Appendix B)

For others whose responses were coded as 'integrated', memorisation appeared to occur automatically (Hallam, 1997), and although memory reinforcement techniques were sometimes used for insecure passages, this did not appear to be conceived of as a separate second memorisation stage in the same way that it was for the 'two-stage learners', but rather as a reinforcement stage:

> Try to play through the piece to understand its over all structure. Practice slowly in sections. (hands separately where appropriate). By this stage, 90% of the memorisation is usually completed for me ... be aware of the sections in which my memory is not perfectly secure. Go to that section and memorise using several methods...
>
> (for further examples see Table B.6 in Appendix B)

Open descriptions coded as 'prior memorisation'

One pianist (3%) reported memorising the material prior to playing in answer to both the forced choice and the open questions:

> I played through the whole piece to have an overall view how does it sound like and what is the structure. Then I analyse the harmony and phrasing and try to learn it in small sections. Also, I incorporate all the sections together and try to play it from memory in faster tempo. Every time I practice, I try to apply the tempo/interpretation marks immediately.

3.3.2.3 Discrepancies between forced choice and open descriptions of approach adopted

Two different methods of questioning revealed discrepancies in responses; according to this analysis there was a disparity between the forced choice and open answers (Figure 3.4). When given a forced choice, 61% respondents defined their approach as integrated and 36% as two-stage, but when writing about their learning in their own words 36% described an integrated process and 61% described a two-stage process. This difference in results was due to nine pianists who reported using an integrated approach when given a forced choice but, in response to the open question, described a two-stage process.

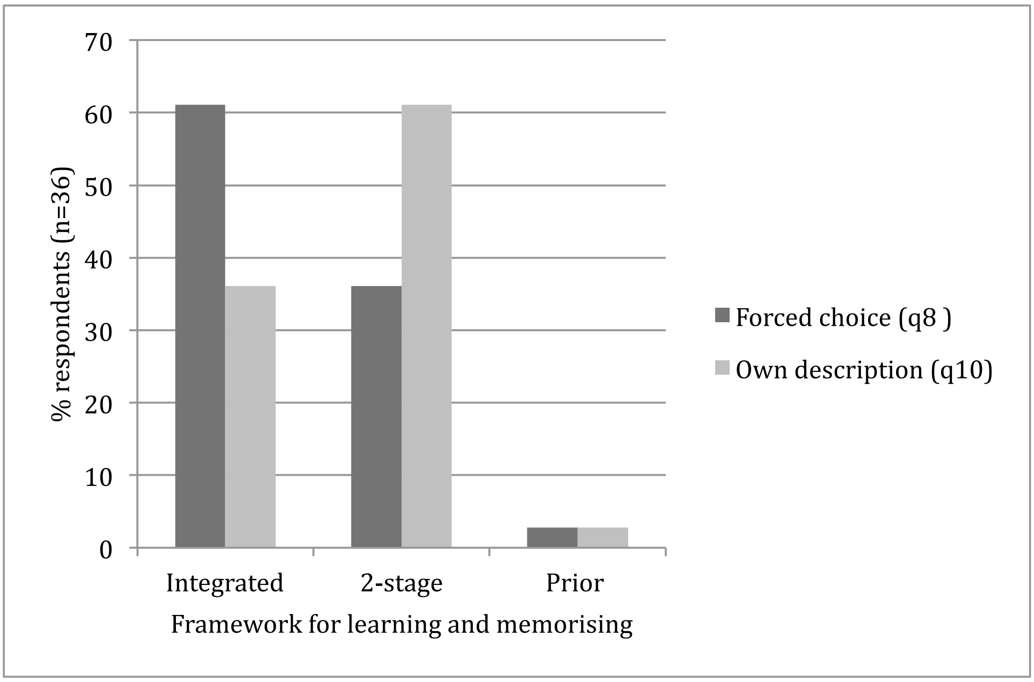


Figure 3.4: Discrepancies between forced choice and open descriptions of learning and memorising, in which 9 pianists (25%) reported using an integrated approach when given a forced choice but described a 2-stage process when writing about the process in their own words.

3.3.2.4 Descriptions of deliberate mental practice included in open descriptions of recent learning

Twenty four respondents (67%) incorporated references to deliberate mental strategies in open descriptions of their practice, including descriptions of auditory, visual, motor and structural imagery (see Table B.5 in Appendix B). Three respondents specifically referred to mental practice of their orientation on the keyboard – 'where the fingers should go'. Several respondents additionally described memorisation techniques that aim 'to get away from relying on muscular memory.' These included practising backwards, inducing memory confusion then trying to recover using visualisation, and playing one voice while memorising another. Five respondents reported using auditory models (recordings) during learning.

3.3.3 Adoption of recommended techniques

Respondents demonstrated a widespread awareness of mental imagery and memorisation techniques, but techniques most likely to be adopted, when they were recommended, all involved playing from the score at the piano (Table 3.2). Auditory imagery strategies were recommended more often than motor imagery strategies; auditory strategies were not adopted as often as teachers recommended, but motor imagery strategies were adopted more often than teachers recommended. Respondents were more likely to adopt the strategy of playing the whole piece from the score until memorised than to adopt the prior memorisation strategy, and were more likely to adopt recommended physical practice techniques than to adopt recommended mental imagery techniques or techniques for understanding and memorising. Respondents found that, even when they were aware of methods they believed to be more effective than the ones they used (Table B.9 in Appendix B), it was difficult to change habits, to use techniques that they found effortful or uninteresting, or to spend time working away from the piano (Table B.10 in Appendix B).

Table 3.2: Table to show the percentage of those respondents who stated that they had been advised to use each of 25 listed strategies for learning and memorising (N) who reported adopting each strategy frequently ('frequent adopters'), and showing mean rating [SD] on a 5-point adoption frequency scale (where 1=never and 5=always)

Strategy	% Frequent adopters (N)	Mean [SD]
Practise slowly	100 (35)	4.83 [0.45]
Sightread	100 (33)	4.56 [0.73]
Play whole piece from score until memorised	100 (22)	3.64 [1.17]
Practise sections + score	97 (30)	4.28 [0.97]
Practise hands separately	92 (36)	4.56 [0.84]
Listen to recordings	84 (31)	3.97 [0.94]
Practise sections - score	79 (33)	4.17 [1.08]
Imagine finger moves, sections + score	78 (18)	2.97 [1.48]
Practise using different rhythms	74 (34)	4.03 [0.94]
Play without score a.s.a.p.	72 (25)	3.25 [1.44]
Imagine sound, whole piece - score	72 (25)	3.50 [1.36]
Associate words, moods or images	71 (31)	3.81 [1.12]
Imagine finger moves, whole piece - score	67 (18)	2.78 [1.49]
Imagine sound, section + score	66 (32)	3.67 [1.33]
Imagine sound, section - score	66 (29)	3.64 [1.25]
Imagine finger moves, sections - score	59 (22)	3.06 [1.49]
Imagine sound, whole piece + score	59 (29)	3.39 [1.34]
Analyse	58 (33)	3.67 [1.01]
Imagine finger moves, whole piece + score	56 (18)	2.67 [1.69]
Listen to live performances	52 (29)	3.39 [0.87]
Sing parts	48 (31)	3.31 [1.12]
Practise on other surface	48 (21)	2.50 [1.28]
Improvise	38 (8)	1.83 [0.97]
Prior memorisation	32 (22)	2.61 [1.27]
Transpose	20 (10)	1.78 [0.87]

3.3.3.1 Techniques recommended

Physical practice techniques

Techniques most frequently recommended included practice techniques which are very widely taught from the first stages of learning - practising hands separately, playing slowly, using different rhythms, practising in sections without the score and sightreading at the piano (Table 3.2).

Mental imagery techniques

All auditory imagery techniques were recommended more frequently than all motor imagery techniques. On average, auditory imagery techniques were recommended to 29 respondents (81%) and motor imagery techniques to 19 respondents (53%). For example, 32 respondents (89%) stated that they had been advised to imagine the sound of a section with the score, while 18 respondents (50%) stated that they had been advised to imagine the finger movements of a section with the score (Table 3.2).

Techniques for memorising and understanding

33 respondents (92%) had been advised to analyse the score. 25 respondents (69%) stated that they had been advised to practise without the score as soon as possible. 22 respondents (61%) said that they had been advised to practice a whole piece from the score until memorised and 22 respondents (61%) that they had also been advised to do effectively the opposite – to memorise away from the piano before playing. Techniques for internalising material which require mental manipulation of the material were much less frequently recommended: 10 respondents (28%) had been advised to transpose and 8 respondents (22%) to improvise (Table 3.2).

3.3.3.2 Comparison of rates of recommendation with rates of adoption

Strategies most frequently adopted, in relation to the rate at which they were recommended, all involved playing from the score at the piano. The strategies of playing the whole piece from the score until memorised, playing slowly and sightreading were adopted by 100% of the number who had been advised to do so, playing sections with the score by 97% and playing hands separately by 92%. Two techniques were adopted surprisingly frequently in relation to rates of recommendation: playing the whole piece with the score until memorised (100%), and imagining finger movements in sections, with the score (78%). One technique – prior memorisation - was adopted very infrequently in relation to the rate of recommendation (32%).

Adoption of physical practice techniques

Listed physical practice techniques involving the score were all used frequently or 'sometimes' by all respondents, except in the case of one pianist (3%) who 'never' practised each hand separately and three pianists (8%) who 'rarely' practised sections without the score. Physical practice techniques tended to be very frequently adopted in relation to the rate of recommendation. At group level, only 3% of the number advised to sightread, practise hands separately or with different rhythms reported doing so infrequently; and only 12% of those advised to practise sections without the score did so infrequently (Table 3.2).

Adoption of mental imagery techniques

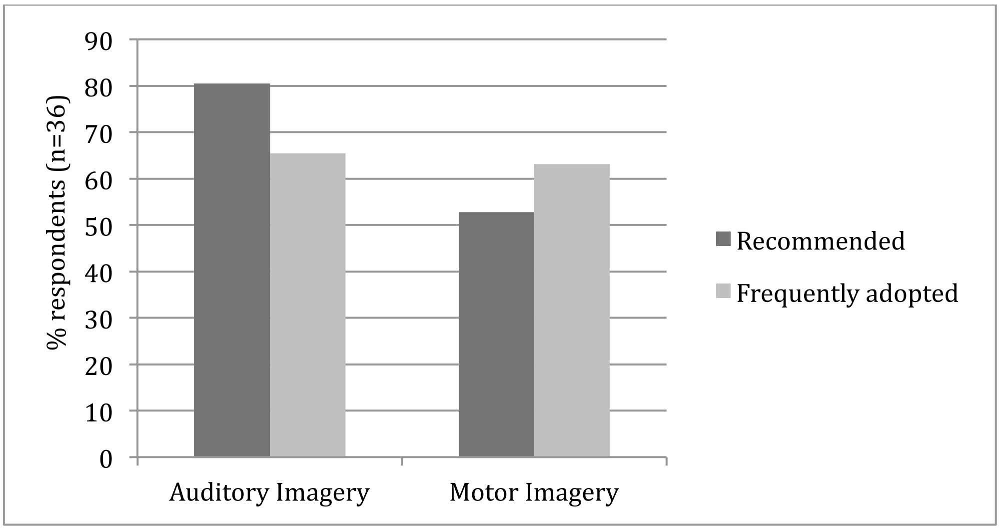
Six pianists (17%) reported frequent adoption of every mental imagery technique, and a seventh reported frequent adoption of every mental imagery technique except one – whether or not they had reportedly been advised to use the techniques; several mental practice techniques were reportedly adopted frequently by students to whom they had not been recommended. Three pianists (8%) reported infrequent adoption of every mental imagery technique.

The imagery technique most likely to be adopted, in comparison to the frequency at which it was recommended, was imagery of finger movements with the score in sections, with 78% of the number to whom it had been recommended adopting the technique. This is of interest as it was reportedly one of three imagery techniques least often recommended by teachers (Table 3.2).

Respondents were more likely to imagine the sound of the whole piece without the score than with the score: 72% of the respondents who stated they had been advised to imagine the sound of the whole piece without the score did so frequently, while 59% respondents who were advised to imagine the sound of the whole piece with the score did so frequently (Table 3.2).

Comparison of auditory and motor imagery adoption rates

On average, auditory imagery strategies were recommended more frequently than motor imagery strategies - but students adopted auditory strategies slightly less often that they were advised to, and adopted motor strategies slightly more often than they were advised to. On average, 81% respondents stated that they had been advised to use auditory strategies, and 66% of the number who had been advised to do so stated that they did so frequently. On average, 53% stated that they had been advised to use motor strategies, and 63% of the number who had been advised to do so stated that they did so frequently (Figure 3.5).



Strategies	Mean adoption rating [SD]
Auditory imagery	3.55 [1.31]
Motor imagery	2.87 [1.48]

Figure 3.5: Percentage of respondents to whom auditory imagery and motor imagery strategies were recommended compared with % respondents who reported adopting the strategies frequently, with table to show mean ratings [SD] on a 5-point adoption frequency scale (where 1=never and 5=always) (c.f. Table 3.2).

Adoption of techniques for understanding and memorising material

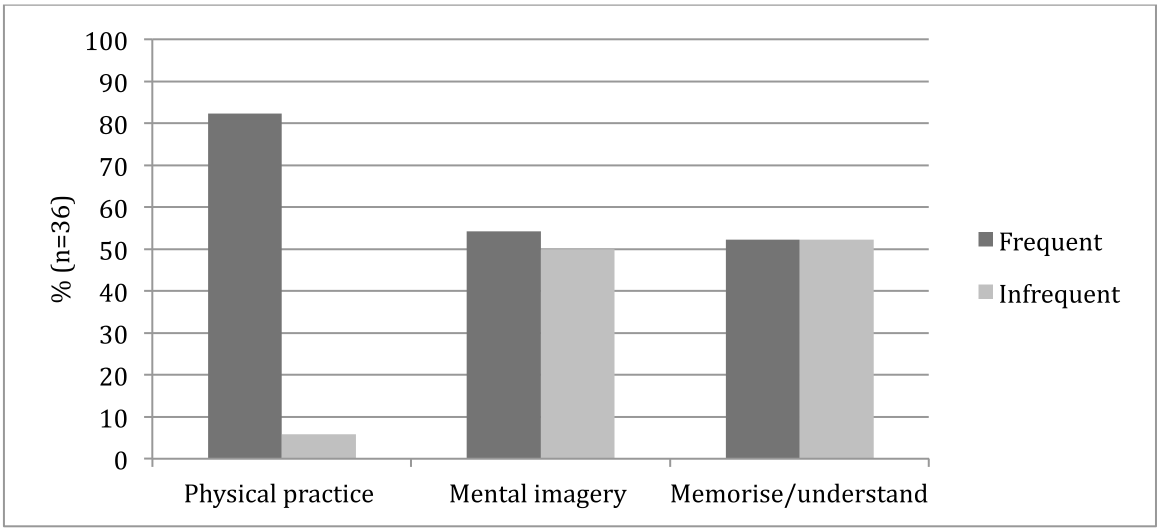
Respondents were more likely to adopt the strategy of playing the whole piece from the score until memorised than to adopt the prior memorisation strategy. Of the memorisation strategies listed, the most frequently adopted was practising the whole piece from the score until memorised; prior memorisation was least likely to be adopted. Both strategies were reportedly recommended to 22 students (61%). Playing from the score until memorised was frequently adopted by 100% of the number of respondents who were advised to use it (22 students), but the prior memorisation strategy was reported to be frequently adopted by only 32% of those advised to use it (7 students) (Table 3.2). The most commonly adopted strategy for understanding and memorising material was listening to recordings, with 84% of those who had been advised to do so using this strategy frequently

(26 students). 58% of those who had been advised to use analysis reported doing so frequently (19 students).

Overall comparison of adoption of physical practice techniques, mental imagery techniques and techniques for understanding and memorising

Averaged over the whole group, respondents were more likely to adopt recommended physical practice techniques than to adopt recommended mental imagery techniques or techniques for understanding and memorising. Recommended physical practice techniques were very unlikely to be adopted infrequently ('rarely' or 'never'), but other recommended techniques were much more likely to be adopted infrequently (Figure 3.6).

On average, physical practice techniques were recommended to 34 respondents (94%); of these, 28 respondents (82%) adopted the techniques frequently and 2 respondents (6%) adopted them infrequently. On average, mental imagery techniques were recommended to 24 respondents (67%); of these, 13 respondents (54%) adopted the techniques frequently and 12 respondents (50%) adopted them infrequently. On average, techniques for memorising and understanding were recommended to 23 respondents (64%); of these, 12 respondents (52%) adopted the techniques frequently and 12 respondents (52%) adopted them infrequently.



Strategies	Mean adoption rating [SD]
Physical practice	4.37 [0.92]
Mental imagery	3.21 [1.44]
Memorise/understand	3.07 [1.32]

Figure 3.6: Bar chart to show % respondents frequently/infrequently adopting recommended physical practice techniques (average responses to 6 listed techniques), mental imagery techniques (average responses to 8 listed techniques) and memorisation/understanding techniques (average responses to 11 listed techniques), with table to show mean ratings [SD] on a 5-point adoption frequency scale (where 1=never and 5=always) (for listed techniques see Table 3.2).

3.3.4 Contexts for knowledge acquisition

Memorisation training was not consistently available. Analysis of scaled ratings found that a range of factors influenced respondents' approach to learning and memorising; explicit instruction and individual lessons were considered more influential than class teaching and overall, instrument-related learning was considered most influential, while strategy training was least influential. Memorisation training was the least influential of all types of training (Table 3.5). Respondents recognised that both explicit and implicit learning influenced their behavior; they felt that they were influenced more by experts than by peers.

3.3.4.1 Memorisation training

Twenty-three respondents (64%) stated that memorisation was not taught at their college, five respondents (14%) stated that memorisation was taught at college and eight (22%) did not know. In open descriptions of skill acquisition, 9 pianists (25%) commented on the lack of memorisation training; this was not necessarily reported negatively, and there was a sense that some respondents did not feel the need for explicit training (Table B.7 in Appendix B).

> … they are just things that are either simply logical or that you pick up from various experiences of learning as you go.

> It has been a LONG time since anyone has advised me on memorising. At least 10 years.

> … in my experience these things [learning/memorising techniques] are not given much mention.

> I wasn't really taught how to learn or memorise, I'm just making it up as I go along

> I pretty much taught myself how to memorise. Nobody really ever taught me specific methods.

Other students had been taught techniques explicitly and some had developed their own methods based on reading. For example,

> I used to be terrible at memorising and I figured that the faster I stop depending on the score, the more secure I am when performing. For this purpose I had to stop memorising by endless repeating and remember specific details the first time I look at the score. A tutor at college once showed me how to memorise away from the piano, which was very helpful. I read about one of the great pianists that he never moves on to the next page until the current one is perfect.

3.3.4.2 Analysis of scaled ratings

Of 49 listed items, explicit instruction was rated as the single most influential factor, with 22 respondents (61%) reporting that they were strongly influenced by specific instruction from their college piano tutor (Table 3.3). A range of other factors contributed to the approach adopted (full results in Table B.8 in Appendix B); to explore the data, results were grouped by context (Table 3.4) and by type (Table 3.5).

Table 3.3: Table to show % respondents who stated that their approach to learning and memorising had been strongly influenced by a sample of listed activities (N = participants), and showing mean rating [SD] on 5-point influence scale (where 1= not at all and 5=profoundly).[a]

Activity	% strongly influenced	(N)	Mean	[SD]
Explicit instruction (college piano tutor)	61	(36)	3.68	[1.04]
Individual piano lessons at college	58	(36)	3.79	[1.20]
Individual piano lessons pre-college	56	(34)	3.32	[1.49]
Practice strategies training outside college	50	(10)	0.82	[1.53]
Individual lessons, other	48	(29)	2.74	[1.68]
College piano tutor, implicit	47	(36)	2.85	[1.69]
Listening to expert performer speaking	47	(34)	3.06	[1.46]
Playing/singing informally	47	(30)	2.74	[1.62]
Analysis training (college piano tutor)	46	(24)	2.12	[1.90]
Explicit instruction (pre-college tutor)	44	(34)	3.29	[1.31]
Tutorials outside college	42	(12)	1.00	[1.63]
Choral singing	41	(34)	2.82	[1.38]
Analysis classes at college	39	(33)	2.65	[1.43]
Watching a masterclass	38	(32)	2.74	[1.58]
Participating in a masterclass	35	(31)	2.44	[1.62]
Watching a group lesson	26	(23)	1.44	[1.58]
Participating in a group lesson	22	(23)	1.59	[1.60]
Doing what other students say they do	14	(36)	2.59	[0.89]
Aural classes at college	13	(32)	2.21	[1.17]

[a] For table of results for all listed activities see Table B.8 in Appendix B.

*General rating; individual aspects (explicit instruction, analysis training, etc.) were also listed separately.

Individual training more influential than class training

When results were grouped by context (e.g. individual piano tuition, group contexts, classes at/outside/before college), individual tuition was found to be more influential than class teaching, with college piano tuition rated as the most influential context overall (Table 3.4). At college, on average, all listed activities included in individual piano tuition strongly influenced 53% participants and class teaching activities strongly influenced 24% participants. Ratings varied across types of classes. For example, college analysis classes strongly influenced 33% participants and college aural classes, 13% participants. Classes at college were slightly less influential than classes before or outside college (Table 3.4). Two classes outside college were rated as the most influential of all classes (practice strategies training and tutorials on practicing/learning/memorising) (Table 3.3).

Table 3.4: Table to show % participants (N) who reported that each training context had strongly influenced their approach to learning and memorising, and showing mean rating [SD] on 5-point influence scale (where 1= not at all and 5=profoundly) (key to categorisation).

(Key)	Context	% participants strongly influenced (N)	Mean	[SD]
(1)	College piano tuition	53 (30)	2.79	[1.78]
(2)	Other styles/instruments/voice	43 (30)	2.63	[1.60]
(1)	Pre-college piano tuition	38 (32)	2.75	[1.54]
(3)	Group contexts	34 (29)	2.25	[1.67]
(4)	Outside college classes	27 (11)	0.79	[1.36]
(4)	Pre-college classes	25 (16)	1.18	[1.52]
(5)	Indirect learning	24 (33)	2.40	[1.20]
(4)	College classes	24 (21)	1.57	[1.57]

Key to categorisation of responses:

(1) Individual lessons; Aural/analysis training by piano tutor; Doing what you think tutor does, without explicit instruction; Doing what your tutor specifically tells you to do.

(2) Individual lessons on another instrument or voice; Choral singing; Playing/singing informally; Improvising.

(3) Being taught/watching others being taught in a masterclass; Listening to an expert performer speaking; Being taught/watching others being taught in a group lesson.

(4) Psychology of music course; Lectures/tutorials on practising/learning/memorising; Aural/analysis/music theory classes; Memorisation/learning strategies training session(s); Practice strategies training session(s).

(5) Doing what other students say they do; Reading about what professionals do; Taking written advice.

Instrument-related learning more influential than other types of training

When results were categorised according to training type (e.g. individual tuition on any instrument or voice; analysis; aural; music theory, etc.) participation levels and influence ratings were found to be highest for instrument-related activities and lowest for strategy training (Table 3.5). The most influential activities related to explicit involvement with an instrument or voice, either directly - via individual tuition, students' own playing or singing in other contexts - or indirectly - through observation of others being taught, listening to experts speaking, or doing what other pianists were assumed to do (Table 3.5). The one exception to this finding was that analysis training strongly influenced an average of 34% participants (here, the influence of analysis training by a college tutor was responsible for the high overall rating (Table 3.3 and Table B.8 in Appendix B).

Individual lessons on any instrument or voice were considered to be the most influential type of training overall, strongly influencing an average of 55% participants (Table 3.5). Other formal and informal types of music making, including other styles and contexts (such as playing in bands, choral singing, improvising) strongly influenced an average of 39% participants. Analysis training was considered to be the most influential type of generic music skills training, strongly influencing 34% participants. Music theory training strongly influenced average 28% participants, and aural training 23%. Memorisation training was the least influential of all listed activities; one pianist (4% participants) was strongly influenced.

Table 3.5: Table to show % participants who reported that each type of training, averaged across all contexts, had strongly influenced their approach to learning and memorising, and showing mean rating [SD] on 5-point influence scale (where 1= not at all and 5=profoundly) (with key to categorisation).

Key	Training type	% strongly influenced (N)	Mean	[SD]
(1)	Individual tuition (any instrument, voice)	55 (33)	3.28	[1.52]
(2)	Explicit advice (verbal, written)	45 (33)	2.98	[1.46]
(3)	Other music making (informal, improv, choral)	39 (31)	2.60	[1.57]
(4)	Analysis (classes, tutor)	34 (25)	2.05	[1.68]
(5)	Implicit learning (tutors/peers, expert opinion)	34 (35)	2.74	[1.39]
(4)	Tutorials on practising/learning/memorising	32 (14)	1.08	[1.57]
(6)	Group and master classes	31 (27)	2.05	[1.67]
(4)	Practice strategies training	30 (11)	0.86	[1.45]
(4)	Music theory classes	28 (27)	2.15	[2.15]
(4)	Psychology of music course	27 (10)	0.74	[1.30]
(4)	Aural (classes, tutor)	23 (24)	1.81	[1.58]
(4)	Lectures on practising/learning/memorising	18 (13)	0.86	[1.28]
(4)	Learning strategies training	13 (10)	0.70	[1.22]
(4)	Memorisation training	4 (9)	0.53	[0.98]

Key to categorisation of responses

(1) Piano lessons (at & pre-college); lessons on other instruments or voice.

(2) Doing what piano teacher specifically tells you to do (at & pre-college); taking written advice.

(3) Choral singing; playing or singing informally (e.g. in bands); improvising.

(4) At, outside & pre- college.

(5) Doing what you think your piano tutor does (at & pre-college); doing what other students say they do; reading about what professionals do; listening to an expert performer speaking.

(6) Being taught/watching others being taught in a masterclass/group lesson.

Explicit/implicit learning from experts and peers

Explicit advice in the form of direct instruction from piano tutors and written advice strongly influenced 45% participants, and 34% participants stated that they were strongly influenced implicitly by doing what they thought - or what they were told - experts and peers did (Table 3.5). Experts were more highly valued than peers; 22 pianists (61%) felt that they were strongly influenced by explicit instruction from college piano tutors and 17 pianists

(47%) were strongly influenced by implicit learning from a tutor; five (14%) felt that they were strongly influenced by what other students said they did (Table 3.3). In a group context, watching others being taught was slightly more influential than being taught oneself.

3.3.5 Skill, confidence, satisfaction and strategy choice

Respondents varied in their attitudes towards activities such as analysis, repetitive practice, sightreading and learning new material, but analysis of open responses showed that there was widespread dislike of effortful memorisation (Tables B.10-B.14 in Appendix B). Thirty one pianists (86%) believed their memorisation ability to be average or above and 32 (89%) reported that memorisation involved some degree of effort (Table 3.6). Twenty seven pianists (75%) believed that the strategies they adopted for learning and memorising musical material were optimal ('satisfied' learners). Respondents who believed that their strategies were suboptimal (nine 'dissatisfied' respondents, 25%) were more likely to rate themselves as below-average memorisers, compared to their 'satisfied' peers. There was a tendency for dissatisfied respondents to rate memorisation as more effortful than satisfied learners.

3.3.5.1 Preference

Analysis of open responses showed that what some respondents enjoyed about learning and memorising, others disliked (Tables B.11 - B.14 in Appendix B). For example, although the most commonly reported source of enjoyment was playing slowly, two respondents disliked this; similarly, three reported that they enjoyed repetition while another four commented that they disliked it. The themes identified in this analysis were that respondents liked activities that felt easy and disliked feelings of effort, liked to work at their own pace and disliked time pressure, and liked memorisation to occur automatically but disliked memorisation which felt difficult and had to be carried out deliberately.

3.3.5.2 Skill and confidence ratings

For most respondents, memorising required effort (Table 3.6). Only four pianists (11%) reported that memorisation was effortless ('I find it very easy and I do not have to work at it'); 25 pianists (69%) reported that it required effort but was manageable ('I find it fairly easy but I have to work at it' or 'I find it okay but it is hard work'), while seven pianists (19%) found it difficult ('I find it very difficult but I can do it' or 'I find it very difficult and I struggle with it'). In between these extremes there was a tendency for those who found memorising 'fairly easy', but requiring work, to rate themselves as good or very good. Two of those who found memorising very difficult but manageable rated themselves as average, and, interestingly, one as 'not very good' and one as 'very good'. Respondents who selected the statement ' I find it okay but it is hard work', which is arguably the statement most open to a variety of interpretations, tended to rate themselves either as average or as very good.

Table 3.6: Table to show the comparison between statements concerning levels of memorisation skill and effort. In each category, the number of respondents who reported being dissatisfied with their choice of strategies is indicated [in square brackets].

Statement (n)	Poor (1)	Not very good (4)	Average (9)	Good (5)	Very good (11)	Excellent (6)
I find it very difficult and I struggle with it.	1 [1]	1	1			
I find it very difficult but I can do it.		1	2 [1]		1	
I find it okay but it is hard work.		1 [1]	5 [3]		4 [1]	1
I find it fairly easy but I have to work at it.		1 [1]	1	5	6 [1]	1
I find it very easy and do not have to work at it.						4

3.3.5.3 Dissatisfaction with working process did not necessarily lead to change

The nine 'dissatisfied' respondents (25%) were asked to describe what prevented them from working in ways they believed to be more effective. Themes identified in the analysis of these responses were that the techniques respondents felt they ought to use were experienced as tiring, difficult and demanding; that time constraints, combined either with a fear of not playing or with the desire to play, meant that non-playing strategies were not adopted; and that habits were hard to change (Table B.10 in Appendix B). Those who expressed dissatisfaction with their working process felt that they should use more mental practice and/or improve their focus during practice, but found that even when they were aware of better methods it was difficult to change habits, to use techniques that they found effortful or uninteresting, or to spend time working away from the piano.

Self-ratings of skill and ease by 'dissatisfied' learners

There was a tendency for dissatisfied respondents to find the memorisation process more effortful than their 'satisfied' peers, and to feel less confident about their ability to memorise (although ratings varied on an individual basis). Dissatisfied respondents tended to rate themselves as below-average memorisers, compared with satisifed respondents. Three out of nine dissatisfied respondents rated themselves as below average, compared with two of 27 who were satisfied (Table 3.6). There was also a tendency for dissatisfied respondents to rate memorisation as more effortful than satisfied learners. Seven of the nine dissatisfied learners stated that it was 'hard work' or 'very difficult' compared with 11 of the 27 'satisfied' group. Interestingly though, only one of the three respondents who found it most difficult, selecting the option 'I find it very difficult and I struggle with it', had stated that they were dissatisfied with their strategies.

'Dissatisfied' learners' approach to learning and memorising

More dissatisfied respondents had adopted a two-stage approach than had adopted an integrated approach. Of the nine dissatisfied respondents, seven had been categorised as two-stage learners and two as integrated learners (according to the analysis of their own descriptions of recent learning – see 3.3.2.2). Dissatisfied learners represented 32% of the two-stage learner group (seven out of 22 pianists) and integrated dissatisfied learners represented 15% of the integrated learner group (two out of 13 pianists).

3.4 Summary and discussion of findings

3.4.1 Summary of key results

- As expected, respondents' conceptions of learning and memorisation varied: some clearly differentiated between the two processes, while for others no distinction existed. In many cases, different respondents' conceptions of the two processes overlapped.
- An unexpected finding was that auditory imagery was ranked at group level as the most important factor in both learning and memorising. For some pianists, memorising (as distinct from learning) was associated with an increased reliance on motor imagery and (less often) on structural and notational imagery.
- Four frameworks for learning and memorising were identified: two-stage, automatically integrated, deliberately integrated and prior memorisation. Some respondents appeared to give inconsistent reports about which of these processes they had most recently adopted.
- There was widespread awareness of mental practice techniques: 24 respondents (67%) incorporated descriptions of deliberate mental practice when writing in their own words about their most recent practice. However, adoption of recommended mental imagery techniques and techniques for understanding and memorising was

less consistent than the adoption of recommended physical practice techniques.

- There were apparent discrepancies between teachers' and students' perceptions of how mental practice should be used. Auditory strategies were not adopted as often as teachers recommended, but motor imagery strategies were adopted more often than teachers recommended.
- As expected, memorisation training was not found to be consistently available. The majority of respondents, 22 pianists (61%), were aware of the prior memorisation technique advocated by NBO, but only 7 pianists (32%) reported adopting it frequently; furthermore, in open descriptions of recent learning only 1 respondent (3%) actually described using it.
- Respondents tended to value practical music making and embedded, explicit training most highly, but there were indications that although various techniques may be recommended they might not always be taught effectively. Training in aural and analytical skills may not be sufficiently embedded in instrumental training at advanced levels.
- There was no clear link between the approach adopted and self-ratings of skill and ease, but pianists who were dissatisfied with their strategies tended to feel less confident about memorising and to find it difficult.

3.4.2 Distinct and overlapping conceptions of learning and memorising

Although the majority of respondents stated that there was a distinction between learning and memorising, there was no consistent agreement about what distinguishes each process. In some cases, both learning and memorising were experienced as one and the same thing. For many respondents the two processes were only partially, or not at all, distinct from one another; furthermore, what some pianists considered an essential component of learning was considered by others to be an essential component of memorising.

Respondents' conceptions of learning and memorising can be described as existing on a continuum, at opposite ends of which 'learning' is felt to involve aspects of knowing that might be characterised as 'external' (understanding content through analysis, and/or knowing physically how to play the notes) and 'memorising' is felt to involve 'internal' aspects (deliberate mental imagery and/or automatic playing). At the centre of the continuum, learning and memorising are indistinguishable and require an integration of procedural knowledge, mental imagery, a sense of emotional connection or ownership - in other words, a multi-dimensional, internalised knowledge of the material that can be expressed through playing (Figure 3.7).

'External' ⟷	*Integrated* ⟷	*'Internal'*
Learning	**Learning and Memorising**	**Memorising**
Procedural knowledge	Procedural knowledge + mental imagery	Automatic playing
AND/OR	Emotional connection/ownership	AND/OR
Understanding content	Internalised knowledge of text	Deliberate imagery

Figure 3.7: Respondents' conceptions of learning and memorising represented on a continuum, at opposite ends of which learning involves 'external' aspects of knowing, and memorising involves 'internal' aspects, and at the centre of which both learning and memorising are indistinguishable.

Thus, although when given a forced choice 81% respondents stated that there was a difference between learning and memorising, analysis of the responses to three subsequent questions suggest that distinctions between conceptions of learning and of memorising were often blurred, with many of the responses to both open and forced choice questions revealing that in fact learning and memorising were considered to comprise the same ways of knowing.

3.4.3 Varying roles of four types of imagery in learning and memorising

Overall, mental imagery tended to be considered more essential for memorising than for learning. Looking at this finding in more detail, several aspects are of interest.

- Auditory imagery was considered to be the most important aspect of learning and memorising. When eight 'ways of knowing' were rated on a Likert-type scale, memorised auditory imagery was found to be the item rated as essential by the greatest number of respondents, and was rated equally 'essential' for both learning and memorising
- For learning, auditory imagery was rated 'essential' more often than all other types of imagery
- For memorising, motor imagery was rated 'essential' almost as often as auditory imagery
- For both learning and memorising, auditory imagery was rated 'essential' more often than the ability to play the piece at tempo, 'almost error-free', or slowly
- Motor, structural and notational imagery were more often rated an 'essential' property of 'memorising' than of 'learning'. This finding corresponds with analysis of qualitative data from the survey, which showed that where a distinction was made, references to imagery occurred in the context of memorising.

What the rating scales reveal is that, while the importance of auditory imagery did not vary significantly between learning and memorising, for some pianists memorising (as distinct from learning) was specifically associated with an increased reliance on motor imagery and (less often) structural imagery and visual imagery of the score.

3.4.4 Respondents may have adopted 'integrated' and 'prior memorisation' approaches adopted less often than they believed they should

Four approaches to learning and memorising were identified: two-stage, deliberately integrated, automatically integrated, and 'prior memorisation'. There was no consistent agreement between statements concerning the difference between learning and memorising and the type of process adopted. Discrepancies between two types of response concerning adoption of the 'two-stage' and 'integrated' processes suggest that an integrated approach to learning and memorising might more often be perceived as a better option, but that some students did not adopt it as often as they (perhaps) thought they should: when given a forced choice, the majority defined their process as integrated, but when writing in detail about their learning in their own words the majority actually described a two-stage process. There were further disparities between responses concerning the 'prior memorisation' process, which again suggest that some respondents felt that they ought to use the technique more often than they did: on a rating scale 32% reported adopting this process 'frequently', but in response to two other questions it was shown to have been adopted by only one pianist (3%) during recent learning.

3.4.5 Awareness of mental techniques, but familiar and easier techniques most frequently adopted

Techniques most likely to be adopted all involved playing from the score at the piano, possibly because these strategies were most familiar and enjoyable and were most often demonstrated in lessons. There was, however, a widespread awareness of mental imagery techniques and an overall sense that mental practice ought to be used. Although mental techniques were less likely to be adopted than physical techniques when recommended, analysis of descriptions of recent learning nevertheless showed that 24 pianists (67% respondents) had used some form of mental imagery rehearsal. Several of those who expressed dissatisfaction with their working process felt that they ought to undertake more mental practice, and only three respondents stated that they never used any form of mental imagery rehearsal.

Techniques most frequently recommended were practice techniques which are very widely taught from the first stages of learning - practising hands separately, playing slowly, using different rhythms, practising in sections without the score and sightreading at the piano. Analysis of scaled responses showed that, in general, the more a technique was reportedly recommended, the more likely it was to be reportedly implemented. Exceptions to this tendency appear to echo qualitative findings that students disliked techniques that they found effortful, and particularly liked physical practice techniques where memorisation occurred automatically. It is not surprising therefore that the techniques most likely to be adopted all involved playing from the score at the piano, or that the strategy of playing the whole piece until it was memorised was the most likely of all those listed to be adopted when it was recommended. In contrast, the opposite technique – prior memorisation - was reportedly adopted very infrequently in relation to the rate of recommendation. As the participant observation study showed, prior memorisation is a challenging technique and rarely appears to be explicitly taught, even though pianists are often aware of it.

3.4.6 Teachers and students may use mental imagery strategies differently

There was some evidence that students developed their own approach to uses of mental imagery, irrespective of what they were advised to do. Some respondents reported that although they had not been advised to use particular techniques they frequently adopted them. In particular, mental imagery of finger movement was frequently used by a greater percentage of respondents than reported being advised to use such strategies. These findings suggest some disparity between the strategies that teachers considered most effective and the strategies that students considered effective or relevant. Given that Koopman (2007) found that students' practice tended to mirror what happens in lessons, it is possible that although teachers recommend mental imagery techniques they may not demonstrate them explicitly, or provide specific practice instructions that would enable students to adopt them consistently.

Strategies for imagining sound were reportedly recommended more frequently than strategies for imagining finger movement and – unexpectedly- rating scales showed that students considered auditory imagery to be almost equally important for both learning and memorising. Despite this, auditory strategies were not adopted as frequently as they were recommended, but motor imagery strategies were adopted more frequently than they were recommended. Of all the mental practice strategies listed, the strategy least often recommended – imagining finger movements of a section with the score – was the one most likely to be adopted, possibly because students tended to focus on motor learning rather than using auditory or other (analytic) mental strategies.

Teachers appeared to recommend the use of auditory imagery strategies during learning, whereas students tended to adopt auditory imagery strategies for overlearning (i.e. as a memory reinforcement strategy once learning had already occurred). Students were more frequently advised to imagine the sound (either of a section or of a whole piece) with the score than without the score, suggesting that teachers more often recommended auditory mental practice as a strategy for developing understanding of the text than as an overlearning strategy. Students, on the other hand, were most likely to adopt the auditory strategy least often recommended – imagining the sound of the whole piece without the score - suggesting a tendency to use auditory imagery as a reinforcement or overlearning strategy (i.e. checking that they could remember the whole piece and mentally rehearsing it) rather than as a means of developing understanding of the text.

3.4.7 Memorisation strategies: Inconsistent training and adoption

The majority of respondents stated that memorisation was not taught at their college (see also Ginsborg, 2004) or that they did not know whether it was. Where memorisation training sessions did take place they were considered, overall, to be the least influential type of all training, suggesting that they were often viewed as poor quality or irrelevant. Indeed, not all respondents felt that memorisation could be taught, or needed to be, although several respondents reported that they had been explicitly taught methods that they found useful. Given that all respondents were able to memorise, and that nearly all respondents (86%) rated their memorisation skill average or above, it is evidently possible for pianists to memorise successfully without explicit training. The survey respondents, however, represent an elite group of successful learners and it is not unlikely that, given the emphasis on memorised piano performance, other pianists fail to reach this stage of training because of lack of confidence or skill.

The inconsistent adoption of memorisation strategies and mental imagery techniques by the survey population suggests that although various techniques may be recommended they may not be explicitly taught. The majority of students were aware of the prior memorisation process, but like NBO's course participants they did not necessarily adopt this approach even when they appeared to believe that they should. Prior memorisation was much less likely to be adopted than the strategy of playing through from the score until memorisation was achieved automatically, despite widespread recommendations to remove the score as soon as possible and to use a variety of mental reinforcement techniques to ensure that multiple encoding (and not just motor encoding) took place.

3.4.8 Practical music making and embedded, explicit training preferred

Respondents said that overall they were most influenced by the learning that occurred in individual lessons and during other practical music making activities, and least influenced by strategy training. In the majority of cases memorisation training was not provided at college, and when it was, it was not highly rated. An interesting exception was that classes outside college sometimes provided effective strategy training and it would be useful to identify which students seek them out and why, and what they learn from them. Students appeared to gain most from explicit instruction embedded in individual instrumental lessons, and preferred all active learning, via various types of music-making, to other forms of knowledge acquisition.

3.4.9 Development of aural and analytical skills

Students rated auditory imagery as the most 'essential' of eight attributes of both learning and memorising. Overall, however, they rated aural training as one of the forms of training that least influenced their own approach to learning and memorising. Several factors suggest that aural training was not embedded in individual lessons as often as might be effective: firstly, teachers recommended auditory imagery strategies frequently but, at college, aural training was more often provided in a class than by a piano tutor. Secondly, students rated aural training more highly when it was provided by a piano tutor (which, for comparison, was not the case with analysis training). Finally, the strategy of singing parts was infrequently adopted, again potentially indicating that this strategy was not embedded within lessons.

Conversely, although structural imagery was rated 'essential' significantly less often than auditory imagery, respondents rated analysis training as one of the most influential activities. Despite this, analysis - which some respondents stated elsewhere in the survey they did not like and which, according to Howell (1992: 693, cited in Vaughan 2002) performers tend to view 'either with considerable suspicion or as a complete irrelevance' - was infrequently adopted in relation to the rate at which it was recommended. These findings suggest that although students might believe analysis to be important they did not always explicitly make use of it in their own learning, either because it was disliked, considered irrelevant, or again was perhaps not explicitly integrated into the approach adopted within lessons.

3.4.10 Skill, confidence and strategy choice

Given the selective nature of advanced piano training, and the fact that memorised performance is likely to form part of advanced training, it was unsurprising that 86% respondents considered their memorisation ability to be average or above, and that all respondents were able to memorise. Like NBO's students, the majority of survey respondents were not explicitly trained to memorise, but training (or lack of it) did not appear to correspond with self-ratings of skill.

Respondents who were dissatisfied with their learning strategies tended to find the memorisation process more effortful than their 'satisfied' peers, and to feel less confident about their ability to memorise. A higher proportion of those who were dissatisfied with their approach had most recently adopted a two-stage, rather than an integrated approach. These learners expressed feelings that they ought to use more mental practice and/or improve their focus during practice, but found that even when they were aware of better methods it was difficult to change habits, to use techniques that they found effortful or uninteresting, or to spend time working away from the piano. These findings suggest that it would be worthwhile investigating whether further, more targeted training could improve confidence and skill in learners who sense that their approach is not optimal.

3.4.11 Limitations of the study

The main limitation of the study was the high drop-out rate (see 3.2.6) and low response rate, which may largely have been due to the length of the questionnaire. Some questions were, in retrospect, too detailed in ways that did not significantly contribute to findings. In particular, Qs 9 & 11 lists of mental practice techniques could have been condensed, and fewer items listed in Qs 15-19.

3.5 Conclusions and further questions

The survey set out to explore gaps between beliefs and practice habits, and between what students were taught to do, advised to do, said they did and actually did. Inconsistent responses and an underlying lack of clarity about what constitutes learning and memorising suggest that, in some cases, respondents had not thoroughly clarified the specific purpose of different aspects of their rehearsal process, or understood how different learning sequences and strategies might affect outcomes. A number of findings suggest disparities between strategies considered effective, explicitly taught, reportedly used and actually used. Although these strategies were considered effective, and students felt they ought to use them, they were not necessarily adopted for a combination of reasons, including that they were inconsistently taught, unfamiliar and effortful:

- Treating learning and memorising as an integrated process
- Analysis
- Mental imagery techniques
- Prior memorisation

The survey echoed a number of findings from the participant observation study; both studies found that students were most likely to adopt strategies that were explicitly taught in instrumental training, but that memorisation techniques were inconsistently taught. Knowing about specific strategies, and believing them to be useful, did not necessarily lead to their adoption. These findings suggest that more detailed evidence is required to support applications of specific techniques and to develop more effective training.

Survey evidence emphasised the critical role mental imagery plays in memorising, and findings from the participant observation study suggested that imagery rehearsal can enhance quality of learning. A third study was therefore designed to examine the neural basis of expert musical imagery processes in more detail, potentially providing insight into reported advantages of mental imagery rehearsal. The first two studies had demonstrated that auditory, structural and motor imagery were central features of expert musical imagery (although the extent to which pianists explicitly employed each type of imagery varied with training and musical experience, and –presumably- skill and preference). The participant observation additionally found that imagery of note patterns on the keyboard was a key learning point, but because this technique was not expected to be familiar to the majority of pianists it was not specifically incorporated in the design of the final study; notational imagery was the least important type of imagery overall and was also not incorporated. As a result of these findings, the third study incorporated structural, auditory and motor imagery in the training protocol, and was designed to examine realistic expert musical imagery and memory retrieval processes.

Chapter 4 An fMRI Study of Expert Musical Imagery

This chapter describes a functional magnetic resonance imaging (fMRI) study investigating the neural basis of musical imagery, in which musical complexity was varied. Fourteen expert pianists memorised two short, novel, ecologically valid pieces of music immediately prior to scanning. Pianists were scanned during imagery and simulated motor performance of the memorised pieces, without auditory feedback. Results showed that increasing musical complexity accentuated activation in prefrontal and superior temporal areas that have previously been identified as playing an important role in musical processing. Furthermore, these areas were increasingly activated by professional (compared with student) participants.

4.1 Introduction

There have been a small number of fMRI studies specifically comparing neural activitation during expert musical imagery and motor performance (Langheim et al., 2002; Lotze et al., 2003; Meister et al, 2004). These studies tended to focus on evidence that imagery and simulated performance engage similar neural regions, including prefrontal, motor and auditory regions, but more recent work has found indications of differences in functional activation alluding to potentially interesting distinctions in cognitive processing between the two conditions. Kleber et al. (2007) studied opera singers imagining and overtly singing phrases from an Italian aria and found that activation in prefrontal and parietal areas was greater during imagined (versus overt) singing. There is also evidence that prefrontal and secondary auditory regions play critical roles in musical imagery. For example, Bangert et al. (2006) used fMRI to study seven pianists and seven non-musicians, who listened to short melodies or pressed keys on a silent keyboard. During the key-pressing task, when presumably pianists imagined the associated sound and non-musicians did not, left IFG was activated more by pianists than by non-musicians. Significant activation in MFG was found bilaterally in the pianist group, but there was no significant MFG activation in non-musicians. Secondary auditory cortex was also activated significantly more by pianists than by non-musicians.

fMRI has excellent spatial resolution and previous studies of expert musicians have demonstrated its suitability for investigating imagined musical tasks (e.g. Lotze et al., 2003; Kleber et al., 2007). The current design was informed by previous studies in which imagery and motor performance of the same musical stimuli were directly compared, and in which there was no auditory feedback in either condition during scanning (Lotze et al., 2003; Meister et al., 2004). However, although four known fMRI studies and one EEG study have directly examined expert musical imagery and motor performance (Langheim et al., 2002; Lotze et al., 2003; Kristeva et al., 2003; Meister et al., 2004; Kleber et al., 2007), task design and familiarity with musical stimuli varied across studies and, in some cases, between participants in the same study (see Chapter 1, 1.3.2). Imagery instructions have varied; where specified, participants have been asked to focus on imagining aspects of movement (Lotze et al., 2003; Kleber et al., 2007). To date, no study has compared two-handed musical imagery with motor performance tasks, or compared tasks at different levels of complexity. With the exception of one EEG study (Kristeva et al., 2003), no investigation of musical imagery has controlled for familiarity during memorised performance. The current study is therefore unique in its use of novel, ecologically valid, bi-manual musical tasks modulated by complexity.

4.1.1 Prefrontal activation during musical imagery

There is converging evidence that prefrontal areas play critical roles in musical imagery (e.g. Kleber et al., 2007; Herholz et al., 2012) and that activation in prefrontal regions relates to imagery vividness. Several studies have shown that musicians exhibit more pronounced activation in middle frontal gyrus (MFG) and inferior frontal gyrus (IFG) than non-musicians (Schlaug, 2006: 147). Activation in MFG and IFG has been observed to increase when experienced musicians imagine the sound associated with observed or executed musical movement (compared with non-musicians) (Haslinger et al., 2005; Bangert et al., 2006), suggesting that these areas are involved in memory retrieval for 'action-related sound' (Lahav, Saltzman, & Schlaug, 2007: 308). Furthermore, there are indications that prefrontal activation increases during imagery (compared with motor performance); a study of expert musical imagery and overt singing performance found increases in MFG and IFG during imagery that the authors interpreted as reflecting increased working memory demands due to the lack of auditory feedback (Kleber et al., 2007: 898).

MFG

MFG is known to be involved in working memory processes (Barbey, Koenigs, & Grafman, 2013), and studies of expert musicians have found MFG activation during musical imagery (Langheim et al., 2002; Lotze et al., 2003; Kleber et al., 2007). Differences between musicians and non-musicians suggest that MFG is specifically involved in the imagining of music. Haslinger (2005) contrasted silent observation of piano playing with silent observation of a resting hand and found that MFG activation was greater in pianists than in non-musicians. Bangert (2006) used fMRI to study seven pianists and seven non-musicians. During a silent piano-playing task, when pianists may have imagined the associated sound and non-musicians may not, significant activation in MFG was found bilaterally in the pianist group but there was no significant MFG activation at any statistical threshold in non-musicians (2006: 920). While this suggests that MFG played a role in imagery induced in the pianist group, the task design and instructions to participants were not specific enough for this finding to be clearly interpreted.

IFG

A number of fMRI studies of experienced musicians have found activation in the inferior frontal gyrus (IFG) during musical imagery and motor performance tasks (Langheim et al., 2002; Lotze et al., 2003; Meister et al., 2004; Kleber et al., 2007); studies of musicians and non-specialists suggest that IFG activation is modulated by musical training and imagery vividness. Bangert (2006) found that left IFG was activated more by pianists than by non-musicians during both a listening task and a silent key-pressing task (923). Lahav (2007) found left IFG activation when (novice) participants listened to music that they had been trained to play, but not when listening to untrained music (311). Leaver (2009) found a correlation between high ratings of auditory imagery vividness and activation in left IFG during anticipatory imagery for familiar music tracks (2481). Evidence that IFG activation increased in the absence of overt movement, when the auditory-motor task had been learnt (Bangert et al., 2006; Lahav et al., 2007) suggests that IFG is involved in action/sound prediction (Lahav et al., 2007: 312) and sensorimotor interactions (Langheim et al., 2002: 907; Kleber et al., 2007: 897).

There is some evidence that IFG activation increases during musical imagery compared with perception or performance, which may reflect increased memory demands or differences in processing due to the absence of external feedback. Haslinger (2005) compared pianists observing piano playing in silence with observation of piano playing with sound, and found that IFG activation during the silent observation task, when sound was (presumably) imagined, was greater than when subjects observed piano playing in conjunction with actual sound. Kleber (2007) compared imagined and overt singing by experts and found that imagining activated IFG to a greater extent than overt singing. Lotze (2003) found that in amateur violinists, imagery increased left IFG activation compared with execution.

4.1.2 Auditory and motor activation during musical imagery

STG

Activation in auditory cortex has been observed during musical imagery in both experts and non-musicians, and is thought to mediate the phenomenological experience of imagining music (Zatorre & Halpern, 2005: 9). Secondary auditory cortex was activated significantly more by pianists than by non-musicians during a silent keyboard-playing task (Bangert et al., 2006) and during observation of piano playing movements without sound (Haslinger et al., 2005). Investigations in non-specialist populations have found evidence that secondary auditory areas play important roles in auditory imagery (see Zatorre & Halpern, 2005 for a review; Herholz et al., 2012). For example, during imagery of familiar tunes, more vivid imagers showed significantly more activity in right STG than those who reported less vivid imagery (Herholz et al., 2012: 1391). Two studies of experts have found activation in secondary auditory areas during musical imagery (Lotze et al., 2003; Kleber et al., 2007), and secondary auditory areas of superior temporal gyrus (STG) were therefore identified as areas of interest.

Motor cortex

fMRI studies comparing neural activation during expert musical imagery and performance have found evidence that imagery and performance engage a similar network of motor regions (Langheim et al., 2002; Meister et al., 2004; Lotze et al., 2003, Kleber et al., 2007), which the present study was broadly expected to corroborate (Chapter 1, 1.3.2). Results concerning activation in primary motor areas during imagery have, however, varied; some studies have observed activation in primary motor cortex during musical imagery (Lotze et al., 2003; Kleber et al., 2007) while others have not (Langheim et al., 2002; Meister et al., 2004) and thus while motor cortex was identifed as a region of interest, no specific prediction was made concerning its activation during imagery.

4.1.3 Hypotheses

The present study was expected to corroborate previous evidence that musical imagery and motor performance recruit shared neural networks, but with some distinctions in prefrontal regions. MFG and IFG were identified as areas of interest, based on evidence of their involvent in musical tasks, including musical imagery (Lotze et al., 2003; Zatorre & Halpern, 2005; Kleber et al., 2007). These regions have previously been observed to be activated significantly more during imagery more than during overt performance (Kleber et al., 2007), which the authors suggested might reflect increased working memory demands during the imagery task. MFG and IFG have also been observed to be activated significantly more by musicians than by non-musicians during musical imagery tasks (Bangert et al., 2006; Schlaug, 2006), which may correspond to vividness of the musical image. Thus it was predicted 1) that MFG and IFG would be activated more by imagery than by motor performance and 2) that MFG and IFG would be activated to a greater extent when musical complexity increased.

Evidence of increased activation during imagery in prefrontal areas associated with memory processing would support the argument that imagery rehearsal can enhance memorisation. The study was expected to confirm previous findings of auditory-motor co-activation, with simulated performance preferentially activating primary motor, sensorimotor and auditory areas. Evidence of motor activation during imagery would support the hypothesis that mental rehearsal has a preparatory effect on motor learning. The key hypotheses for the study were therefore that:

1. MFG and IFG would be activated significantly more during imagery than during motor performance.
2. Activation in MFG and IFG would increase significantly when musical complexity increased.
3. Imagery would activate auditory and motor areas.

4.2 Materials and methods

4.2.1 Ethical approval

The study was approved by the West of Scotland Research Ethics Committee and by the Research Ethics Committee of Edinburgh College of Art, University of Edinburgh. All participants were fully informed - in writing and verbally - of the procedures involved, gave written consent to all experimental procedures and were screened prior to scanning (Appendix C, sections C.1.1 to C.1.4).

4.2.2 Recruitment

Participants were recruited from the experimenter's professional network and from specialist music training courses at the Royal Conservatoire of Scotland (Glasgow), the University of Edinburgh and Napier University (Edinburgh). Potential participants were initially contacted by email, either directly by the experimenter or via research and teaching staff at the relevant institution. On initial contact, participants received a letter of invitation that outlined the study and inclusion criteria (Appendix C, section C.1.1) and a participant information sheet explaining research procedures (Appendix C, section C.1.2).

4.2.3 Participants

Fifteen expert pianists took part in the study, but data from one participant had to be discarded due to computer error during scanning. All results are shown for 14 pianists (6F, 8M). On average, participants had played for 27 years (range 13-50 years). All had begun piano training ≤ age 8 (mean starting age 6 years; range 2-8 years) (Table 4.1).

Table 4.1: Table showing participants' mean age, start age, years of piano playing and current weekly playing [range] (SD) (n=14) (6F, 8M)

	Age	Start age	Years playing	Current weekly playing (hours)
Mean	33	6	27	16
[Range]	[19-52]	[2-8]	[13-50]	[5-30]
(SD)	(11.48)	(1.75)	(11.69)	(7.87)

4.2.4 Design

An fMRI block design was used to compare musical imagery and motor performance, modulated by complexity, using a 2x2 factorial design (Figure 4.1). Stimuli were designed to manipulate the complexity of the musical image while controlling motor aspects of the task, with the aim of gaining further insight into the neural mechanisms involved in musical imagery.

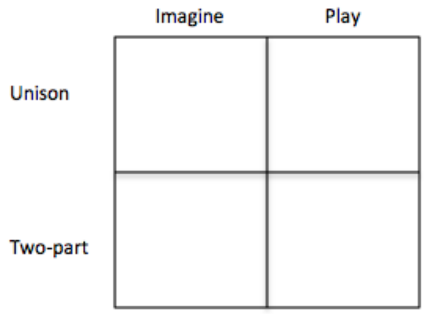


Figure 4.1: Figure showing 2 x 2 design comparing imagery and motor performance of musical pieces at two levels of complexity

Prior to scanning, pianists followed carefully scripted procedures (based on procedures described in Chapter 2, 2.3.1) designed to ensure that all participants followed a similar learning process (4.2.7.1). Each pianist memorised two short novel pieces, one of which (Two-part) was more complex than the other (Unison) (Figure 4.2). During scanning, auditory feedback was absent and sound was imagined. Pianists performed both pieces in two conditions: in 'Imagine', they imagined the music; in 'Play', they simulated playing by moving their fingers on the scanner bed as if playing on a real piano while imagining the music.

4.2.5 Stimuli

Two novel musical stimuli were designed to be as musically realistic as possible, given the physical constraints of a scanning environment. They were also designed to be relatively easy to memorise within the experimental context and not to present any technical challenges to an expert pianist. Each stimulus consisted of a short piano piece, 2 bars long (repeated), total duration 13 seconds (Figure 4.2). Both pieces used all five fingers of both hands, with the pitch set limited to five notes in each hand in order to constrain hand, wrist and arm movement in the scanner. The pieces were designed to be ecologically valid and were composed in a familiar western classical style using standard contours, pitch and rhythm.

The pieces conformed to specific criteria and were designed to be equal to each other in all respects except one. Motor requirements were equal (although not identical) for both pieces. Both were in the same key, contained the same number of notes and phrases, were in the same metre, required the same rhythmic co-ordination between the hands and were played at the same speed. In each case, two of the four phrases were identical (phrases 1 and 3) (Figure 4.2). The critical difference between stimuli was that one piece (Two-part) was musically more complex than the other (Unison). Unison contained only one melody, performed simultaneously by both hands, one octave apart; participants therefore had to imagine or play one melody, doubled. Two-part contained two melodies performed simultaneously, each moving independently from the other; participants therefore had to imagine or play two melodies simultaneously. The criteria for stimulus design are summarised as follows:

- Equal motor requirements
- Same duration
- Same number of notes
- Same rhythmic co-ordination between hands
- Same speed
- Same metre
- Same phrasing
- Same key
- Difference in number of melodic lines

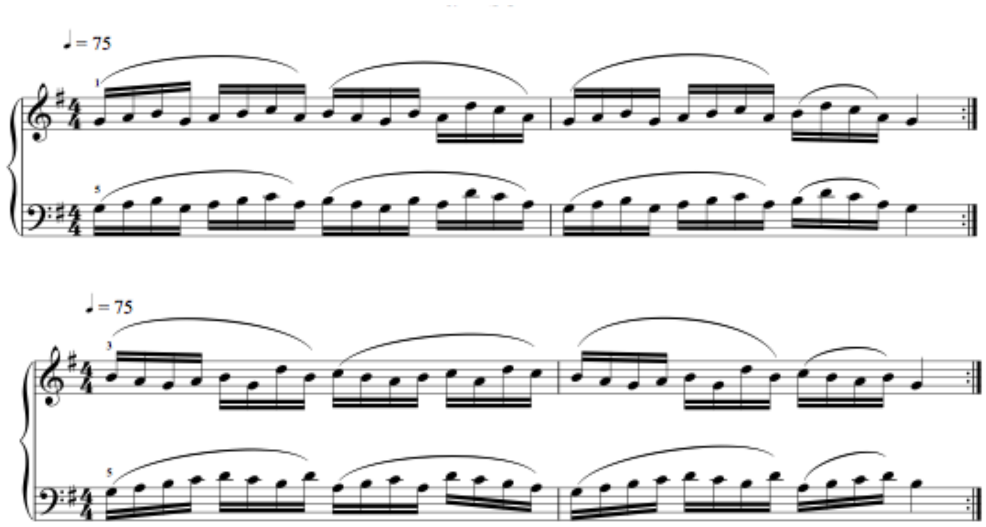


Figure 4.2: Figure showing two musical pieces, Unison (upper system) and 2-part (lower system)

4.2.6 Materials

During learning, participants rehearsed on a digital piano keyboard (Roland JV-35) with auditory feedback through headphones (Beyerdynamic DT 250). Hard copies of the musical scores, and a digital metronome with visual display and audio click options (Pure Tone PTN100529), were provided for use as required. On completion of learning, performances were audio recorded directly from the keyboard (Zoom H2 Handy). Scanning took place on a 3-Tesla Verio MR system (Siemens Medical Systems, Erlangen, Germany). During scanning, written instructions were presented on goggles (NordicNeuroLab VisualSystem) using Presentation® software (Version 0.70, www.neurobs.com); participants wore earplugs and occluding headphones with noise attenuation of +30dB (NordicNeuroLab AudioSystem). Post-hoc measures were administered using a semi-structured interview schedule (Appendix C, C.1.7), the Edinburgh Handedness Inventory (Oldfield, 1971), and a Mental Imagery Questionnaire (Appendix C, C.1.8). All MRI data were analysed using Brain Voyager QX software version 2.6 (Brain Innovation, Maastricht, Netherlands). Brain regions were labelled according to the Talairach Daemon database (http://www.talairach.org/). The timings of actual and imagined performances were calculated using GarageBand software (version 3.0.5, Apple Inc.).

4.2.7 Procedure

Figure 4.3 shows an outline of the training procedure and timeline used in this study (for further details see Figure C.1 in Appendix C, Section C.1.5).

Protocol (minutes)	Intro. (10)	Learning (50)	Verification (15)	Mock scan (10)	Scan (40)	Post-scan (20)
Measures		•Learning time	• Audio recording		• EPI • T1	• Interview • Imagery questionnaire • Handedness questionnaire

Figure 4.3: Timeline showing outline of study procedure with approximate timings.

4.2.7.1 Learning session

The learning session (max. 50 minutes) took place within the Clinical Research Imaging Centre (CRIC) immediately prior to scanning. The experimenter presented participants with two novel musical scores (Figure 4.2) and verbally guided them through a simple analysis of the two pieces using a prepared script (Appendix C, section C.1.6). Participants were asked to memorise the pieces by mentally rehearsing as well as playing on a digital piano keyboard with auditory feedback through headphones. Participants were asked to work by themselves, initially from the scores, and to spend an equal amount of time imagining the pieces, focusing particularly on the sound, and rehearsing on the keyboard. They were instructed to continue learning until they could imagine and play both pieces of music comfortably from memory at the correct speed. No other instructions were given and neither the order of learning the two pieces nor the amount of time allocated to each was specified. A digital metronome with visual display and audio click options was provided for use as required. Careful pilot work established scripted procedures designed to reassure participants of the quality and usefulness of their contributions and to minimise any performance anxiety; the experimenter left the room during the learning session but returned briefly to ask how the participant felt they were progressing (at intervals of 20 minutes, then 10 minutes, then 5 minutes) until the participant felt confident that they had completed the learning.

4.2.7.2 Learning verification

On completion of learning, participants were asked to demonstrate that they could perform and imagine both pieces fluently. The experimenter monitored the length of time taken to perform and to imagine the music. The order in which pieces were performed and imagined was counterbalanced across participants. Firstly, the participant was asked to play each piece on the keyboard, and then to play it again when the experimenter gave a verbal four-beat count-in. If there was any innaccuracy, more time was allowed to consolidate learning. Secondly, the participant was asked to imagine each piece. In order to demonstrate the length of time taken to imagine, participants were asked to play the first notes and last notes (both hands) on the keyboard at the same time as they imagined them (procedure adapted from Clark & Williamon, 2012). The experimenter monitored the accuracy of the notes played at the beginning and end of each piece via headphones. If timing or pitch was innacurate, participants were asked to repeat the imagined performance. After each imagined performance, participants were questioned about imagery vividness and where necessary were asked to repeat the exercise until they reported that they could imagine both melodic lines vividly. Finally, imagined and live performances of both pieces were audio recorded directly from the keyboard, in each case counted in at tempo by the experimenter, in order to verify that participants had completed learning before scanning. Start and end points of imagined performances of both pieces were recorded for comparison with overt performances, in order to verify (as far as possible) that participants were able to imagine the pieces accurately.

4.2.7.3 Training in mock scanner

Once participants had demonstrated that they could perform and imagine both pieces fluently, they were trained to perform the pieces in a mock MRI scanner in two conditions - Imagine and Play. In the Imagine condition they were instructed to imagine the music while keeping completely still, and in the Play condition to perform on the bed of the scanner, as if playing on a real piano keyboard, while imagining the music. Participants were asked to perform both pieces in both conditions while keeping their head and body perfectly still, and to practice switching between tasks when instructed to do so verbally. Training in the mock scanner took as long as required for the participant to be confident and comfortable with the procedure (average 10 minutes).

4.2.7.4 Scanning procedure

A short (2m 23s) dummy run, in which each of the four active tasks occurred once, was designed to familiarise participants with the tasks in the scanning environment. The main functional run (20m 32s) followed. The T1-weighted scan (c. 5 minutes) was carried out at the end of the scanning session.

Once in the scanner, participants heard an audio click (75bpm) on the keynote (G5) for four bars to remind them of tempo and pitch. Musical scores were presented on the goggle screen as a reminder. For active blocks, the written instruction appeared on screen for 2 seconds, after which the screen went blank (Figure 4.4). Participants were instructed to begin the task as soon as the screen went blank, to continue performing the task until the cross appeared on screen, and to stop immediately the cross appeared. During rest blocks participants were asked to focus on the centre of the cross.

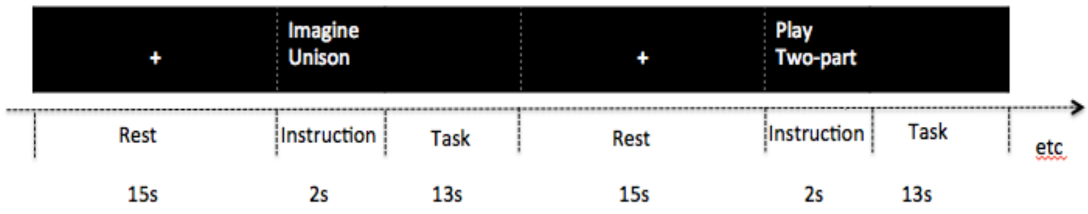


Figure 4.4: Figure showing sample section of functional scan timeline, task instructions and rest blocks.

4.2.7.5 Scanning set-up

No keyboard was used in the scanner and the sound of the pieces was imagined in both conditions. Participants lay in a supine position, with knees elevated by a foam bolster and arms by their sides. Foam cushions were used to support wrists and arms, and sandbags were placed under the hands in order to maintain comfort; the aim was to simulate a comfortable piano-playing position for the forearms, wrists and hands. Participants were instructed to remain entirely still and, when instructed to play, to move only the fingers. They were monitored visually to ensure that they did not move their head, trunk or legs during performance, and to ensure that fingers were still during the imagined condition. Goggles were attached to the head coil and positioned just above the participants' eyes so that written instructions were clearly visible on the goggle screen. Earplugs and occluding headphones were worn to minimise background scanner noise; the experimenter could talk to the participant through the headphones between scans. During the imagined condition, fingers were kept entirely still, and during the played condition participants simulated playing by moving the fingers on the scanner bed as if playing on a real piano.

4.2.7.6 Questionnaire measures

Following the scan, a short semi-structured interview provided an opportunity for participants to reflect on all aspects of the experiment, and to provide information about their musical training and experience (C.1.7 in Appendix C). Age, age of training onset and estimated weekly hours of playing were assessed. Participants were asked about the nature of their imagery and imagery vividness during scanning. They were asked to provide scaled ratings of the difficulty of each piece (scale 1-10; 1=very easy, 10=very difficult) and to describe learning the two pieces. Interviews were audio recorded. The Edinburgh Handedness Inventory (Oldfield, 1971) was then administered. Finally, participants completed a brief questionnaire rating their use of musical imagery strategies. This was developed for the experiment in order to assess the relative importance of different modes of musical imagery, how often participants used each mode of imagery and how skilled they were in each mode (C.1.8 in Appendix C).

4.2.8 Image acquisition

All data were acquired at the Clinical Research Imaging Centre (CRIC), Edinburgh. Blood oxygen dependent imaging (BOLD) data were acquired using a 3 Tesla Verio MR system using an interleaved echo planar imaging (EPI) fast gradient echo sequence. The scan parameters were as follows: TR=3000ms, TE=30ms, flip angle=90°, slice thickness=3mm, 36 transverse slices covering the whole brain, field of view=24 cm, matrix size=64×64. A total of 408 functional volumes were acquired for each participant, with the exception of one participant for whom, due to a computer error, only 368 volumes were acquired. The first three EPI volumes from each run were discarded prior to data analysis to allow for T1 saturation effects. In addition to the functional data, high-resolution structural images were obtained using a T1-weighted sequence (MPRage; 160 slices with 1 mm effective thickness).

A classical fMRI box-car design was used, alternating fixation rest (15 s) and activation (15 s) blocks. Each participant completed one functional run lasting 20 minutes and 32 seconds, in which the four active tasks each occurred ten times (or in one case of computer error, nine times) in pseudo-randomised order (Figure 4.5).

+	I2	+	PU	+	P2	+	IU	+	P2	+

Figure 4.5: Example section of design, alternating fixation rest (15s) and activation blocks (15s) of the four pseudo-randomised musical tasks, Imagine Unison (IU), Imagine 2-part (I2), Play Unison (PU), Play 2-part (P2).

4.2.9 Data analysis

4.2.9.1 Analysis of behavioural and questionnaire data

Audio recordings of actual performances were independently assessed for accuracy by two expert pianists. All performances were rated on a scale of 1-5, where 1 was poor and 5 was excellent. The timings of actual and imagined performances were calculated and the results compared in order to assess temporal accuracy of imagined performances. Questionnaire and interview measures were tabulated.

4.2.9.2 fMRI analysis

All analyses were completed using Brain Voyager QX software version 2.6 (Brain Innovation, Maastricht, Netherlands). Functional data were pre-processed to correct for head motion artifacts in 6 directions (3 translations and 3 rotations) using trilinear/sinc interpolation, with no participants exceeding a maximum motion tolerance of 4mm in any direction. Functional data were spatially smoothed with a 6mm Gaussian filter, corrected for temporal linear trends and differences in slice scan time acquisition using trinlinear interpolation. Preprocessed functional data were co-registered to the corresponding high-resolution anatomical images and interpolated into standard Talairach space (Talairach & Tournoux, 1988).

For statistical analysis of functional data, the general linear model (GLM) was calculated using a single-factor design with four predictors (imagine unison, imagine two-part, play unison, play two-part) modelled over baseline rest. At the first level, the GLM was run separately for each subject to estimate condition effects (beta values). The resulting statistical maps were entered into a multi-subject GLM. Random-effects group analyses and summary statistics random-effects group analyses were performed across the entire brain using the general linear model (GLM), which assesses the extent to which variation in blood oxygenation-dependent (BOLD) fMRI signal can be attributed to the experimental manipulations (Friston et al., 1999). For visualization of results in two dimensions, an average cortex representation was created from the fourteen individual subject standardised anatomical images. The template Colin27 brain (BrainVoyager QX) was used for 3D visualization on a rendered brain.

For ANOVA analysis (2 x 2 ANOVA, *F* tests of 'task' and 'complexity'), the statistical threshold was set as $p<0.01$, corrected for the whole brain (false discovery rate; FDR; Forman, 1995; Genovese et al., 2002). Additional analysis of activation in pre-determined areas of interest (4.1.2) was carried out via direct contrasts (*t*-tests, $p<0.05$, corrected for the whole brain). Finally, a 2x2x2 ANOVA was conducted to discover whether there were any significant differences in activation between subgroups of professional (n=7) and student (n=7) participants (*F* tests, $p<0.01$, corr). A minimum threshold of 4 voxels was set for each cluster (unless otherwise stated). For each cluster, local maxima were labelled according to the Talairach Daemon database (http://www.talairach.org/) (Lancaster et al., 2000; Lancaster et al., 1997) (see Belardinelli et et al., 2009: 193).

4.3 Results

4.3.1 Questionnaire measures

4.3.1.1 Handedness

All participants were assessed as right handed on the Edinburgh Handedness Inventory (Oldfield, 1971).

4.3.1.2 Imagery during scanning

During the semi-structured post-hoc interview all pianists confirmed that during scanning they had imagined the sound in both conditions. Six participants had imagined note patterns on the keyboard and four stated that they had consciously imagined finger movements. Three participants reported that their imagery included a general 'sense of playing'. Two participants had imagined the musical notation, and one participant had imagined the timbre and the look of different pianos (Appendix C, Table C.2).

4.3.2 Performance measures

4.3.2.1 Learning time

On average, pianists took 31.07 minutes (SD=7.12) (range 20-40 minutes) to reach the point where they could comfortably demonstrate to the experimenter that they could imagine and perform both pieces from memory at the correct speed.

4.3.2.2 Performance assessment

Two experienced pianists independently assessed audio recordings of participants pre-scan performances post-hoc and verified that all participants had performed both pieces fluently before scanning. All performances were rated by both assessors as average (3) or above on a scale of 1-5 (1=very poor, 5=excellent) (Appendix C, Table C.6). Recorded timings of the imagined and actual performances were compared and found to be very similar, and very close to the standard inter-onset time between first and last notes (12s). On average, participants took 11.86s (SD=0.84) to perform the unison piece and 12.25s (SD=0.85) to imagine it, and took 12.25s (SD=0.83) to play the two-part piece and 12.46s (SD=0.82) to imagine it (Appendix C, Table C.5).

4.3.3 fMRI results

This section begins by reporting the results of the second level analyses of main effects in each condition versus rest, followed by a conjunction analysis of all four conditions. Subsequently, results of a 2x2 ANOVA are presented to show interaction effects, main effects of task-type (Imagine versus Play), and main effects of complexity (Two-part versus Unison). Results from the direct contrast between Imagine Two-Part and Imagine Unison are then reported. Finally, results of a 2x2x2 ANOVA to test the main effect of experience (comparing the professional pianists with the student pianists) are presented.

4.3.3.1 Individual conditions versus rest

Second level analysis of main effects in each condition versus rest found that a similar network of neural regions was activated during both imagery and motor performance of both pieces of music (Figure 4.6) (for further details see Appendix C, section C.3.1).

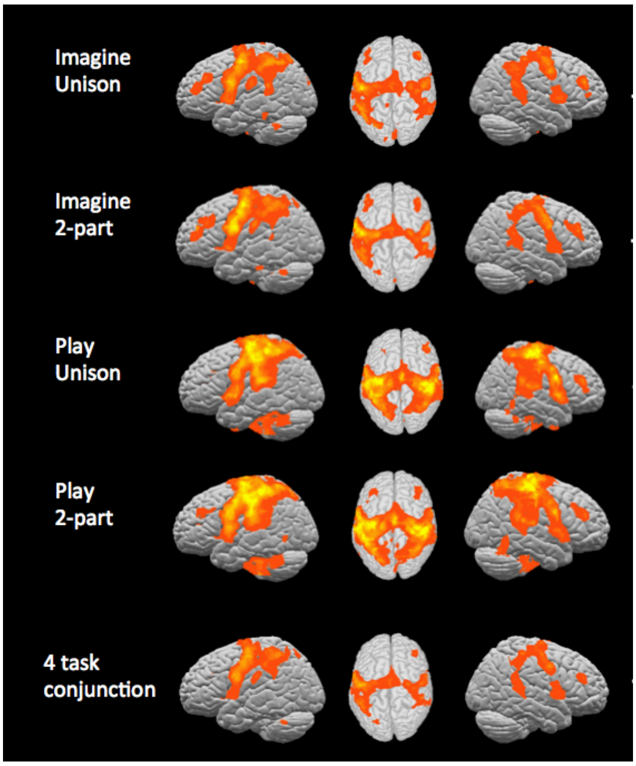


Figure 4.6: 3D renderings of significant activation effects onto a template brain showing, from top to bottom row, Imagine Unison > rest; Imagine 2-part > rest; Play Unison > rest; Play 2-part > rest; conjunction of all 4 conditions (*p*<0.05, FDR corrected for the whole brain).

4.3.3.2 Conjunction analysis, all four conditions

A main effects conjunction analysis of all four conditions showed that both imagery and playing activated motor networks including SMA, bilateral premotor and primary motor cortices. Prefrontal and superior temporal regions were also significantly activated by all four tasks (Figure 4.6, Table 4.2).

Table 4.2: Brain regions activated in conjunction analysis of all four conditions (IU, I2, PU, P2) ($p<0.05$, FDR corrected for the whole brain).

Area	BA	mm	*x*	*y*	*z*	*t*	*p*
L_M1	4	31	-46	-11	45	6.309969	0.000027
R_M1	4	34	35	-26	48	3.914551	0.001777
R_M1	4	25	44	-11	51	4.236138	0.000972
SMA	6	36	2	-5	60	6.974281	0.00001
L_PMC	6	34	-25	-17	51	3.901618	0.001821
R_PMC	6	36	26	-17	51	4.270185	0.000912
R_STG	13	22	56	-41	21	3.930181	0.001725
R_STG	22	25	56	-35	9	5.231668	0.000162
R_MFG	10	24	35	37	24	5.2459	0.000158
L_PrCG	6	35	-55	1	22	5.114616	0.000199
R_PrCG/IFG	6	32	50	-2	39	5.002529	0.000242
L_PrCG/IFG	44	32	-49	4	11	3.960113	0.00163
R_PrCG	44	30	47	4	13	4.21227	0.001016
L_INS	13	31	-34	16	6	4.215935	0.001009
R_INS	13	26	32	16	9	4.126071	0.001193
L_IPL	40	37	-37	-38	42	6.275894	0.000029
L_IPL	40	16	-58	-23	27	3.671452	0.002819
R_IPL	40	36	38	-41	39	3.376941	0.004957
R_ PoCG	40	24	46	-32	51	4.121185	0.001204
R_cingulate	32	29	5	13	39	3.612643	0.003155
L_cingulate	24	31	-4	4	43	4.044505	0.001391
L_putamen		26	-22	-5	9	4.283565	0.00089
R_ putamen		27	20	-2	6	3.566648	0.003445
L_ cerebellum_culmen		11	-40	-50	-27	3.670531	0.002824
R_ cerebellum_culmen		21	23	-53	-24	3.167557	0.007417

BA, Brodmann's area; *x*, *y* and *z* represent Talairach and Tournoux (Talairach and Tournoux, 1988) coordinates (for list of abbreviations see Appendix C, C.1.9).

4.3.3.3 Interaction effects

A 2x2 whole brain ANOVA identified significant interactions in a small number of areas including left primary motor cortex (L_M1), left somatosensory cortex (L_S1) and right secondary auditory cortex (R_STG) (Figure 4.7, Table 4.3). Each of these areas was activated more by playing than by imagining, and during playing activation increased when musical complexity increased. During imagining, activation decreased when complexity increased.

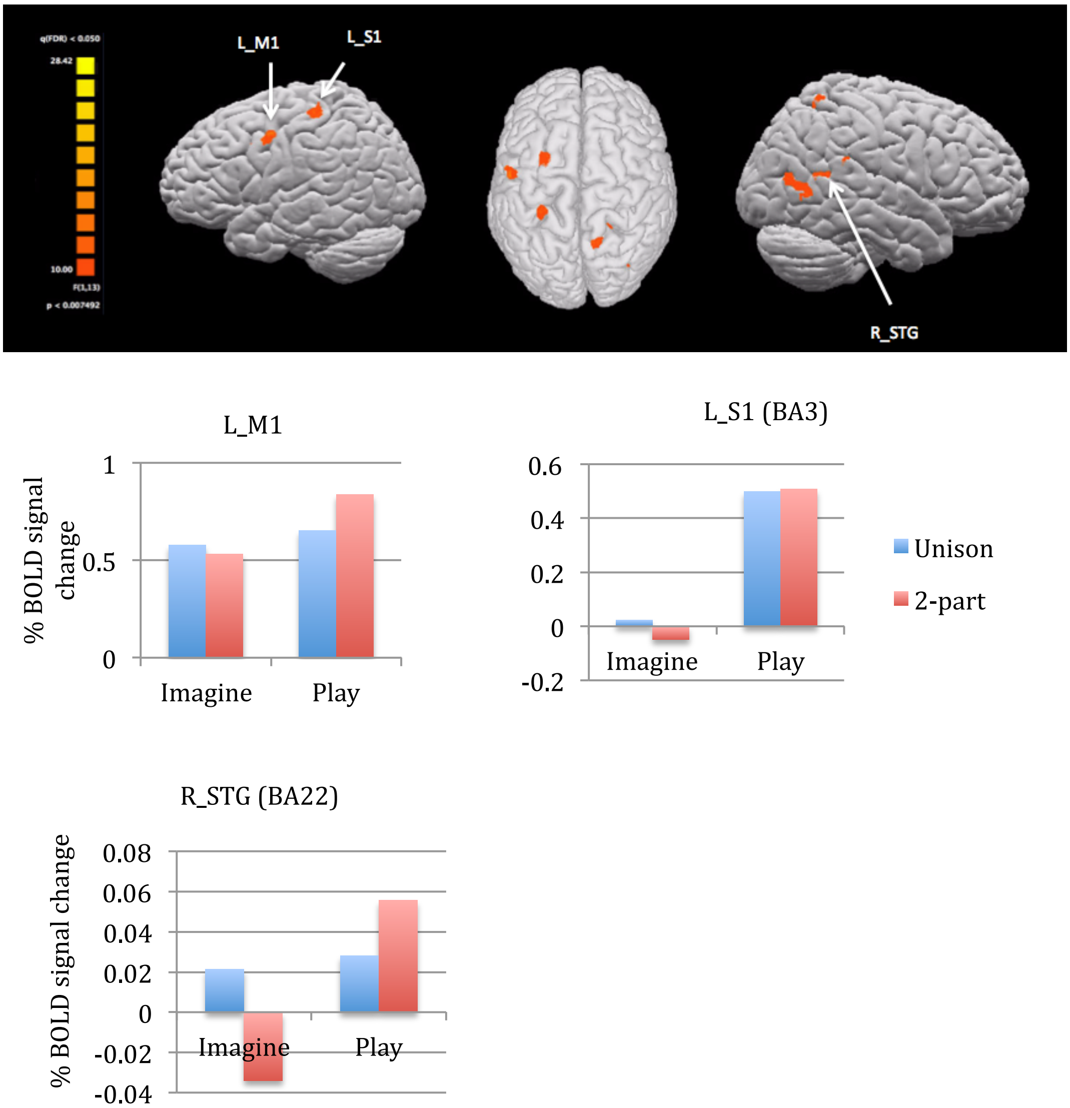


Figure 4.7: 3D renderings onto a template brain of 2 x 2 ANOVA, showing significant interactions in L_M1, L_S1, R_STG (p<0.01, FDR corr); bar chart showing % BOLD signal change.

Table 4.3: Showing significant interactions identified in 2x2 ANOVA (p<0.01, FDR corrected for whole brain).

Area	BA	voxels	*x*	*y*	*z*	*F*	*p*
frontal lobe subgyral*	-	10	-25	4	33	15.055261	0.001896
L_S1	3	8	-28	-32	57	21.991455	0.000423
L_M1	4	5	-49	-8	45	16.540483	0.001333
R_PCUN	7	5	8	-53	57	18.420174	0.000876
R_STG_BA22	22	9	32	-50	15	20.512009	0.000566
temporal subgyral*	-	7	-28	-50	18	16.174932	0.001451
R_LING**	19	6	32	-62	6	12.609848	0.003549

BA, Brodmann's area; n = voxels in cluster*;* *x*, *y* and *z* represent Talairach and Tournoux (Talairach and Tournoux, 1988) coordinates (for list of abbreviations see Appendix C, C.1.9).
* white matter
** deactivated in all tasks

4.3.3.4 Main effect of task-type

F tests across the whole brain for 'task' (Imagine and Play) found significant effects in prefrontal, motor, somatosensory, insular, temporal, parietal and limbic regions (Table 4.4). Most regions were activated significantly more by motor performance than by imagery; clusters in two left prefrontal regions were activated more by imagery than by playing. Detailed results are presented below for prefrontal regions (MFG, IFG), auditory regions (STG), and motor regions (M1, PMC, SMA).

Prefrontal activation

F tests (p<0.01, corr) identified clusters in two left prefrontal regions (MFG, IFG) which were activated significantly more during imagery than during motor performance (Figure 4.8, Table 4.4). An additional cluster in L_MFG (BA 10) was included in the analysis despite its small size (2 voxels), because t-tests in each task > rest and in contrasts IU>PU and I2>P2 had identified clusters in this location that were activated significantly more by imagery than motor performance (p<0.05, corr) (section C.3.1 in Appendix C). A strip in right IFG (BA 9 - 44) was activated significantly more during motor performance than during imagery. In BA 44, activation during I2 was greater than during IU during motor performance, but during imagery activation in I2 was less than during IU.

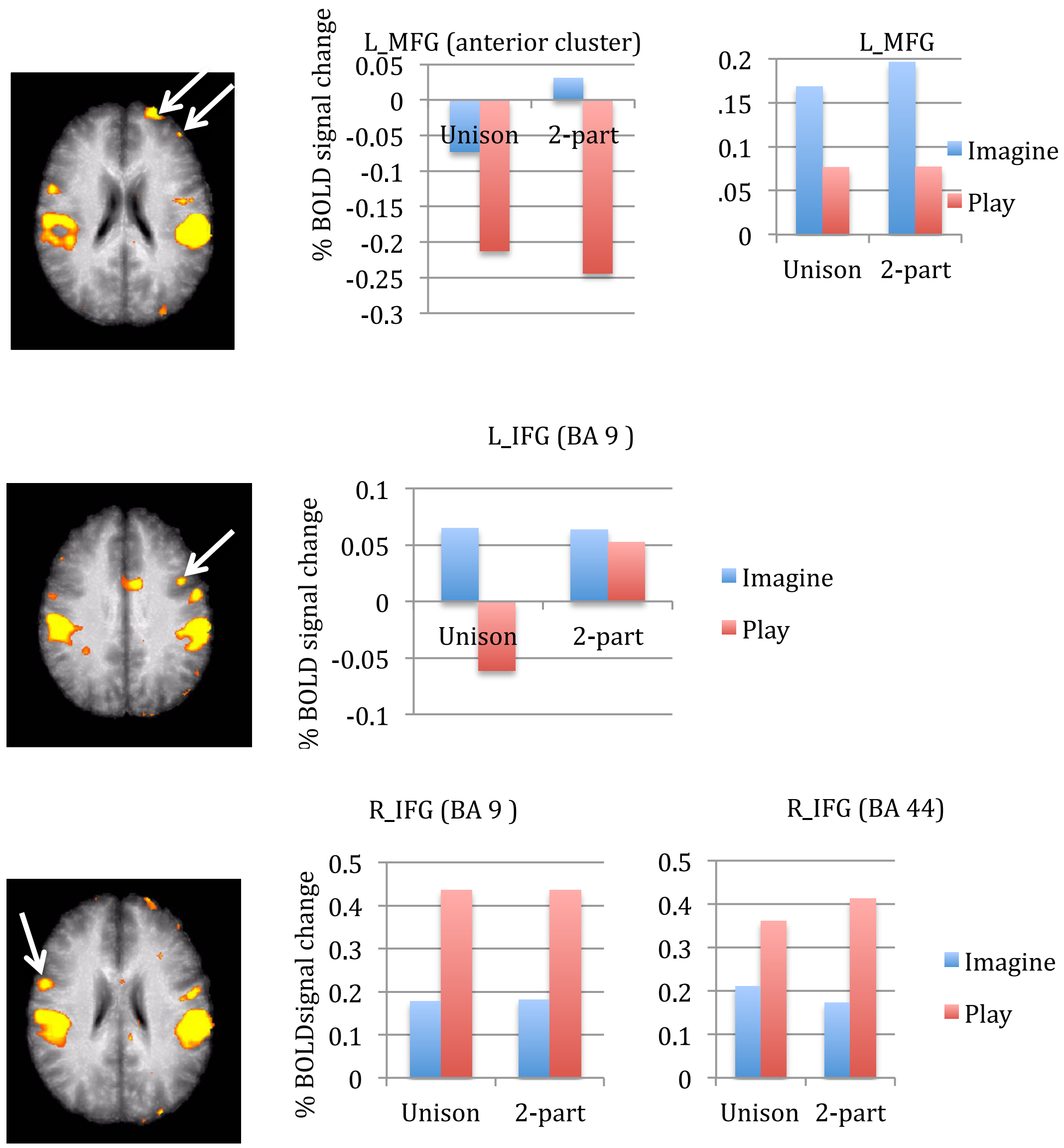


Figure 4.8: Volume maps showing activation in prefrontal areas in *F* test of task (*p* < 0.01 corr.) (L_MFG, z = 21; L_IFG, z = 30; R_IFG, z = 24); bar charts showing % BOLD signal change.

STG activation

STG was activated significantly more during motor performance than during imagery (Figure 4.9, Table 4.4). R_ STG (BA42) was significantly activated during motor performance, barely activated during IU and deactivated during I2. In a large cluster on the right (peak activation in right INS, extending into STG (BA 41), significant activation was observed during motor performance and deactivation during imagery. On the left, a large cluster with peak activation in postcentral gyrus extended into STG (BA41/42) and insula. Activation was significantly greater during motor performance than during imagery.

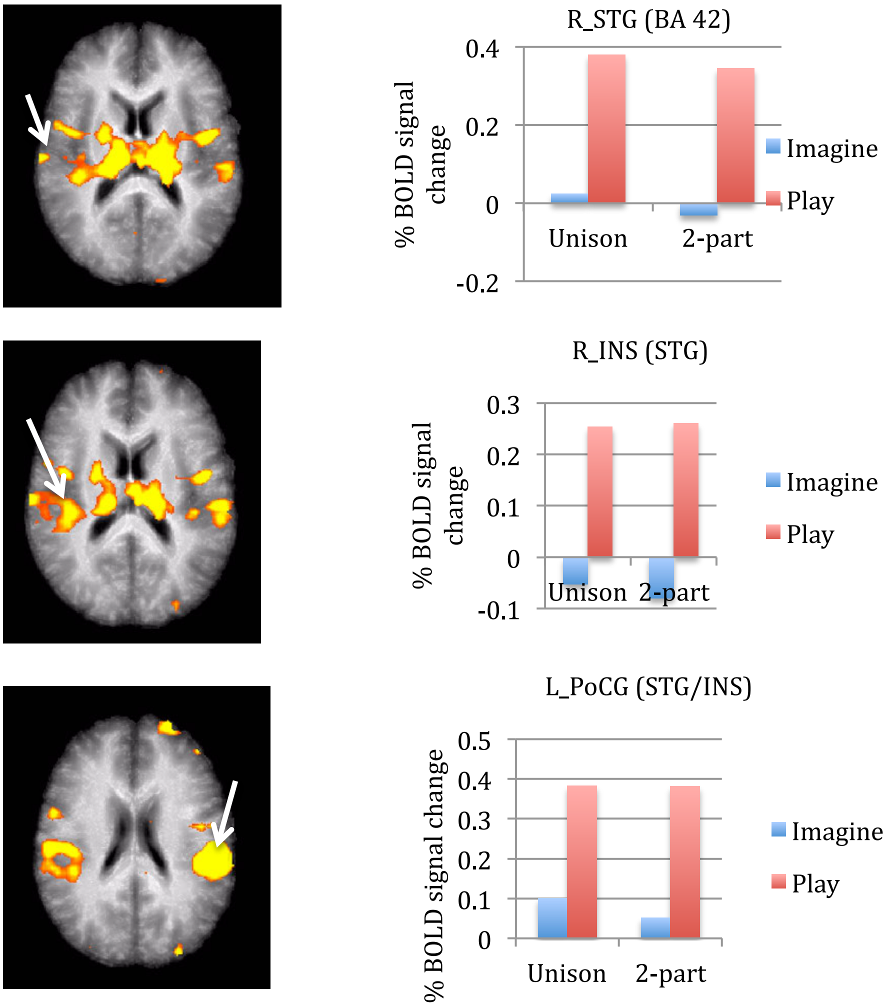


Figure 4.9: Volume maps showing activation in STG identified in *F* test of task (R_INS (STG), z= 15; R STG, z = 12; L_POCG (STG/INS), z = 21) (p<0.01); bar charts showing % BOLD signal change.

Motor cortex activation

All motor regions including primary, premotor and supplementary motor areas were activated significantly more during motor performance than during imagery (Figure 4.10, Table 4.4).

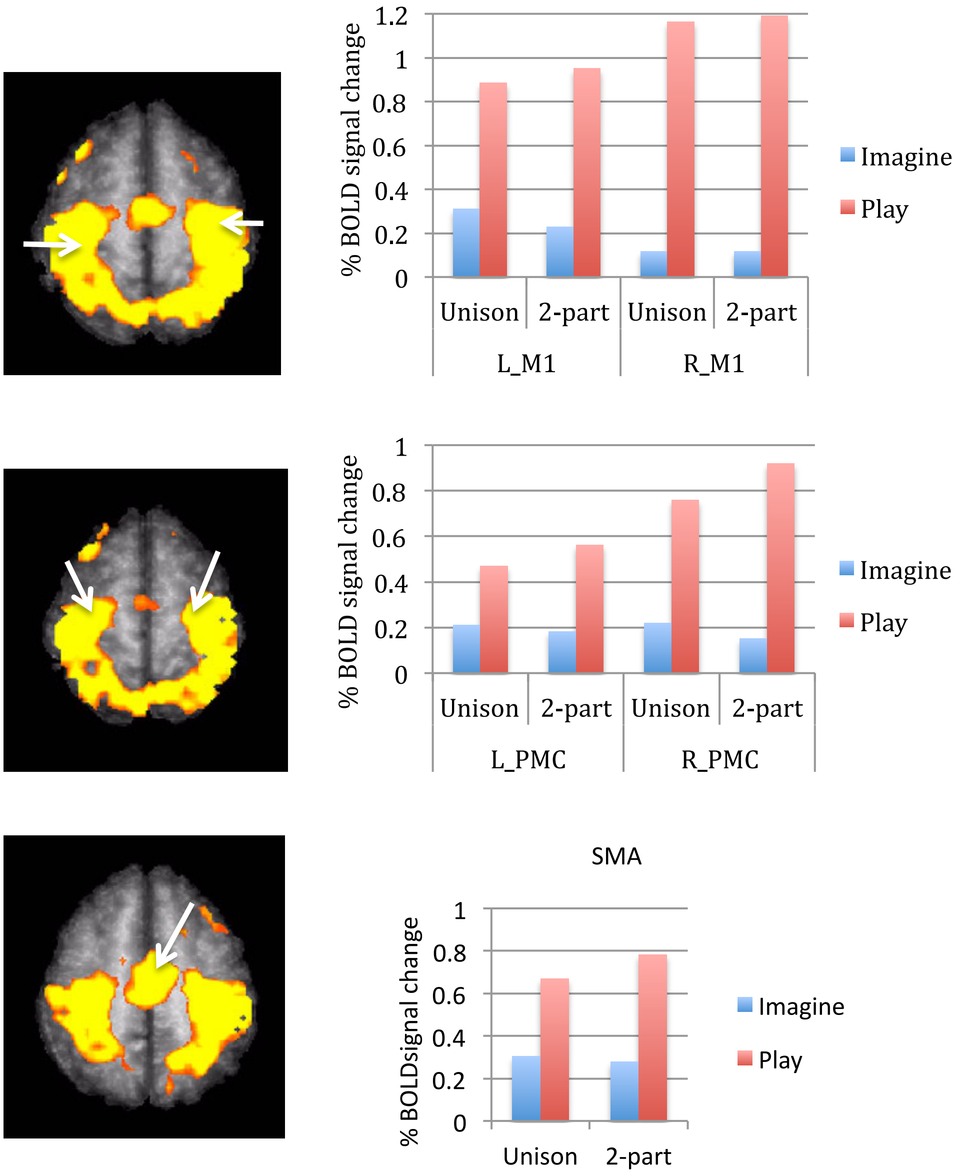


Figure 4.10: Volume maps showing activation in parts of the motor system identified in *F* test of task (L_& R_M1, z = 54; L_& R_PMC, z= 57; SMA, z = 48) (p<0.01); bar charts showing % BOLD signal change.

Table 4.4: Areas showing significant effects of ‘task’ & ‘complexity’ for the whole brain (F tests, p <0.01, FDR corrected), with additional t test results for direct contrasts (shown in brackets, p<0.05, FDR corrected).

	Task: P>I *except where indicated*								**Complexity: *2>U except where indicated***							
	Area	BA	n	*x*	*y*	*z*	*F*	*p*	*BA*	n	*x*	*y*	*z*	*F*	*p*	
	L_M1	4	981	-37	-17	54	222.850769	0	-	-	-	-	-	-	-	
	R_M1	4	1000	32	-28	54	80.87513	0.000001	4	114	38	-14	54	11.839915	0.004384	
	L_S1	2	1000	-49	-29	39	40.523933	0.000025	-	-	-	-	-	-	-	
	L_S1[1]	3	991	-35	-17	51	91.069397	0	-	-	-	-	-	-	-	
	R_S1	2	989	49	-23	42	45.699318	0.000013	-	-	-	-	-	-	-	
	R_PCL	5	-	-	-	-	-	-	5	208	2	-32	57	15.878636	0.001556	
	SMA	6	977	-7	-8	48	92.916466	0	6	354	2	1	63	20.171747	0.000607	
	L_PMC	6	969	-23	-17	57	65.726395	0.000002	6	755	-19	-14	51	41.816822	0.000021	
	R_ PMC	6	960	19	-16	66	31.808403	0.000081	6	656	23	-8	51	28.69174	0.000131	
	L_PreCG[2]	6	530	-49	-5	24	32.526875	0.000073	6	784	-49	-5	39	34.389599	0.000056	
	L_MFG	9	-	-	-	-	-	-	9	164	-31	37	30	17.423443	0.001091	
	L_MFG	9	-	-	-	-	-	-	9	373	-43	22	30	22.678558	0.000371	
(I>P)	(R_MFG	9	113	48	25	30	*t* 3.620724	0.003106)	9	118	38	19	30	15.04658	0.001900	
I>P	L_MFG	10*	67	-40	43	20	16.004217	0.001760	-	-	-	-	-	-	-	
I>P	L_MFG	10	530	-22	58	21	30.386536	0.0001	-	-	-	-	-	-	-	
I>P	L_IFG	9**	218	-40	7	30	20.110615	0.000615	44	189	-49	1	18	11.202599	0.005251	
	R_IFG	9 /44**	613	53	4	24	21.261566	0.000488	9	160	50	4	30	26.3174	0.000193	
	L_INS	13	908	-40	-5	9	47.57011	0.000011	13	572	-43	-14	12	51.271217	0.000007	
	L_ INS	13	969	-55	-32	19	29.090553	0.000122	-	-	-	-	-	-	-	
	R_INS (STG) ***	13/41*	949	38	-27	15	22.476471	0.000386	-	-	-	-	-	-	-	
	R_INS	13	500	41	-2	18	22.384247	0.000392	13	161	35	13	0	16.066858	0.001489	
	R_MTG***	-	-	-	-	-	-	-	21	331	62	-20	-6	38.66489	0.000031	
	L_STG***	-	-	-	-	-	-	-	41	229	-40	-29	9	20.963697	0.000517	*U>2*
	(L_STG	-	-	-	-	-	-	-	22*	112	-52	-29	6	*t* 2.847294	0.013728)	(P2>PU)
	(R_STG[3]	-	-	-	-	-	-	-	22	712	32	-50	15	*t* 3.277451	0.006003)	(P2>PU)
	R_STG	42*	349	62	-17	12	27.099173	0.000169	-	-	-	-	-	-	-	

Area	BA	n	*x*	*y*	*z*	*F*	*p*	*BA*	n	*x*	*y*	*z*	*F*	*p*
L_FFG	20	122	-49	-32	-24	27.399906	0.000161	-	-	-	-	-	-	-
L_PCUN	7	995	-16	-53	54	50.308395	0.000008	-	-	-	-	-	-	-
R_PCUN[4]	7	850	5	-59	54	62.006954	0.000003	-	-	-	-	-	-	-
L_PoCG (STG/INS)	40	967	-52	-20	21	56.632687	0.000004	-	-	-	-	-	-	-
L_PAR	-	-	-	-	-	-	-	40	617	-34	-41	36	23.233255	0.000335
L_SPL	7	734	-19	-62	54	20.367371	0.000583	-	-	-	-	-	-	-
L_LING	-	-	-	-	-	-	-	18	218	-19	-71	3	27.725142	0.000153
L_thalamus	-	1000	-13	-14	6	181.912674	0	-	-	-	-	-	-	-
R_thalamus	-	1000	11	-17	9	135.270325	0	-	-	-	-	-	-	-
R_claustrum***	-	-	-	-	-	-	-	-	119	35	-14	9	17.181301	0.001152
L_cingulate	24	-	-	-	-	-	-	24	863	-10	-2	48	38.919579	0.000030
R_cingulate	24	-	-	-	-	-	-	24	331	11	13	30	17.983408	0.000964
R_ putamen	-	737	23	-5	12	26.190092	0.000198	-	-	-	-	-	-	-
L_cerebellum (culmen)		1000	-7	-53	-9	227.842575	0	-	182	-31	-41	-27	26.605291	0.000184
R_cerebellum (culmen)		1000	6	-56	-18	68.375175	0.000002	-	137	23	-44	-12	16.125788	0.001468
R_brainstem red nucleus		758	5	-21	-9	38.39843	0.000032	-	-	-	-	-	-	-
L_ claustrum		360	-37	-17	-6	22.547295	0.000381	-	-	-	-	-	-	-

BA, Brodmann's area; n = voxels in cluster*;* *x*, *y* and *z* represent Talairach and Tournoux (Talairach and Tournoux, 1988) coordinates (for list of abbreviations see Appendix C, C.1.9).

* Areas activated significantly more by professionals than by students, cluster in identical location (Table 4.7)

** Areas activated significantly more by professionals than by students, cluster in different location (Table 4.7)

*** Areas deactivated during Imagine

[1] interaction, see 2x2 ANOVA (4.3.3.3)

[2] corresponds with L_M1 (BA 4) interaction identified in 2x2 ANOVA (4.3.3.3)

[3] interaction, see 2x2 ANOVA (4.3.3.3)

[4] interaction, see 2x2 ANOVA (4.3.3.3)

4.3.3.5 Main effect of complexity level

F tests across the whole brain found significant effects of musical complexity (i.e. differences between unison and two-part pieces) (p<0.01 corr) in a number of regions (Table 4.4). In most regions, 2>U; in a subset of these regions, motor performance was reponsible for this effect, and there was either a non-significant increase or a reduction in BOLD signal response in I2 compared with IU. In one area, U>2 during motor performance (L_STG, BA 41, Figure 4.12). Detailed results from F tests in prefrontal, auditory and motor areas are reported below. Results for the contrast I2>IU (t-tests) are reported separately (4.3.3.6).

Complexity in prefrontal regions

Activation in left and right MFG (BA9), left IFG (BA 44) and right IFG (BA9) increased in line with task complexity (Figure 4.11, Table 4.4). In two clusters in left MFG, the difference between 2-part and Unison BOLD signal changes was greater in the played condition than in the imagined condition; in right MFG, the difference between 2-part and Unison BOLD signal changes was greater during imagery than motor performance. In IFG a significant effect of musical complexity was observed in left IFG (BA 44) during play, and in right IFG (BA 9) during play and imagine. Observed differences between 2-part and Unison BOLD signal changes was greater in the played condition than in the imagined condition, and greater on the right than on the left.

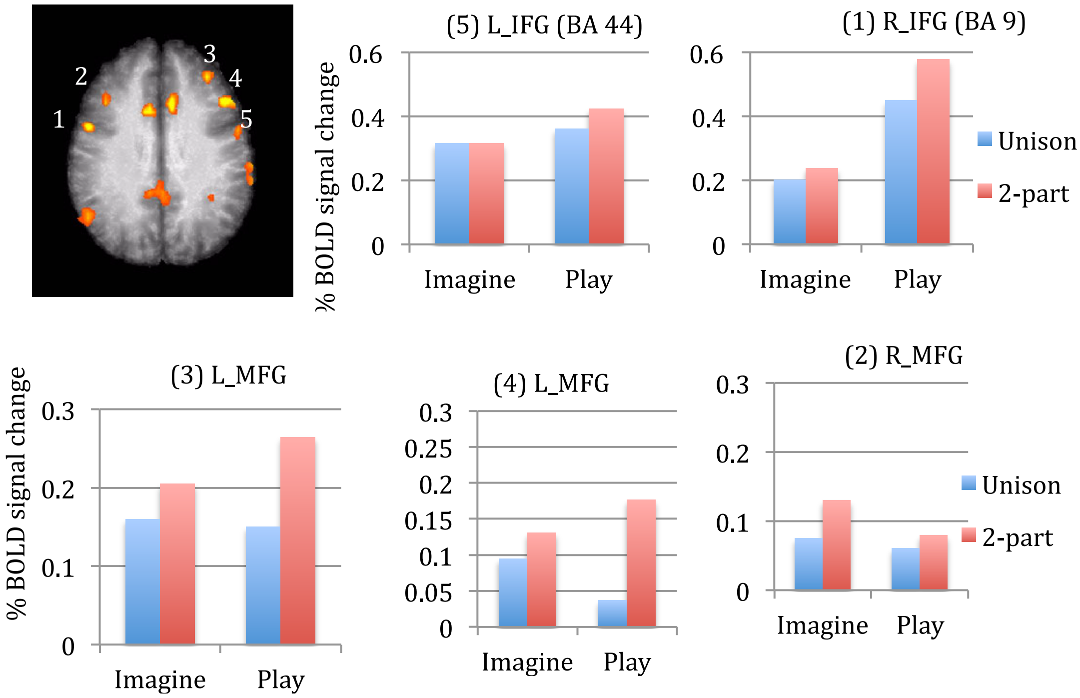


Figure 4.11: Volume map showing regions activated significantly more during 2-part than unison piece: L_IFG, R_IFG, L_MFG, R_MFG (z = 30) (F test of complexity factor, *p*<0.01, corr); bar charts showing % BOLD signal change.

Complexity in STG

One cluster in STG (left BA 41) was identified in the *F* test of complexity (Figure 4.12, Table 4.4). This cluster was deactivated during imagery; during play, it was activated more during the unison than during the two-part piece. In contrast P2>PU, activation was found to be significantly greater in left STG (BA 22) (Figure 4.12, Table 4.4) and right STG (BA 22) (Figure 4.7).

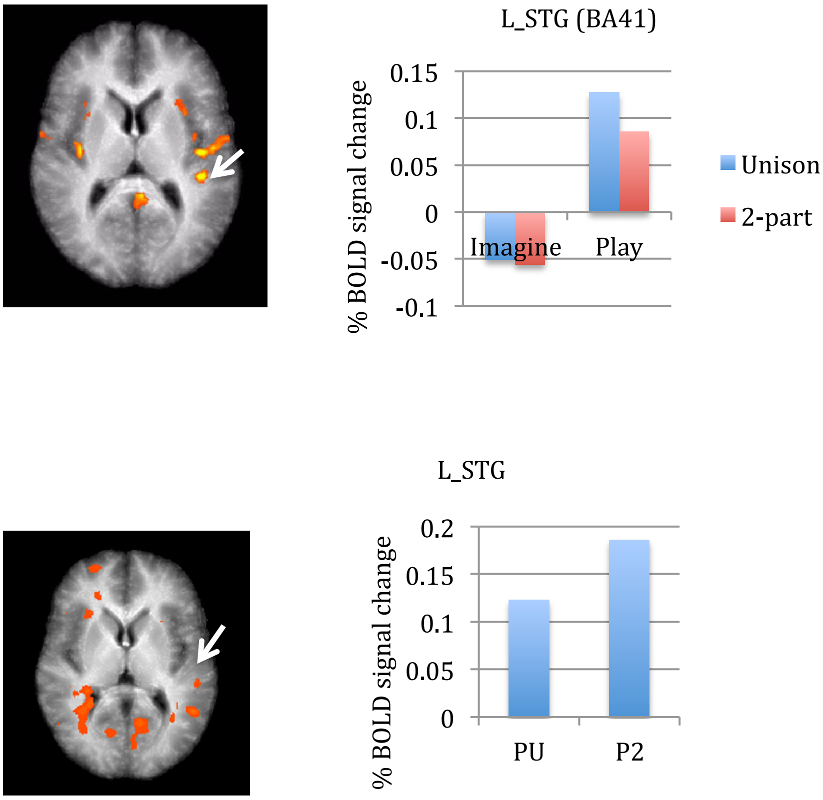


Figure 4.12: Volume maps showing activation in L_STG (BA41, z = 9) in *F* test of complexity (p<0.01, corr) and in L_STG (BA 22, z = 6) in contrast P2 > PU (*p*<0.05, corr); bar charts showing % BOLD signal change.

Complexity in motor cortex

F tests of the factor 'complexity' showed that the motor system was activated significantly more during motor performance of the two-part piece than of the unison piece (Figure 4.13, Table 4.4). During imagining the difference between unison and two-part pieces was more variable. Activation increased slightly in right M1 when the two-part piece was imagined, compared with the unison piece (Figure 4.13, Table 4.4); activation in SMA (Figure 4.13, Table 4.4) and in left M1 (Figure 4.7, Table 4.3) decreased during imagery of the two-part piece, compared to the unison.

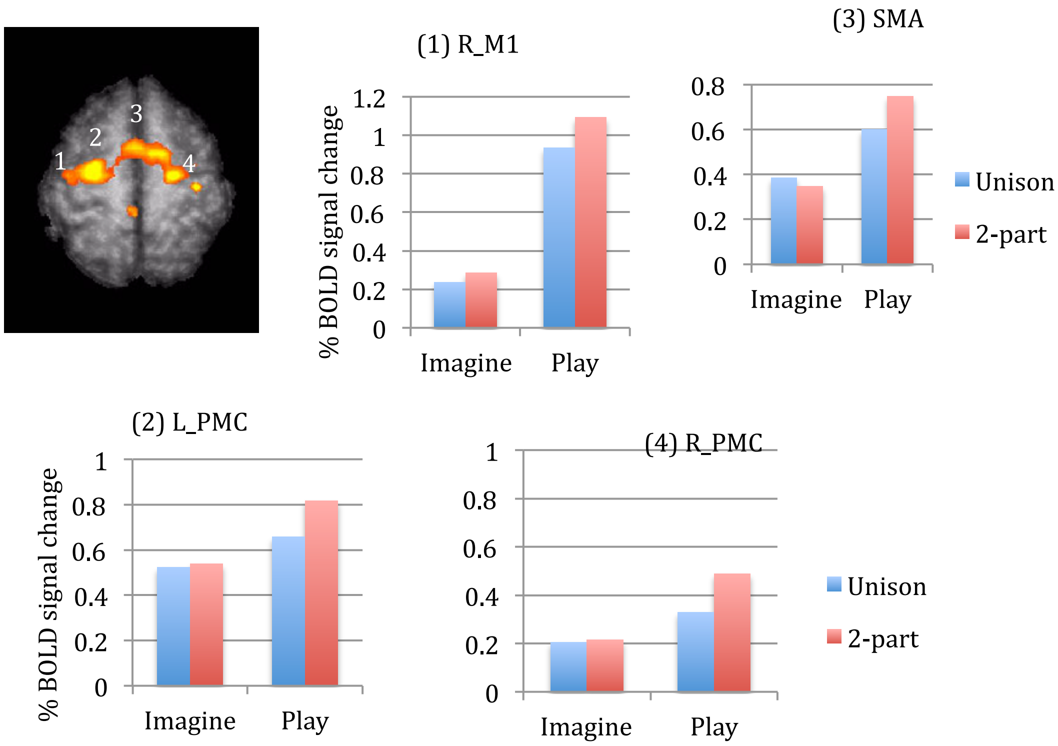


Figure 4.13: Volume maps showing activation in motor system in F test of complexity (R_M1[1], L_PMC[2], SMA[3], R_PMC[4], z = 54;) (p<0.01); bar charts showing % BOLD signal change.

4.3.3.6 Direct contrast between I2 > IU

Increasing musical complexity during imagining led to significant increases in the BOLD signal in several regions (p<0.05, corr), including right PMC (BA 6) and right PrCG (BA 6) (clusters correspond to those identified in F test of complexity), and in left MTG (BA 21) and L_FFG (BA 37) (Figure 4.14, Table 4.5).

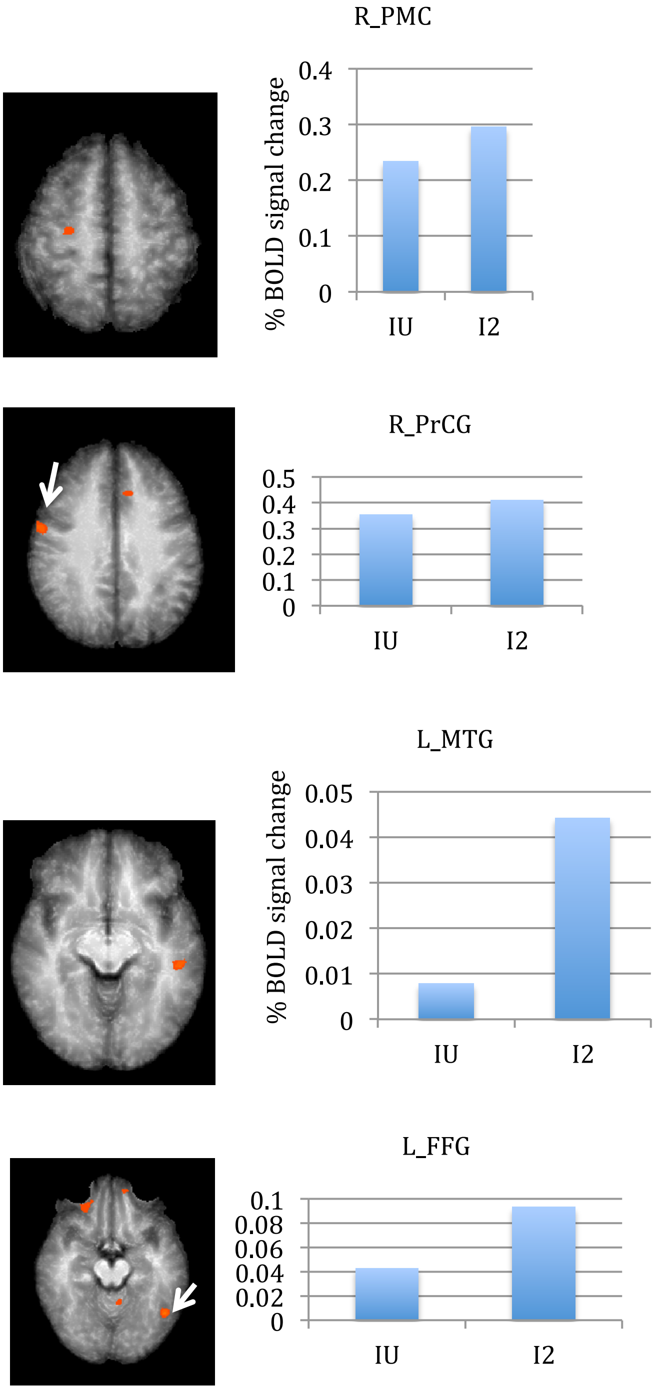


Figure 4.14: Volume maps showing activation in I2>IU in R_PrCG (z = 33), R_PMC (z = 51), L_MTG (z = -6), L_FFG (z = -12; bar charts showing % BOLD signal change.

Table 4.5: Areas showing significant effects in I2>IU (p<0.05, FDR corr).

Area	BA	n	*x*	*y*	*z*	*t*	*p*
R_PrCG	6	270	53	-2	33	4.004601	0.001499
R_PMC	6	163	23	-17	51	2.806235	0.014851
L_MTG	21	135	-49	-26	-6	2.925455	0.011816
L_FFG	37	269	-46	-56	-12	5.024222	0.000233

BA, Brodmann's area; n = voxels in cluster*;* *x*, *y* and *z* represent Talairach and Tournoux (Talairach and Tournoux, 1988) coordinates (for list of abbreviations see Appendix C, C.1.9).

4.3.3.7 Main effect of experience

Post-hoc analysis investigated whether there were significant differences in activation relating to participants' musical experience. Analysis of questionnaire data showed that seven participants were currently working as professional pianists, and that seven were either in the final year of a piano training course at tertiary level or had recently completed training to this level but were not working professionally as pianists ('students'). The average age of the student group (n=7) was 24 years (range 19-38) and the average age of the professional group (n=7) was 42 years (range 30-52). On average, students had begun piano training at the age of five, and professionals at age six. The students had played for an average of 19 years (range 13-33 years) and the professionals for an average of 35 years (range 22-50 years) (Table 4.6).

Table 4.6: showing mean age, start age, years of piano playing and current weekly playing for professional (n=7) and student (n=7) subgroups [range] (SD).

		Age	Start age	Years playing	Current playing (hours/week)
Professionals	Mean	42	6	35	13
(2F, 5M)	[Range]	[30-52]	[2-8]	[22-50]	[8-15]
	(SD)	(8.38)	(2.06)	(9.74)	(2.38)
Students	Mean	24	5	19	19
(4F, 3M)	[Range]	[19-38]	[4-8]	[13-33]	[5-30]
	(SD)	(6.6)	(1.4)	(6.83)	(10.38)

ANOVA with two within-subjects and one between-subjects (grouping) factor was conducted to discover whether there were any significant differences in activation between groups in prefrontal regions and auditory areas of STG. Results showed that professionals activated a number of regions significantly more than students (Table 4.7). In tests reported below, no interactions were observed between task, complexity or level of experience.

Professionals activated a small cluster in left MFG (BA 10) more than students in every condition (overall significance $F(1, 12) = 7.643$, $p = 0.017132$) (Figure 4.8). Imagining activated the area significantly more than playing ($F(1, 12) = 12.310$, $p = 0.004313$). There was no significant effect of complexity ($F(1, 12) = 0.677$, $p = 0.426764$). Professionals activated R_MFG (BA 10) significantly more than students in every condition ($F(1, 12) = 18.107$, $p = 0.001117$) (Figure 4.15); there were no significant effects of task ($F(1, 12) = 0.983$, $p = 0.341002$) or complexity ($F(1, 12) = 0.408$, $p = 0.534774$).

Professionals activated L_IFG (BA 9) significantly more than students in every condition (overall significance $F(1, 12) = 12.592$, $p = 0.004007$); there were no significant effects of task ($F(1, 12) = 1.529$, $p = 0.239851$) or complexity ($F(1, 12) = 2.757$, $p = 0.122686$) (Figure 4.15). The cluster identified in this analysis was anterior to the cluster identified in the *F* test of task, which was activated significantly more by imagery than motor performance (Figure 4.8). Professionals activated R_IFG (BA 44) significantly more than students in every condition (overall significance $F(1, 12) = 35.996$, $p = 0.000062$) (Figure 4.15). there were no significant effects of task ($F(1, 12) = 2.521$, $p = 0.138342$) or complexity ($F(1, 12) = 0.243$, $p = 0.630995$).

Professionals activated L_STG (BA 22) significantly more than students in every condition (overall significance F (1, 12) = 11.879, p = 0.004835) (Figure 4.15); there were no significant effects of task (F(1, 12) = 0.962, p = 0.345958) or complexity (F(1, 12) = 1.203, p = 0.294304).

Professionals activated right STG (BA 41) significantly more than students in in every condition (except that the cluster was deactivated in both groups in I2) (overall significance F(1, 12) = 8.522, p = 0.012860) (Figure 4.15, see also Figure 4.9). Playing activated the area significantly more than imagining (F(1, 12) = 18.395, p = 0.001052). There was no significant effect of complexity (F(1, 12) = 3.383, p= 0.090719). Professionals activated right STG (BA 42) significantly more than students in every condition (overall significance F(1, 12) = 32.623, p = 0.000097) (Figure 4.9). Playing activated the area significantly more than imagining (F(1, 12) = 14.435, p = 0.002533). There was no significant effect of complexity (F(1, 12) = 0.001, p= 0.973792).

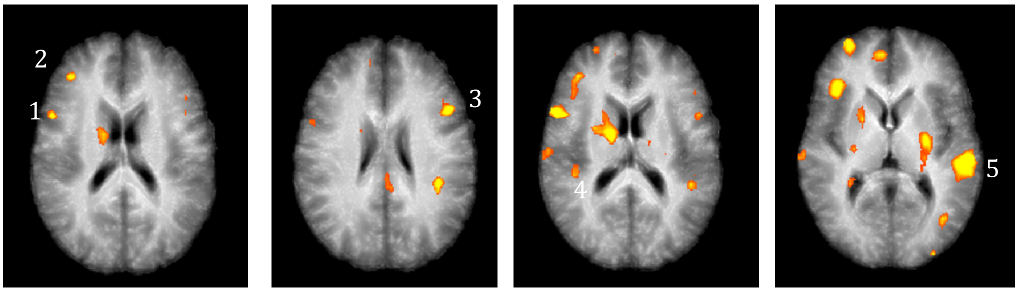


Figure 4.15: Volume maps showing clusters activated significantly more by professionals than by students ([1]R_IFG BA 44; [2]R_MFG, BA 10; [3]L_IFG BA 9; [4]R_STG BA 41; [5]L_STG BA 22).

Table 4.7: Showing clusters activated significantly more by professionals (n=7) than by students (n=7).

Area	BA	n	*x*	*y*	*z*	*F*	*p*	cf
L_IFG	9	471	-46	16	24	23.331882	0.000412	F task**
R_IFG	44	587	53	10	15	38.445835	0.000046	F task**
L_MFG	10	64	-40	43	20	16.004217	0.001760	F task*
R_MFG	10	328	38	37	18	19.077097	0.000916	Each>rest***
L_STG	22	978	-52	-29	6	24.260826	0.000351	P2>PU*
R_STG	41	117	41	-31	15	13.626360	0.003084	F task*
R_STG	42	169	65	-24	9	28.414711	0.000179	F task*

BA, Brodmann's area; n = voxels in cluster; *x*, *y* and *z* represent Talairach and Tournoux (Talairach and Tournoux, 1988) coordinates; cf active clusters identified in other tests.

* cluster in identical location (Table 4.4)
** cluster in different location (Table 4.4)
*** Appendix C, Figures C.2 & C.3

4.4 Discussion

As expected, and in line with previous findings (Chapter 1, 1.3.1-2), results showed that imagery and playing activated a similar network, including prefrontal, auditory and motor areas. In two left prefrontal regions (MFG, IFG), and in R_MFG, increased activation was observed during imagery (compared to playing), as predicted (4.1.3). Unexpectedly, increased activation during playing (compared to imagery) was observed in right IFG. When musical complexity increased during imagining, increased activation was observed in MFG bilaterally and in right IFG, as predicted (4.1.3). When musical complexity increased during playing, activation in bilateral MFG and bilateral IFG increased. Motor areas, including bilateral M1, were activated during imagining, and activation increased in line with musical complexity. STG was activated bilaterally in all conditions; in line with previous findings, STG activation was significantly greater during playing than during imagining. When musical complexity increased during playing, increased activation was observed bilaterally in STG.

4.4.1 Hypothesis 1

MFG

In line with previous evidence that MFG plays a significant role in musical processing, bilateral activation in MFG was observed in every task versus rest (Appendix C, C.3.1). Left MFG was activated to a significantly greater extent during imagining (compared with playing) (Figure 4.8). This finding fits the prediction that prefrontal activation would be greater during imagery, based on previous evidence that the increased processing demands of imagery, compared with performance, are reflected in increased prefrontal activation (Lotze et al., 2003; Kleber et al., 2007).

IFG

Bilateral activation in IFG was observed during both playing and imagining (Appendix C, C.3.1). Activation in left IFG (BA9) was significantly greater during imagining (versus playing) (Figure 4.8); this finding fits the prediction that prefrontal activation would increase during imagery, based on previous evidence of increased IFG activation during imagery compared with perception or performance (e.g. Haslinger et al., 2005; Kleber et al., 2007). Unexpectedly, activation in right IFG (BA44) was observed to be significantly greater during playing (versus imagining) (Figure 4.8). The observed task lateralization effect in IFG fits with findings from an EEG study by Kristeva (2003) in which bilateral frontal opercular regions (IFG) were shown to be involved in both playing and imagining a short, newly memorised violin phrase, with playing predominantly activating right side and imagery predominantly left side. Furthermore, a recent meta-analysis of neuroimaging studies found that fine motor control mapped to right IFG (specifically to a cluster in BA 45/47 inferior to that identified in the present study), and that working memory mapped to left IFG (Liakakis, Nickel, & Seitz, 2011: 344). Increased left IFG activation during imagining in the present study is therefore interpreted as reflecting increased memory demands due to the absence of external feedback, and increased right IFG during playing as reflecting an increased requirement for fine motor control.

4.4.2 Hypothesis 2

MFG

As predicted, increased activation in bilateral MFG was observed when the complexity of the musical task increased during imagery (and during playing) (Figure 4.11). These increases are believed to relate to increased demands on memory retrieval, working memory and mental monitoring processes due to increased musical complexity (Leaver et al., 2009: 2482; Herholz et al., 2012: 1394). Increased activation in MFG fits with previous findings of this region's involvement in working memory (Barbey et al., 2013) and in top-down attentional processes (Kincade et al., 2005; Vossel, Thiel, & Fink, 2006).

IFG

As predicted, activation in right IFG increased in line with task complexity during imagery; during playing, activation increased on both sides (L_ BA 44, R_BA 9) (Figure 4.11). This is in line with previous evidence that the IFG is involved when sound and action are linked during imagery (e.g. Bangert et al, 2006; Lahav et al., 2007). In a study of the role of left IFG in language tasks, Wright and colleagues (2010) found greater activation for complex compared with simple words when participants performed both lexical decision making and passive listening tasks. The increased activation observed in the present contrast is interpreted to relate to increased memory and auditory-motor integration demands of the two-part, compared with the unison piece.

4.4.3 Hypothesis 3

STG

Activation in bilateral STG was observed in each condition (Appendix C, C.3.1). Activation during playing was significantly greater than during imagining in bilateral STG; in line with previous findings (Lotze et al., 2003, Meister et al., 2004, Kleber et al., 2007), activation was observed in BA 41 during playing but not imagining, although it cannot be confirmed whether BA 41 clusters identified in the present study are in primary auditory cortex as no measures were taken to localise primary auditory areas in participants.

As musical complexity increased, increased activation in bilateral STG (BA22) was observed during playing (when sound was imagined), underlining the role that this region plays in musical imagery (Zatorre & Halpern, 2005; Haslinger et al., 2005) (Figure 4.12). During imagining, increased activation was observed in left MTG (BA21), an area in which Bangert (2006) observed increased activation (bilaterally) during a silent key-pressing task by pianists, compared with non-pianists (Figure 4.14). Activation in L_STG (BA 41) during playing decreased significantly as musical complexity increased (Figure 4.12). These differences are all understood to reflect the increased auditory processing demand of the two-part piece compared with the unison.

This study employed two-handed tasks that were equally matched motorically, and the resulting bilateral activation in STG during both imagery and playing provides new evidence of bilateral involvement of auditory cortex during imagery of instrumental music. Previous fMRI investigations of musical imagery in instrumentalists have used one-handed tasks (Lotze et al., 2003; Meister et al., 2004; Bangert et al., 2006). Bangert and colleagues found increased left-lateralised activation in STG in pianists (compared to non-musicians) but could not rule out the possibility that this result was attributable to the one-handed nature of the task and/or to level of expertise (2006: 922). Hemispheric differences have also been observed in studies of auditory imagery in non-experts: predominantly right-sided activation has been observed in secondary auditory cortex during imagery of instrumental music, which the authors attributed to the importance of right auditory areas for pitch processing (Halpern & Zatorre, 1999; Zatorre, Belin, & Penhune, 2002; Halpern et al., 2004). In a study of song imagery, these authors observed bilateral activation in secondary auditory cortex during, which they interpreted to reflect imagery of sung text and the musical component (Zatorre & Halpern, 2005:10). The current findings demonstrate that in expert pianists, instrumental music is processed bilaterally in STG.

Motor cortex

Results showed that imagery significantly activated the motor system including SMA, bilateral premotor and primary motor cortices (Table 4.2), providing further evidence of auditory-motor coupling in musicians (see for example Bangert, 2006). Although earlier fMRI studies of professional musicians did not find significant M1 activation during imagery (Lotze et al., 2003; Langheim et al., 2002), Kleber et al. (2007) subsequently found that M1 was activated during imagined singing. In the present study, R_M1 was activated during imagery at approximately 10% of the intensity during playing, and L_M1 at approximately 29% (Appendix C, Section C.3.2, Figure C.4). This is broadly in line with previous findings that imagining involves M1 at about 30% of the intensity of executed performance (Lotze et al., 1999; Porro et al, 1996; Kleber et al., 2007). The difference between left and right M1 activation during imagery in the present study is understood to reflect the relative vividness of imagining the right hand part (L_M1) compared with increased demand/decreased vividness of imagining the left hand part (R_M1) (Appendix C, Table C.3). During playing, R_M1 was activated more than L_M1, which is interpreted as reflecting increased effort in performing the left hand part (R_M1).

In contrast to previous findings by Lotze (2003), playing activated the supplementary motor area (SMA) significantly more than imagining (Figure 4.10); during playing, activation in SMA increased as complexity increased, but during imagining, activation in SMA decreased as complexity increased. In Lotze's study, musicians were asked to imagine movement, whereas in the present study the majority of participants reported that they focused on imagining sound (Appendix C, Table C.2) and these variations in the nature of the imagined tasks may contribute to this difference in results.

Unexpectedly, activation in motor areas (M1, PMC, SMA) increased in line with complexity during playing, despite the equal motor requirements of both tasks, and presumably reflecting the increased planning demands of the two-part piece (Figure 4.13). During imagining, activation in L_M1 (Figure 4.7) and SMA (Figure 4.13) decreased as complexity increased, suggesting that imagery vividness reduced as task difficulty increased.

4.4.4 Experience

Professionals (n = 7) activated MFG, IFG and STG significantly more than students (n=7) (Table 4.7). Because findings from studies in non-specialist populations have identified correlations between auditory imagery vividness and activations in MFG (Belardinelli et al., 2009), IFG (Leaver et al., 2009; Belardinelli et al., 2009), and STG (Zatorre, Halpern, & Bouffard, 2009; Belardinelli et al., 2009; Herholz et al., 2012), questionnaire data was examined to discover whether there were any significant differences between the two groups' use of auditory imagery. Professionals on average reported using auditory imagery during practice significantly more frequently than students (Appendix C, C.2.2). A one-tailed independent t-test showed that there was a significant difference in the frequency scores for professionals (M= 6.71, SD=0.76) and students (M=5.14, SD=2.12); t (12) = 1.78, p = 0.044. Professionals also rated auditory imagery as significantly more important than students: a one-tailed independent t-test showed that there was a significant difference in the importance scores for professionals (M= 6.71, SD=0.49) and students (M=5.29, SD=1.60); t (12) = 1.78, p = 0.022. No significant differences were found between professional and student ratings of the importance or frequency of use of any other types of imagery, or between self-ratings of imagery skills on any of the questionnaire items (Appendix C, C.2.2). Questionnaire and fMRI findings thus suggest that musical imagery was more vivid in the professional group.

Professionals (n=7) activated left and right MFG (BA 10) significantly more than students (n=7) in all conditions (Bangert et al., 2006). Professionals activated a cluster in left IFG (BA9) significantly more than students in all conditions; this was specifically in the same location as that identified by

Liakakis as relating to working memory (2011: 343), suggesting that memory retrieval processes in professionals were more efficient that in students due to increased practice. Professionals activated right IFG (BA 44) significantly more than students, possibly reflecting increased fine motor control due to increased years of practice. Professionals activated left STG (BA 22) and right STG (BA 41, 42) significantly more than students, suggesting that auditory imagery was more vivid in the professional group (see 4.1.2).

4.5 Summary and future directions

Imagery preferentially activated prefrontal regions involved in attentional and memory processes (MFG, IFG). Increased musical complexity accentuated activation in regions associated with attention, memory, motor and auditory processing. For the first time, the study demonstrated that increasing musical (but not motor) complexity accentuated activation in MFG, IFG and STG, areas that have been previously been identified as playing an important role in musical processing (e.g. Lotze et al., 2003; Kleber et al., 2007; Herholz et al., 2012), and more activated by musicians than by non-musicians during musical imagery tasks (Bangert et al., 2006; Schlaug, 2006: 147). These areas were increasingly activated by professional (compared with student) participants, which fits with evidence from other domains that imagery ability increases with experience (see for example Rodgers et al., 1991). As expected, imagery recruited similar brain structures to playing, corroborating previous evidence of the potential priming effect of imagery rehearsal on motor performance (e.g. Lotze et al., 2003; Kleber et al., 2007).

A key strength of the study was the use of carefully designed, novel musical tasks. The use of matched, two-handed musical tasks provided evidence for bilateral STG activation during musical imagery. Two shortcomings of the study were a) that during scanning, finger movement during imagery was only monitored visually, with no additional measures to show that fingers were kept entirely still and b) that primary auditory areas were not localised in participants. Future studies should investigate the role of auditory cortex in imagery tasks as current results suggest that there may be differences in activation, possibly in primary as well as secondary areas, relating to the vividness of participants' imagery.

Chapter 5 Conclusions

5.1 Aims

The underlying aim of this thesis was to enrich current understanding of expert musical imagery processes, and its central argument that strategic uses of imagery during learning can enhance performance. A key objective of the research is to provide evidence that could inform the development of systematic pedagogy for effective learning, thus helping to reduce physical and psychological stress in performing musicians. The design of the thesis was informed by three specific aims: 1) to examine applications of mental imagery to musical learning, 2) to explore current training in memorisation and mental imagery techniques and 3) to extend current knowledge of the neural mechanisms supporting musical imagery.

Three studies were designed to explore expert musical imagery, adopting a mixed methods approach. A participant observation study of a course for advanced pianists taught by Nelly Ben-Or [NBO] (Chapter 2) addressed the first two research aims. The study incorporated detailed description and analysis of imagery and memorisation techniques demonstrated by NBO. It also explored ways in which advanced pianists implemented NBO's training and what they felt they gained from adopting the techniques demonstrated. The study generated rich description of imagery techniques and examined real-world issues concerning the advantages and drawbacks of employing mental strategies. A questionnaire survey of advanced piano students (Chapter 3) also addressed the first two aims. This study examined which memorisation and imagery techniques were being advocated, taught and implemented at music conservatoires in the UK; it explored students' underlying conceptions of learning and memorisation, and examined frameworks used to scaffold the process(es). The survey examined the extent to which respondents implemented recommended techniques, and contexts in which knowledge was acquired. It also investigated potential relationships between strategy choice, confidence and skill. Finally, an fMRI study (Chapter 4) addressed the third aim by examining the neural mechanisms that support musical imagery. A key objective was to investigate whether neural differences between imagery and motor performance might provide insight into reported advantages of imagery rehearsal. An additional objective was to examine overlaps between imagery and motor performance, potentially corroborating previous evidence that mental and physical rehearsal activate similar neural networks and that imagery rehearsal may thus effectively replace some physical rehearsal. This chapter sets out key findings from each of the three studies in turn. In the central section, findings from all three are discussed in relation to the literature on musical memorisation, performance, attention to movement and neuroimaging. The final section discusses the particular strengths and limitations of the thesis and makes some suggestions for future research.

5.2 Key findings

5.2.1 A participant observation study of a course for advanced pianists taught by Nelly Ben-Or

A participant observation study of a five-day course for 11 advanced pianists aimed to develop a holistic understanding of NBO's teaching and to explore its outcomes. Data collection incorporated observation, participation, questionnaires, video documentation of piano sessions, photographs, video documentation of informal and semi-structured interviews, and handwritten notes. Numerical data generated by questionnaire responses were explored in descriptive terms through tabular analysis, and thematic analysis was used across the entire dataset. The study aimed a) to generate an interpretative description of NBO's pedagogy, b) to explore how course participants implemented her ideas and c) to examine advantages and drawbacks of the approach.

5.2.1.1 Three key features of NBO's pedagogy

The study identified three key, inter-related features of NBO's approach: 1) a 'prior memorisation' strategy, 2) explicit imagery techniques and 3) psycho-physical performance enhancement.

1) NBO taught pianists to internalise novel musical material away from the piano, combining analytical procedures and elaborative description with mental imagery. The aim of this prior memorisation strategy is to achieve meaningful learning and 'total inner' memorisation away from the keyboard, prior to rehearsal on the instrument. 2) NBO taught specific techniques combining visual imagery of the keyboard, visual imagery of note patterns on the keyboard and auditory imagery, both during the initial learning phase and for problem solving during rehearsal. Occasionally, fingerings were discussed, potentially eliciting some motor imagery, but NBO stated that she did not deliberately imagine finger movement. Technical difficulties were often addressed via visual imagery, and NBO demonstrated how other deliberate cognitive strategies, such as mental chunking and re-chunking note patterns, could be used to improve performance fluency. 3) Pianists were taught to apply principles of Alexander Technique [AT] to piano playing. NBO physically 'guided' students during their playing and advocated moving as simply as possible in order to produce the required sound, without no excess movement (but without restriction). The purpose of simplifying body movement is to reduce potentially damaging tension and to increase the focus on sound; and, ultimately, to achieve a sense of

'wholeness' that integrates expressive purpose, physical ease and emotional engagement with the performance feedback.

5.2.1.2 Participant responses

NBO's approach consists of a number of acquired skills that can be taught and improved over time; high levels of training and motivation are required if it is to be adopted in full. Course participants adapted aspects of the training to their own needs, preferences and habits and rarely used the approach in its entirety. Several factors mediated successful adoption of the approach, including adequate technical, sightreading, aural and theoretical skills, and the ability to maintain mental focus. For all respondents, learning material away from the piano required time, patience and motivation. No participants had been taught to use the prior memorisation technique except by NBO and in fact, none had been explicitly taught any techniques for memorising music except by NBO. Participants were more likely to report implementing strategies that had been clearly and explicitly taught, but they did not implement everything they were taught to do, even when they believed that they should. Following the course, participants reported reduced (or maintained) levels of physical practice and increased use of analysis/explanation, auditory imagery (with the score) and visual imagery (of the keyboard and of hand positions).

5.2.1.3 Advantages and disadvantages

Deliberate mental strategies, combined with increased body awareness, were associated with positive outcomes; overall the approach generated a sense of 'wholeness' or 'flow'. Participants believed that NBO's teaching resulted in improvements in physical performance, technical facility, musical quality, and memory security, although some reservations were expressed about the extent to which movement should be limited, and about participants' ability or motivation to adopt difficult aspects of the approach. Two participants worried that too great an economy of physical movement might inhibit expressivity and communication in performance, and that too great an emphasis on the mental aspects of learning might be detrimental to physical technique. More generally, some participants found it difficult to change habits, even when they felt they should, and one pianist reported that she was not fully able to use score study and imagery techniques prior to playing on the instrument due to a lack of analytical and aural skill. Participants reported that NBO's approach helped them to reduce physical tension, to reduce tiredness and to prevent technical difficulties. Understanding and being aware of how the body is moving appeared to lead to greater control and to a reduction in physical effort. Unexpectedly, although pianists were taught to become more aware of how they used their bodies, they reported that NBO's approach helped them to focus their awareness on the sound and the instrument, and that focus on fine motor movement actually decreased.

In summary, the participant observation study found that training in explicit memorisation and imagery techniques enhanced learning, and that these techniques could be viewed as acquired skills that improve with training and practice. These techniques did not appear, however, to be consistently taught.

5.2.2 Learning and memorisation amongst advanced piano students: Findings from a questionnaire survey

A survey questionnaire therefore set out to explore what a larger population of advanced piano students in the UK knew about mental (and other) learning and memorisation strategies. The questionnaire was structured around five key questions exploring 1) how respondents conceived of learning and memorising, 2) in what order respondents' most recent learning and memorising occurred, 3) how frequently students adopted recommended strategies and techniques, 4) the extent to which different learning contexts and types of activity were perceived to influence the development of personal practice strategies and 5) relationships between strategy choice, confidence, self-perception of skill and ease. Each of these five key questions was probed with mixed question types (Likert-type scales, forced-choice and open questions). Data were collected online from 36 pianists, studying at six music colleges around the UK. Numerical data generated by forced-choice and Likert-type answers were explored in descriptive terms through tabular analysis and thematic analysis was used to analyse responses to open questions.

5.2.2.1 How respondents conceived of learning and memorising

As expected, respondents' conceptions of learning and memorisation varied; some clearly differentiated between the two processes, while for others no distinction existed. Overall, conceptions of learning and memorising were interpreted as existing on a continuum, at opposite ends of which 'learning' is felt to involve aspects of knowing that might be characterized as 'external' (understanding content through analysis, and/or knowing physically how to play the notes) and 'memorising' is felt to involve 'internal' aspects (deliberate mental imagery and/or automatic playing). At the centre of the continuum, learning and memorising are indistinguishable and require integration of procedural knowledge, mental imagery and a sense of emotional connection or ownership – in other words, a multi-dimensional, internalised knowledge of the material that can be expressed through playing. Unexpectedly, the survey found that mental imagery was at least as important as being able to play the material for memorised performance. Furthermore, auditory imagery was identified as the most important factor in both learning and memorising.

5.2.2.2 Order in which respondents' most recent learning and memorising occurred

Four frameworks for learning and memorising were identified: two-stage, automatically integrated, deliberately integrated and prior memorisation. Some respondents appeared to give inconsistent reports about which of these processes they had most recently adopted. No consistent relationship between the type of process adopted and reported conceptions of learning and memorising was identified. Responses suggested that an integrated approach to learning and memorising might more often be perceived as a better option, but that some students did not adopt it as often as they (perhaps) thought they should.

5.2.2.3 *How frequently students adopted recommended strategies and techniques*

There was widespread awareness of mental imagery techniques: 67% respondents incorporated descriptions of mental practice when writing in their own words about their most recent practice. However, adoption of recommended mental imagery and deliberate memorisation techniques was less consistent than the adoption of recommended physical practice techniques. There was some evidence that students developed their own approach to uses of mental imagery, irrespective of what they were advised to do, with apparent discrepancies between teachers' and students' perceptions of how mental imagery should be used. Auditory strategies were not adopted as often as teachers recommended, but motor imagery strategies were adopted more often than teachers recommended. The majority of respondents (61%) were aware of the prior memorisation technique advocated by NBO, but only 32% reported adopting it frequently; furthermore, in open descriptions of recent learning only one respondent (3%) actually described using it.

5.2.2.4 *The extent to which different learning contexts and types of activity were perceived to influence the development of personal practice strategies*

Memorisation training was not consistently available, and where it did exist was considered the least influential of all types of training. Respondents tended to value practical music making (in a variety of formal and informal contexts) and embedded, explicit training most highly; they recognized that both explicit and implicit learning influenced their behavior, but felt that they were influenced more by experts than by peers. There were indications that although some techniques were recommended they might not always be sufficiently embedded in instrumental training at advanced levels for students to adopt them consistently. These included analysis, mental imagery techniques and the prior memorisation strategy.

5.2.2.5 Relationships between strategy choice, confidence, self-perception of skill and ease

There was widespread dislike of effortful memorisation. Those who expressed dissatisfaction with their working process felt that they should use more mental practice and/or improve their focus during practice, but (in line with findings from the participant observation study) found that even when they were aware of alternative methods it was difficult to change habits. Mental strategies were sometimes experienced as tiring, difficult and demanding; time constraints, combined either with a fear of not playing or with the desire to play, meant that non-playing strategies were not always adopted, even when students thought that such strategies might be beneficial. Dissatisfied respondents were more likely to rate themselves as below-average memorisers, and to find memorisation more effortful, than peers who were satisfied with their choice of methods.

Evidence from both the observation and questionnaire studies, however, suggested that imagery techniques were often experienced as difficult and were not consistently taught or implemented. Qualitative findings from the participant observation study suggested that strategic uses of imagery enhanced pianists' quality of learning and improved technical fluency, over and above what could be achieved via physical practice. These findings motivated an investigation of the neural basis of musical imagery that sought to explore the basis musical imagery, and potentially to illuminate qualitative findings.

5.2.3 An fMRI study of expert musical imagery

A study of 14 expert pianists aimed to extend findings from previous neuroimaging research by manipulating musical complexity while controlling for motor complexity. Pianists were scanned during imagery and motor performance of novel, bi-manual musical tasks, apparently for the first time. Previous studies of expert imagery have either used one-handed tasks that were more or less familiar to different participants (Langheim et al., 2002; Lotze et al., 2003; Kleber et al., 2007), or in which pianists performed one-handed novel tasks (Meister et al., 2004). In the present study, participants memorised two short, novel pieces of music immediately prior to scanning, following guided learning procedures (developed on the basis of findings from the two preceding studies). They were scanned during imagery and simulated motor performance of the memorised pieces, without auditory feedback. It was predicted that specific increases in activation in regions associated with musical and working memory processing - middle frontal gyrus (MFG) and inferior frontal gyrus (IFG) - would occur a) during imagery (compared to playing) and b) when musical complexity increased. It was predicted that imagining and playing would in general recruit shared neural networks, including motor networks and auditory areas of superior temporal gyrus (STG).

Results showed that as predicted, activation in prefrontal regions (left MFG, left IFG) increased during imagery (versus playing). For the first time, the study demonstrated that increasing complexity accentuated activation in MFG, IFG and STG, areas that have been previously been identified as playing an important role in musical processing (e.g. Lotze, 2003; Kleber, 2007; Herholz, 2012). Interestingly, these areas were activated significantly more by professional than by student participants. Research in other domains has found that imagery ability increases with experience (c.f. Rogers, Hall & Buckolz, 1991), and the present results suggest that these regions might be implicated in increased imagery ability, or vividness.

As expected, imagery recruited similar brain structures to playing, including motor networks, corroborating previous evidence of the potential priming effect of imagery rehearsal on motor performance (e.g. Lotze, 2003; Kleber, 2007). Unexpectedly, increased activation during playing (compared to imagery) was observed in right IFG. Importantly, findings also demonstrated that in expert pianists, instrumental music is processed bilaterally in superior temporal gyrus (STG).

5.3 Discussion

> … there is no thing that is just physical or just mental (NBO, interview)

For fluent performance, pianists require multi-dimensional, internalised knowledge, or imagery, of the material that can be expressed through playing (Chapter 3). Survey findings illustrated the fact that mental imagery is an essential part of memorised performance, echoing Bernardi's recent statement that performance necessarily includes mental imagery processes (2013: 285). The pianists who took part in these three studies work, almost exclusively, within the western musical tradition of notated composition; many of the concerns of this thesis are therefore specific to the particular situation in which a pianist aims to translate a written text into a lived musical experience, which 'may be regarded as an expression or manifestation of their personality' (Miklaszewski, 2004: 32). In other words, the notation has to have been understood and encoded in memory so that it can be recalled and reproduced in a manner that feels as though it is – and appears to be – a creative and expressive act, rather than a mechanical act of reproducing a series of sounds via key presses. An important finding from the participant observation study was that separating mental imagery rehearsal from physical rehearsal processes resulted in increased integration between musical intention and physical execution. While it may seem counterintuitive to argue that separating thinking from physical practice would result in greater integration, the observation data clearly speak to this idea.

This section brings together findings from across the thesis. It first explores the nature of expert musical imagery, and then discusses the various frameworks for memorising, or ways of internalizing the musical image, identified in the studies. Next, the potential benefits of imagery rehearsal are explored and finally, imagery training is discussed.

5.3.1 Aspects and uses of expert musical imagery

> … I think that it's a kind of memory that includes an inner sense of the action of playing that music which I see … the mental image includes the image of each happening on the keyboard, which includes a sense of the layout and how the hand proceeds on it, how it walks and runs around it, so that becomes a kind of total memory (NBO, interview)

All three studies corroborate previous evidence that expert musical imagery is, by nature, multi-dimensional (Holmes, 2005; Mishra, 2005: 75; Chaffin, 2009: 354). The participant observation study identified some apparently undocumented uses of expert musical imagery, as well as elaborating ways in which specific techniques can be applied and taught. An interesting observation was that technical difficulties were often addressed via visuo-spatial and auditory imagery. An unexpected (and unexplained) finding was that manipulating perception during difficult tasks, for example by reducing the perception of distance by re-imagining the layout of the keyboard, appeared to make tasks easier to execute. This technique, and that of re-imagining technically difficult passages (c.f. Chapter 2, 2.3.2.2) does not appear to have been described elsewhere. The visuo-spatial imagery techniques described in the study echo and expand on findings from an earlier study in which a guitarist reported visual imagery of finger patterns, like 'constellations', on the instrument (Holmes, 2005: 229).

NBO's pedagogy makes explicit a number of strategies for memorising text and pre-experiencing performance (c.f. Clark, Williamon, & Aksentijevic, 2011) without playing on the instrument. She aims to understand the text not only on the page but also, crucially, by imagining how it will be experienced as sound and on the keyboard during the act of playing. In order to learn an unfamiliar piece of music for memorised performance, she recommends a brief preview at the piano so that

> …you have a sense of how it will sound. Then explain it to yourself. To such a degree that you absorb the text in its complete experience on the keyboard. I don't know quite how to put it ... often I've suggested for someone to learn a piece away from the piano, they will then come and wouldn't know where to play it. So that made me realise that actually one has to memorise, not the text as a text on the page, but as a text translated into the happening of the music on the piano. (NBO, interview)

Although the research did not explicitly set out to compare the relative importance of different aspects of imagery, an unexpected finding of both the survey and fMRI studies was that auditory imagery was, overall, rated as the most important type of imagery. This fits with evidence that auditory imagery ability correlates with memorisation skill (e.g. Nuki, 1984; Bernardi et al., 2013) and that experts rely more on auditory imagery than on motor imagery when performing musical sequences from memory (Brown & Palmer, 2013). Conversely, at the end of a course in which imagery techniques involving visuo-spatial and structural imagery were taught more explicitly than auditory imagery, NBO participants reported that imagery of the keyboard and structural imagery were more important than auditory imagery; this may in part have been due to social desirability effects (Bryman, 2012: 227). What all three studies did agree on was that overall, pianists considered auditory imagery to be more important than motor imagery, and that structural imagery was also an important component (possibly becoming more important than motor imagery as expertise increased). This fits with converging evidence that secure establishment of a structural image is an important feature of expert memorisation (Williamon & Valentine, 2002; Chaffin, 2006). Finally, each study found that notational imagery was the type of imagery used by the least number of participants; this is in line with other evidence that while some musicians vividly imagine the score, others have no conscious access to a visual image of the text (Chaffin, 2009: 356).

5.3.2 Ways of internalising the musical image

> It's very easily possible… when you play it, when you practise it, that your fingers learn it and that you actually don't know what you're playing! (NBO interview)

The most commonly documented approach to memorising is to work at the instrument during the initial learning phase, and to memorise once performance is secure (Chaffin & Imreh, 1994; Miklaszewski, 1995; Mishra, 2005; Chaffin, 2007), sometimes incorporating score study or mental practice in the memorisation phase (Hallam, 1997). As the participant observation and survey studies showed, however, other learning models are available. Using NBO's approach, which is unusual but not unprecedented (Gieseking & Leimer, 1932; Brée, 1969; Hill, 2002) the pianist works away from the instrument during the initial phase, which includes both learning and memorisation. Meaningful learning is prioritized, and multiple musical images are deliberately rehearsed. Physical rehearsal is then a separate, second phase used for motor learning, checking feedback, refining and over-learning; during this second phase, note-reading is not required as the pianist has already memorised the musical text. The survey identified another alternative framework; some respondents described a deliberately integrated approach to learning and memorisation that incorporated deliberate cognitive strategies from the outset. For example, one respondent reported that

> [I] Played through the piece to have an idea of the structure and find the most difficult places to play and to memorize – started learning these sections, by dividing them into phrases and motives, playing each one slowly, then memorizing the left hand, right hand, hands together without score, up to speed without score, not moving on to the next phrase until satisfied, memorizing with everything on the score, try to never play mechanically …

Like this questionnaire respondent, advocates of prior memorisation emphasize the importance of a conscious approach to learning new material. NBO argues for only a brief preview at the piano, 'Not too much, so that you don't *unwittingly* simply teach your fingers to play …' (NBO, interview) (c.f. Hill, 2002: 131).

5.3.3 Potential benefits of imagery rehearsal

5.3.3.1 Clarity of intention facilitates ease of execution

> …[Lipati and Perahia] emphasize the getting to know the music as *the* most important aspect and then the mechanics of playing … [are] the last bit that has to be dealt with. And even that, I maintain, can be much enhanced and [one can] shorten the time of learning by intelligent scrutiny of what needs to be done... (NBO, interview)

NBO demonstrated ways in which imagery strategies could be used to clarify and understand musical content and intention and to memorise more securely, without inadvertently automating motor memory. As discussed above, studies observing instrumentalists memorising under natural conditions have more often shown that memorisation takes place towards the end of the learning process, once performance on the instrument is secure, and some survey respondents reported adopting this 'two-part' approach. Depending on the skill of the pianist relative to the difficulty of the musical task, a two-stage approach may not always be ideal, because 'memory is encoded during every learning activity, however deliberate or automatic the behavior' (Chaffin, 2009: 361). While memorisation is not necessarily articulated as an aim of this first stage of preparation, several forms of memory encoding are clearly taking place, more or less explicitly. During this initial stage, the text is read for content, structure and meaning (Aiello & Williamon, 2002); musical notation may be translated into sound in the mind (Brodsky et al., 2008) and notation is translated to a series of motor commands (Jäncke, 2006: 28). In this complex, multi-modal learning situation, the process of getting to know the material is intricately connected with the processes of encoding multiple images and simultaneously monitoring auditory and sensorimotor feedback.

For some learners, the main focus of attention during initial physical practice may be on producing the required sounds via score reading - in other words, on developing a procedural memory for performance – rather than on deeper processing of musical content and intention. Previous research has shown that implicit memory formed through repetitive practice is relatively inflexible; and that unlike explicit memories, which can be compared and revised, implicit memories can only be slowly refined rather than radically changed (Snyder 2000: 73). In practice this means that an automated habit, such as a suboptimal fingering, can be difficult to improve. From this point of view it makes sense that motor memory should be encoded explicitly, with 'awareness' (NBO, interview) rather than implicitly, by allowing the learning to be 'taken over by the fingers' (Rubin-Rabson, 1937: 12).

The fMRI study provides some insight into ways in which neural mechanisms are engaged when imagery rehearsal is separated from motor performance. Results showed that imagery and motor rehearsal each engaged aspects of both cognitive and motor processing differently. During imagery (versus motor) rehearsal, prefrontal regions involved in attention, working memory and musical imagery processes were more significantly activated. During motor performance, motor cortex was activated significantly more than during imagery. Both these findings suggest that in the absence of movement, increased attention was available for, and was necessarily directed towards cognitive aspects of the task.

A plausible explanation for the observed increases in prefrontal activation during imagery is that because the pianist is freed from having to engage with actual motor execution and feedback, the number of task demands is reduced and thus more attention is available for processing the musical image. Seven participants commented that musical imagery seemed more vivid in the absence of movement '…because I'm concentrating on just the one thing' (fMRI, P5). However, this was not always the case. For the two pianists with the greatest number of years of experience, there was no difference between the two conditions, while five participants reported that that having to imagine, rather than letting the fingers 'take over', makes 'the brain' work harder:

> When you're moving your fingers you've got access to the muscular memory bit, which is so reliable, and therefore you don't need to work as hard in the brain to do it properly … so I was definitely working harder on the imagined ones than on the playing ones (fMRI, P9)

5.3.3.2 Adopting mental learning strategies early in learning

Both the prior memorisation and deliberately integrated learning strategies prioritise deep learning, multiple memory encoding and early retrieval practice, all of which have been shown to be features of expert memorisation (e.g. Rubin-Rabson, 1950; Hallam, 1995; Chaffin & Imreh, 2002; Ginsborg, 2004; Holmes, 2005). Memory failure in performance may occur when retrieval codes differ from those used during encoding (Hallam, 1997: 96). From this perspective, beginning the learning process by unconsciously encoding automated programmes (via playing) and subsequently creating structural retrieval cues (via score study) may create a mismatch during performance, or may at least be inefficient or redundant. If deliberate cues are to be used for retrieval during performance it may be more efficient and reliable to prioritise them from the outset of learning, in order to avoid unconscious encoding of automated cues. In creating a stable memory for performance the pianist is likely to make use of multiple images, bringing different images into the focus of awareness as conditions require or allow. During both learning and performance the musician may need to prioritise attention towards particular images at the expense of others, and the order of priority during learning and performance might therefore ideally reflect each other.

According to common-coding theory (Prinz, 1990, 1997), perception and action require a common representational medium. Thus, actions will be more effective if they are planned in terms of their intended outcome or effect, rather than in terms of the specific movement patterns (Wulf & Prinz, 2001). It is widely recommended that during musical practice, performers should focus on sound and musical structures, not on the actions that produce the sound – in other words, that practice goals should match performance goals (e.g. Hallam, 1995; Highben & Palmer, 2004). One advantage of mental rehearsal in the absence of physical rehearsal, particularly during the initial stages of learning novel material, may be that specific movement patterns do not need to be planned, and thus increased attention can be focused on the intended effects of movement.

5.3.3.3 Attention to movement effects increases ease of execution and sense of flow

An interesting and unexpected finding from the participant observation study was that although pianists were taught to become more aware of how they used their bodies, they reported that focus on movement actually decreased, while their focus on sound and sense of connection with expressive intention increased. This was achieved both through the initial 'explanation' and mental learning of the text, and through imagery of the keyboard, patterns on the keyboard, auditory imagery, and through awareness of the whole body as an integrated whole. An outcome of this approach was that pianists could focus more attention on intended outcomes/distal effects, rather than on fine motor movement. Survey findings suggested that other teachers were also encouraging students to focus more on auditory than motor imagery. There may be good reason for expert musicians not to focus on motor sequence learning during the first stage of learning, because for optimal performance, attention is ideally diverted away from the process of performing the task (see for example Milton et al, 2008; Dietrich, 2008; Highben & Palmer, 2004). Focusing attention on content and interpretation during the initial stages of learning might therefore promote a continued focus on these aspects of memory during subsequent playing, in preference to a focus on motor performance.

> I practise it [mentally] so that the actual external physical thing …gets the experience of it because I've internalized it completely. And it will come from inside … when I play it I don't feel that I have to run to get the next thing, they are there waiting for me so to speak, they are there in my mental representation waiting to be audible. (NBO interview)

The participant observation findings suggest that, provided they have sufficient skill, pianists can usefully pay more attention to cognitive and non-motor aspects of musical tasks, and less to the fine motor aspect, than often thought (or taught). Once the mental image is clear, technical issues can be reduced or eliminated. These qualitative findings fit nicely with a study by Duke and colleagues (2011), who tested the extent to which learners performing a simple keyboard passage would be affected by directing their focus of attention to different aspects of their movements. Results showed that temporal evenness was most accurate when participants focused on the effects their movements produced (i.e. the sound) rather than on the movements themselves. These authors found that the more distal the focus of attention, the more accurate the motor control (c.f. Chapter 1, 1.2.13). Thus mental imagery rehearsal provides a means of directing attention away from the motor task, effectively reducing cognitive load by chunking information in manageable stages, prioritising attention and consequently, a means of increasing ease of execution.

5.3.4 Training in imagery techniques

All three studies showed that explicit training in memorisation techniques is not essential, as many pianists achieve levels of professional excellence with little or no explicit instruction. The participant observation study, however, showed that even expert pianists felt that training in imagery techniques did confer considerable benefits, which fits with suggestions that musicians benefit from explicitly adopted memorisation strategies (c.f. Aiello & Williamon, 2002). One advantage of NBO's approach is that mental imagery processes, which are part of performance, are made explicit:

> I think the teaching made many sub-conscious aspects of playing easier to understand and this has helped me, (P8, Q3)

Expert uses of mental learning techniques such as analytical pre-study and the deliberate rehearsal of musical imagery have been previously documented (Gieseking and Leimer, 1932; Hallam, 1997; Hill, 2002), and as the survey showed, these techniques are generally accepted to be of value and are widely recommended. Some research suggests that mental techniques enhance learning (e.g. Rubin-Rabson, 1937, 1941; Ross, 1985) or can effectively replace a certain amount of physical rehearsal (Theiler & Lipmman, 1995; Coffmann, 1990; Bernardi et al., 2013), but music pedagogy does not appear to incorporate their use widely (Holmes, 2005). Both the survey and participant observation studies indeed found evidence that training in memorisation skills was inconsistently provided (c.f. Ginsborg, 2004: 149). Survey data showed that (averaged across all contexts), 26% respondents had taken part in memorisation training sessions, and 29% respondents in learning strategies training sessions. Only 14% reported that memorisation was taught at their college, and none of NBO's course participants had been trained to memorise except by NBO. The survey population was, however, more aware of mental strategies than previous research might indicate, suggesting that – at least at advanced training levels – pianists are becoming aware of the growing literature on imagery strategies (c.f. Holmes, 2005; Gregg, Clark, & Hall, 2008; Clark, Williamon, & Aksentijevic, 2011).

The participant observation explored detailed teaching of imagery techniques that do not appear to have been described elsewhere. Many expert pianists use a combination of mental learning and score study in various sequences (see for example Hallam, 1997), but what appears to be particular to NBO's approach is the emphasis on learning the material from an integrated, multi-dimensional perspective prior to physical rehearsal. A prior memorisation approach was advocated by Gieseking & Leimer (1932) and Leschetizky (Brée, 1969), and was found to have been recommended to 62% of the advanced piano students questioned in surveyed (Chapter 3). None of those surveyed, however, reported having been taught how to use it (and only 3% had used it in recent learning). Similarly, none of the participants in NBO's course had been taught to use this learning method other than by NBO.

5.3.4.1 Acquired skill

Inconsistent adoption of mental practice and memorisation strategies by the survey population suggests that various techniques may be recommended more often than they are explicitly taught: the majority of respondents were aware of a variety of imagery techniques, but like NBO's course participants they did not necessarily adopt these strategies. The memorisation strategy that students were most likely to adopt, when it was recommended, was that of playing through from the score until memorisation was achieved automatically - despite widespread recommendations to remove the score as soon as possible and to use a variety of mental reinforcement techniques to ensure that multiple encoding took place. Those who expressed dissatisfaction with their working process felt that they should use more mental practice and/or improve their focus during practice (which might be a similar thing), but like NBO course participants, found that mental strategies were often experienced as tiring, difficult and demanding. Time constraints, combined either with a fear of not playing or with the desire to play, meant that non-playing strategies were not always adopted, even when students thought that such strategies might be beneficial.

Both the observation and survey studies for this thesis found that some advanced pianists, despite years of thorough musical instruction, had never been taught strategies for deliberate memorisation. Some pianists on NBO's courses reported that they often spent large amounts of time practising without improving problematic sections. Less proficient participants, and some survey respondents, were frustrated by their inability to memorise quickly and anxious about their reliance on text. The first two studies found that while teachers may advocate the use of mental practice, students are not often taught how to implement specific techniques. Presumably because mental imagery techniques are not sufficiently embedded within teaching, and are not taught early enough, they are experienced as difficult and many pianists do not use them regularly, or in ways advocated by teachers, even when they feel that they should. Although there are suggestions throughout the music psychology and pedagogical literature, that musicians should use mental imagery during practice (Connolly & Williamon, 2004; Rosset i Llobet & Odam, 2007), the existing literature on exactly how to implement imagery techniques in rehearsal is sparse. A significant benefit of NBO's work appears to be that she teaches practical working methods for deliberately using imagery during learning. Advanced pianists on the course, including highly trained professionals, were observed to make considerable technical and musical progress when taught these techniques.

5.4 Strengths and limitations of thesis and methods

The key strengths of this thesis are that it draws on real-world, expert knowledge. Whereas much previous research has focused on evidence that imagery rehearsal might effectively replace some physical rehearsal, this research set out with a different aim - to understand how, and why, performance might be enhanced by applying imagery techniques to learning. By using mixed methods the thesis is able to present a nuanced and multi-layered account of the experience, advantages and drawbacks of musical imagery rehearsal. Qualitative findings from the first two studies contributed to the design and interpretation of an empirical brain imagining study, and in turn, findings from this study provide insight into the experiences of imagery rehearsal reported in the two qualitative studies. The thesis contributes novel findings to the literature on expert musicians' imagery by providing detailed descriptions of previously undocumented techniques and by showing that these can – and should more often - be taught as acquired skills. In addition, the novel design of the fMRI study produced results that corroborate and extend previous findings concerning the neural mechanisms supporting imagery processes.

While the adoption of a mixed-methods approach provides a broad perspective, results across studies cannot be directly compared, and the advantages gained are potentially achieved at the expense of some depth in the analysis, particularly because several data analysis techniques are adopted. There were inconsistencies in some of the questioning due to the iterative nature of the research. For example, not all the strategies identified in the first study were probed in the second; furthermore, a more fine-grained understanding of motor imagery emerged only during the course of the final study and could not be incorporated retrospectively. Each study had a number of methodological issues. In the participant observation study, the design of the three questionnaires was somewhat inconsistent, and the follow-up questionnaire did not adequately assess whether views reported at the end of the course had been modified over time. Because questioning in this study failed to distinguish between different aspects of motor imagery, some of the findings were unclear. The survey questionnaire did not include participant observation findings concerning keyboard imagery. In this study, clearer questioning about how imagery skills are actually taught would have added validity to a number of interpretative findings. Finally, fMRI study did not include localisation of primary auditory cortex in individual participants, which would have facilitated a fuller interpretation of results in the superior temporal gyrus.

5.5 Implications for future research

A number of specific suggestions for future research arise from this work. Focusing on different types of imagery may be more or less beneficial and may have different outcomes (cf. Nuki, 1984; Belardinelli et al., 2009; Duke, Cash, & Allen, 2011; Bernardi et al., 2013) and therefore research should continue to examine ways in which attending to different aspects of the musical image may affect outcomes. Specific techniques and strategies identified in this thesis could be usefully examined using a variety of methods. These include the use of non-motor imagery to encourage focus on distal effects and the use of condensed imagery of the keyboard for improving performance of complex material. Future neuroimaging work should examine differences in auditory cortex activations arising from different levels of expertise and relative to differences in imagery vividness.

An issue that has been repeatedly encountered by previous researchers (c.f. Bernardi et al., 2013; Clark, Williamon, & Aksentijevic, 2011) is that participants in experimental studies of musical imagery have had very little prior training or experience in deliberate imagery techniques. The findings from this thesis evidence a number of practical techniques that might be used to train participants in future studies, and that can be used to develop more fine-grained investigations of imagery rehearsal.

The thesis proposes that imagery rehearsal can enhance the quality of expert musical performance, and found that, for NBO course participants, improvements in their own experience of learning and performing were important outcomes of the training. It is suggested therefore that qualitative measures of how imagery rehearsal affects the experience of musical learning and performance should be used, alongside other qualitative and quantitative measures of performance, in order to continue developing well-researched training programmes. Many of the pianists who contributed to this research stated that, even when they had been taught how to use mental imagery and believed that it benefited their learning, they preferred to play. Future studies could investigate practical methods that encourage students to incorporate a variety of strategies, and at various stages of training, and should explore the extent to which such strategies might improve confidence and reduce anxiety.

The studies in this thesis did not set out to test whether any of the strategies identified were superior to others. One NBO course participant was already using the type of strategies advocated by NBO but not in the order she proposes. This pianist (on the evidence of the observation) was able to memorise reliably and quickly, which begs the question of whether prior memorisation is necessarily superior to, for example, a mixed approach in which imagery rehearsal is interspersed with physical practice (c.f. Rubin-

Rabson, 1941). Prior memorisation strategy be usefully compared with an integrated approach, in which imagery techniques are adopted alongside physical practice from the first stages of learning novel material, and both of these strategies compared with a two-stage approach which, present findings suggest, may be less effective overall.

5.6 Concluding remarks

This thesis explores the idea that targeted uses of imagery rehearsal techniques can produce qualitative differences in learning and performance. Separating imagery rehearsal from physical rehearsal resulted in positive outcomes for all NBO course participants; subsequent physical effort was reduced, while the focus on sound and sense of 'flow' increased. Survey responses emphasised that mental imagery is an essential part of memorised performance, and suggested that an integrated approach to learning and memorising may sometimes provide a more effective means of internalizing the multiple images required for performance than a two-stage approach. In all three studies, whatever learning strategies participants adopted, memorised performance was achieved, and lack of explicit training did not prevent the majority of participants from developing high levels of skill. However, when pianists were explicitly trained in mental learning techniques, memory security was enhanced; even at very advanced levels, distinct benefits were reported. fMRI findings provide further evidence of distinctions during cognitive processing during imagery rehearsal that may explain some of these observed effects; in this study, activation in prefrontal areas associated with working memory processes increased during imagery, compared with playing. In addition, the participant observation study demonstrated that imagery techniques can be taught as acquired skills that improve with practice. Analysis of fMRI data to some extent backs up these findings: results shows that as experience increased, areas associated with musical processing were increasingly activated.

Findings suggest that imagery rehearsal is much more than a substitute for physical rehearsal. Specific techniques can and should be taught in practical contexts. They can be used to enhance memorisation, to focus awareness on the intended outcomes of performance, rather than the means of reproduction, and to improve body awareness during playing. Perhaps most importantly for the musician, findings from the participant observation study suggest that imagery rehearsal can help to facilitate integration between the demands of physical execution and the performer's expressive intent, physicalised in sound.

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Appendix A Supplemental Materials for Chapter Two: A Participant Observation Study of a Course for Advanced Pianists

A.1.1 Letter of introduction

Contact Details

Dear Colleague,

I am carrying out PhD research into the learning and memorisation of piano music, based at the University of Edinburgh.

As part of my research I would like to document as much as possible of Nelly Ben-Or's teaching this week on video. I am also interested in your experiences.

I have two questionnaires for everyone taking part this week. You are under no obligation to complete the questionnaires or to be videoed - it is entirely up to you whether or not you wish to do so.

If you ARE willing to complete the questionnaires, please find the first one attached. The second will be handed out towards the end of the course.

If you ARE willing to be videoed, please sign the attached form.

If at any point you decide you do not wish to be involved, please just let me know (by email, phone, text or in person).

Many thanks for your time!

Kirsteen Davidson Kelly

A.1.2 Consent form

NAME:………………………………………………………………………..

AGE:…………

I am happy to take part in the video recording of this week's course and for Kirsteen Davidson Kelly and Nelly Ben-Or to analyse the material.

Signature…………………………………………………………………………

I am happy for video extracts containing my image to be used in public presentations.

Signature…………………………………………………………………………

A.1.3 Questionnaire 1 (Q1)

At what age did you begin playing the piano?
Do you consider yourself to be professional/semi-professional/amateur?
Are you primarily a teacher or performer?
What is your musical training background?
Do you find it easy to memorise?
Were you explicitly taught how to memorise music?
Describe what you were taught to do:
Which teacher or method did you learn from?
How do you currently learn a new piece? Describe the process from first listening to the piece or reading the score through to the full performance (whether or not this is in public).
Why did you decide to come on this course?
What do you hope to get out of the course?

Rate your skills prior to this week's course on the following scale by circling one number.
1 = no skill and 5 = expert

Memorisation 1 2 3 4 5	Detailed analysis 1 2 3 4 5
Score reading 1 2 3 4 5	Understanding of form 1 2 3 4 5
Transposition 1 2 3 4 5	Piano technique 1 2 3 4 5
Teaching 1 2 3 4 5	Performance skills 1 2 3 4 5

Rate the amount of training you have received prior to this week's course.
1= none and 5 = professional level.

Memorisation 1 2 3 4 5	Detailed analysis 1 2 3 4 5
Score reading 1 2 3 4 5	Understanding of form 1 2 3 4 5
Transposition 1 2 3 4 5	Piano technique 1 2 3 4 5
Teaching 1 2 3 4 5	Performance skills 1 2 3 4 5

When learning a piece, which aspects are most important to you? Rate the following on a scale where 1 is not important and 5 is very important.

VISUAL	Image of score	1 2 3 4 5
	Image of keyboard	1 2 3 4 5
	Image of hand positions	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
AURAL	Listening to recorded or live performances	1 2 3 4 5
	Imagining sound by reading score	1 2 3 4 5
	Recalling sound from memory	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
MOVEMENT	Practising on piano	1 2 3 4 5
	Imagining movement	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
STRUCTURAL	Understanding form	1 2 3 4 5
	Analysing content	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
ASSOCIATIVE	Mood	1 2 3 4 5
	Narrative	1 2 3 4 5
	Other (please describe)	1 2 3 4 5

A.1.4 Questionnaire 2 (Q2)

NAME: ………………………………………………………………………..

Was the course what you were expecting?
What did you benefit from most?
Was there anything you did not understand?
What will you take away and do differently?
Were there any aspects you would not wish to adopt, and why?
Would you come on the course again, and why?

Do you have any further comments you wish to add?
May I contact you in the future? If so, please give your postal address and/or email.

Having taken part in this week's course, to what extent do you expect the following aspects of your work to be affected in the future?

Rate the level of impact you think the course will have on your work by circling one number.

1 = no change to my existing method………… 5 = complete revision of my method

Memorisation	1 2 3 4 5	Detailed analysis	1 2 3 4 5
Score reading	1 2 3 4 5	Understanding of form	1 2 3 4 5
Transposition	1 2 3 4 5	Piano technique	1 2 3 4 5
Teaching	1 2 3 4 5	Performance skills	1 2 3 4 5

Which aspects of learning a new piece might be most important to you in future? Rate the following on a scale where 1 is not important and 5 is very important.

VISUAL	Image of score	1 2 3 4 5
	Image of keyboard	1 2 3 4 5
	Image of hand positions	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
AURAL	Listening to recorded or live performances	1 2 3 4 5
	Imagining sound by reading score	1 2 3 4 5
	Recalling sound from memory	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
MOVEMENT	Practising on piano	1 2 3 4 5
	Imagining movement	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
STRUCTURAL	Understanding form	1 2 3 4 5
	Analysing content	1 2 3 4 5
	Other (please describe)	1 2 3 4 5
ASSOCIATIVE	Mood	1 2 3 4 5
	Narrative	1 2 3 4 5
	Other (please describe)	1 2 3 4 5

A.1.5 Questionnaire 3 (Q3)

1 What aspects of NBO's teaching have helped you most?

2 What aspects of NBO's teaching have not helped you?
Is this because you disagree with her methods/they do not suit you/ you need further teaching?

3 How has your whole approach to playing developed since beginning your studies with NBO?

4 Which physical aspects of your playing have been affected by NBO's teaching, and how?

5 Has NBO's teaching affected the way you think about learning and/or memorizing piano music, and if so how?

6 I would summarise NBO's approach to learning a new piece as follows:

- i Play through from the score once or twice.
- ii Analyse ("explain") the piece, in outline and in detail.
- iii Prepare and memorise the piece away from the piano, combining structural knowledge with mental representations of the keyboard, of your movement on the keyboard, and of the sound.
- iv Play on the piano once the piece is known
- v Refine at the piano and away from it

a) Do you agree with my summary, or do you have an alternative description of the method she proposes?

b) Describe how you actually learn new pieces currently. Do you do what NBO recommends, or have you found that another approach works better for you?

7 Which of the aspects of learning described in question 6 do you find

a) Easy b) Challenging c) Impossible

8 What are the benefits of working on music away from the piano BEFORE working on the instrument itself?

9 What difference, if any, do you think there is between memorising away from the piano BEFORE playing, compared to learning at the piano and THEN working away from the piano to understand and memorise?

10 What are the difficulties of applying NBO's learning method?

11 Since beginning your studies with NBO, how have you changed the way you spend your time? (please tick one box each process):

	More time	Less time	Same amount of time
Analyzing/explaining			
Imagining sound by reading score			
Recalling sound from memory			
Working on mental representations of keyboard			
Working on mental representations of hand positions			
Working on mental representations of movement			
Practising on the piano			

12 Do you have any further comments or questions? THANK YOU!

A.1.6 NBO semi-structured interview script

1. Could you summarise what the course is about?
2. Tell me about your very first musical experiences.
3. When did you start playing the piano?
4. Whom did you study with and where?
5. What other aspects of music were you trained in?
6. How were you initially taught to learn and memorise music?
7. Is your current working process different? How did you arrive at it?
8. Would you describe how you now learn an unfamiliar piece?
9. Why do you consider this the most effective way to work?
10. Are you aware of other musicians who work in similar ways? Is it common?
11. Have you been influenced by particular teachers or methods of memorisation, mental practice or other techniques?
12. To what extent do you distinguish between learning and memorisation?
13. Does your approach differ if you are not aiming to perform from memory?
14. During learning, do you listen to other people's performances?
15. Does it make any difference in the long term whether you memorise a piece before or after playing it?

16. Could you talk in more detail about how you prioritise the various aspects of learning a new piece?

17. Is it possible to separate a mental image of the sound from a mental image of the movement required to produce the sound? Would you want to do this?

18. What type of analysis do you use as an aid to performance?

19. Which types of memory do you rely on in performance implicitly/explicitly?

20. What common learning and memory techniques do you deliberately avoid and why?

21. Have you ever experienced memory lapses in performance? What caused them?

22. How has your memorizing ability changed over the course of your career?

23. How do you think most students are taught to learn and memorise?

24. Can you identify students for whom your approach works best/not at all?

25. Have you seen significant changes in the way in which pianists are taught during your career?

Nelly Ben-Or

Professor at the Guildhall School of Music & Drama, London, since 1975.

This distinguished pianist (who is also a senior Alexander teacher) is recognised internationally as being the leading exponent of the application of the Alexander Technique to piano playing. She has specialised in this field for more than forty years and gives master classes on this subject to pianists in many countries throughout the world.

Nelly Ben-Or works on various aspects of piano playing, such as ways of learning and memorising new scores, deepening the player's understanding and interpretation of the music. She also aims at improving freedom, velocity and fluency in playing. This approach leads to increasing the player's listening awareness for greater clarity of performance. Through applying the basic principles of the Alexander Technique to playing. Nelly Ben-Or teaches pianists a way of working which prevents disturbing tensions or possible injuries which can often result from faulty ways of practising.

Participants have individual sessions at the piano with Nelly Ben-Or and a short daily session in the Alexander Technique.

These courses generate a supportive and informal working atmosphere in which many questions of interpretation and technical challenges are worked on. They attract advanced students, professional pianists and piano teachers, a number of whom have returned many times.

Figure A.1: Showing extract from course leaflet, July 2007.

A.1.7 Data analysis

Date	Time	Pianist	Piece	Notes
16/7	2.55	2		N asks J sit lower. manipulates neck gently & mid back.
NBO — AT	at piano open-ness			listen to own playing from conditioned open-ness where you don't pull yrself into the piano. pulling etc 'feels necessary because we are used to it'
listening	intention			head "delicately preset". before playing listen to first phrase. then transfer intention to kbd so it gives you the voice you want to hear. (All time touching his back & upper chest) J "VERY strange. I've never sat this low before ever in my life".
inner hearing & contact with kbd				N you begin to form relationship between inner hearing & contact with keyboard. (Piotr arrives).
Perahia	learning			Murray Perahia said, 4 new piece: 1st "fake it" then away from piano (he studied comp & conducting) studies from score & writes extraction of musical score. showed N ms of his own musically notated extraction (5 or 6 pages of Goldberg). Then knows it then takes to piano, then may have to work some technical aspects & finalise intentions.
NBO piece but	has sense of WHERE happening not	on kbd HOW		N: (image a) sense of where a piece will be happening on kbd but not how.
egs	great	pianists		YouTube Rubinstein playing Appassionata. Sits almost doing nothing. mentions video of him playing Mendelssohn D minor trio with Heifetz, same thing.

Figure A.2: Showing course notes with initial coding annotations.

✓ 52 receive from the keys in order to bring out mid voi[ce]

52.50 See bass in small area

? 53.30 Re[illegible] works.

power of intelligence to bring out what we wish for

52.13 we do need autopilot to concert, but v. well recorded

(PLANNING INTENTION)

56? change of fingering to get line won't break but habit still there.

1.01:00 C says aware of shoulder NBO "be in there (hands)

1.03 more flowing tempo

1.05 issue of not being in self NBO - give to kbd

plays again - different

CONNECTION WITH SELF ✓ 1.06 ASK more & more, then less after 'good' playing

wholeness openess (wiggles fingers).

1.06.38 Whole of yourself. AT. Centre, connected w[ith]

depth of self.

1.07.30 plays it again compare?

? transformation through mental adjustment 1.08.30 STAY in pool of sound (happy - easy)

do less, get more.

1.09.30 C explains feeling of being connected

moves become smaller.

letting go of worrying. trusting.

1.11.11 piece unfolding,

1.11.50 Stay in kbd (NBO hands on)

1.12.30 slow practice gave probs. learn wrong how to play staccato! physical behavio[ur]

PHYSICAL LOCKING 1.18 don't 'go' with wrists - rock

1.20 DISTANCES

1.20.55 image of musical movt is NOT same as physical movt

plays again differently.

MUSICAL MOVT VS OUR PHYSICAL MOVT

image of musical movement does not have to correspond with image of physical movement

add ✓

Figure A.3: Showing video review notes with initial coding annotations

Appendix B Supplemental Materials for Chapter Three: A Questionnaire Survey of Advanced Piano Students

B.1 Conceptions of learning and memorising

Table B.1: Open descriptions of learning categorised according to 5 themes emerging from analysis of responses (n=28).

Learning is … Learning to play: procedural knowledge (12 responses)

- Being able to play the music
- teaching your fingers where they should automatically place themselves
- fairly straight forward. it's just a case of learning the notes etc
- Mainly motoric, physical memory
- making the technical details of playing automatic
- to read the notes, rhythms and details of the music
- reading the notes and playing them
- Learning the notes
- gaining the ability to play a piece of music
- learning techniques and skills you can apply to a piece
- being able to play fluently while glancing at the music for frequent reminders (if the passage is difficult, or reading if it's easy)
- to read the notes, rhythms and details of the music

Learning is … Understanding content/intention (6 responses)

- understanding what you play, what is behind the notes and how to convey this
- understanding the piece - perhaps through theory
- Knowing what you're doing
- understanding the subject
- understanding why you do something the way you do
- One can have a complete artistic conception of a piece without memorising it

Learning is … Mental & physical (3 responses)

- is process, that could be devided in many different aspects ... such as -today I am learning harmonical structure… I am learning just technical difficulties of left hand … Sometimes it takes lot of time just to get "right " idea of WHAT we want to do with certain piece of music-how we are going to "shape" it. So learning could be mental process (sic)
- getting to know the musical composition as a whole, both the notes as well as all the movements etc involved in playing the piece.
- Learning the notes and then the interpretation

Learning is … Memorising (2 responses)

- internalizing information
- Memorising, Interpretation, Modifying pieces on successive performances

Learning is … General familiarisation (5 responses)
• step by step process
• developing skills and knowledge necessary to perform a piece
• Preparing a piece of music for performance
• becoming familiar with the music
• to get acquainted with the music

Table B.2: Open descriptions of memorising, categorised according to four themes emerging from analysis of responses (n=27, 1 uncategorised).

Memorising is … Removal of the score (9 responses)

- simply being able to recall the notes - they can be linked, for example memorisation cannot truly and properly take place until a piece is understood and learnt. From a purely definition point of view there is an obvious difference - you can memorise without learning in theory, although this is never disirable and is detrimental to the sense of the music. (sic)
- not having to rely on the printed page anymore
- remembering these skills
- just learning to play the notes without the score
- repeating a certain definition of a subject
- commiting the notes to memory
- recording information
- to remember the things that worked on into the system (sic)
- Learning a piece of music and committing it to memory

Memorising is … Internalising or automating (8 responses)

- put everything into brain and play automactically (sic)
- being able to do something without really thinking about it or paying much attention to what you are doing
- doing it without thinking
- the next step. It allows you to take the music, and not think too much about what the next note is, but being able to put a lot more personal expresion/touch to the piece. (sic)
- another level of learning. Making the overall shape of the piece automatic
- internalising the music
- being able to feel the music and believe in it
- almost becoming the piece itself

Memorising is … Acquiring mental & physical knowledge (4 responses)

- physical memory and structural
- developing skills and knowledge necessary to perform a piece without any reference to a score - memorisation is a special subset of learning
- knowing the score well enough to be able to review the work in your mind without the score and being able to play it at the instrument without the score successfully.
- is part of learning process, while we (all in diferrent way) approach to memorise piece. it should be enough just by watching the score. First creatin mental picture of music that is writen than analysing harmonical -compositional structure of it. But sometimes performers don t do that:(or just if they do, they are not able to play all as it is writen is schore-they need time to practise. (sic)

Memorising is … Mental imagery (5 responses)

- knowing in your mind, and your ear where your fingers should go, without having to demonstrate by playing
- the ability to think about the melody and the harmony and not just notes
- being able to hear the music in your head from start to finish
- learning the form and contours of a piece
- mental learning

Table B.3: Open descriptions of ways of knowing that contribute to a sense of having learnt a piece, categorised according to three themes emerging from analysis of responses (n=13).

Memory reinforcement techniques incorporating a physical aspect (6 responses)

- Being able to play, then to stop, to play mentally several bars, and then to carry on naturally on the piano
- To be able to split the piece up, into small sections, and play the piece backwards … Also, to be able to pick the piece up at any given point
- Being able to conduct it
- Being able to play on the surface of keyboard without making sounds
- Hands separately from memory
- Being able to play hands separately without the music

Ownership and emotional connection (5 responses)

- you want to "give " by playing piece, your own image or its sound, that is connected with your personal state and emotions about piece-explesion of something that belongs just to us … [sic]
- Having … mental space to improvise, rather than having all the mind taken up with just playing back the piece …Playing with the music rather than just playing it.
- Being able to feel the music
- Being able to identify emotionally with what you feel is embodied in the score
- Emotionally connected, feel absolutely confident playing it

Learning process (2 responses)

- Listening to a recording greatly enhances the rate of memorisation. When learning a new piece, it's essential to take in every detail whether it be bar by bar or in its entirety. including, fingering, dynamics, correct technique, articulation ect..from the very beginning and get it right.
- For some performance memory is either not possible (i.e. some contemporary music) or not practical (i.e. chamber music). In these instances I do not feel it is vital to be able to recall the entire work from memory in order to feel you have learnt - the process of learning this sort of repertoire is different because you know you are going to perform with music. Having a conscious memory and understanding of structure and sound is important, muscle memory tends to be acquired naturally as you learn and practice.

Table B.4: Open descriptions of ways of knowing that contribute to a sense of having memorised a piece, categorised according to two themes emerging from analysis of responses (n=6).

Memory reinforcement techniques (mental processes)
• Being able to write the score out on blank manuscript paper.
• Being able to recall the fingering
• … I use photographic memory most of the time, I find it's the quickest to memorise a piece.

Emotional connection
• Being able to feel the music
• I work on emotional content/ projection after I've memorised the notes
• This is a hard question to answer as the definition of memorisation is different from the experience of memorisation. I rarely memorise a piece straight away and generally spend time trying to understand the music, deciding my reaction to it and finally how to convey this.

B.2 Strategies for learning and memorising

Table B.5: References to mental practice strategies included in open descriptions of recent learning by 24 respondents, categorised according to 5 types of strategy identified in the responses.

Analytic strategies (9 descriptions)

- When I come to particularly difficult passage (coordination wise) I try to look for patterns and find the most efficient way to organize it in my brain so that I will catch on to it quickly.
- Study score away from the piano. Some structural analysis was done at this point, as well as mental practice of desired sounds and identification of musically/technically thorny passages…
- I analysed the structure vaguely and some of the chords and key structures.
- analysed the structure
- Trying to analyse structure of the piece, which help with memorising.
- I analyse the harmony and phrasing
- looked at score away from keyboard
- Once the piece was reasonably fluent … I started to do detailed work with score away from the piano
- I analize the structure memorize the overall shape of the piece (sic)

Auditory strategies (6 descriptions)

- … mental practice of desired sounds
- Before memorising a section I would learn the section so I could almost sing the melody and harmony in my head then try to play it without the score.
- it was easily singable and I often caught myself just randomly humming the tune away from the piano.
- sing parts back- with then without score
- … singing parts or voices…
- … sing parts back, with then without score…

Multi-modal imagery strategies (5 descriptions)

- Do mental practice imagining the sound of a piece and where the fingers should go.
- Memorise using several methods...such as geographic memory, muscle memory, vision memory on the score and memory with ears.
- When I go on to practice how I should work on the expressive elements, I walk away from the piano and work with my score, imagining the sound, the position of the fingers, and the touch of the keyboard in my head.
- Contact with piano score, mental connection without playing of sound I know and writen music… So thought & mental picture of sound, hands.
- … remembering touch and sound…

Visual imagery strategies (1 description)

- Memorize the music visually by studying the score (this often happens automatically)

Unspecified mental practice (6 descriptions)

- Further mental rehearsal away from piano, with and without score.
- Practice away from the piano and score, trying to visualize playing the entire work, referring to the score when getting stuck …
- … the mental practice of 'working' through the piece while I walk or travel...
- Mental Practice
- Memorisation was done with the score at the piano but primarily away from the piano with the score until I could think through the work from memory.
- Mentally practice the piece without score

Listening to auditory models (5 descriptions)

- Listened to recordings (2 responses)
- Listening to various recordings helped my general understaning and feel of the piece, and makes it much easier to ultimately memorise.
- Listen to recording and/or live performances.
- listen to a large number of recordings in detail.

Table B.6: Examples of open descriptions of recent learning categorised as two-stage or integrated.

Descriptions coded as 'two-stage'

- Practised hands together, section by section at extremely slow speed. Practised section by section, from extremely slow to as fast as possible, with metronome, marking the maximum tempo achieved on the score for each section. Hands separately. Same again, hands together. Worried about memorisation (because I hadn't done anything specifically to address memorisation yet). Tried to play from memory, section by section, slowly then faster and up to speed.
- I learnt the whole piece first. I then played a line at a time without using the music and when I had memorised that line I went onto the next line. I continued this until I learned the whole piece.
- It was a Ligeti etude. I had to first learn how to play it, then I memorised first the left hand, and then the right hand. After that, I started to try to play by memory hands together, which was very hard, because the music is complicated. I did that bar per bar.

Descriptions coded as 'integrated', incorporating a deliberate attempt to memorise from the outset

- I listened to a recording first to get a general idea of the piece. I then learnt the score at the piano, memorising fragments as soon as I started to play them. Once the notes memorised [sic] I could only play it at a slow tempo so I worked through the piece, increasing the tempo and beginning to incorporate dynamics and expressive markings…
- Played through the piece to have an idea of the structure and find the most difficult places to play and to memorize - started learning these sections, by dividing them into phrases and motives, playing each one slowly, then memorizing the left hand, right hand, hands together without score, up to speed without score, not moving on to the next phrase until satisfied, memorizing with everything on the score, try to never play mechanically …

Descriptions coded as 'integrated' in which memorisation occurred automatically

- Play the piece through with the score at a slower tempo. Still slowly, practise any tricky passages (usually hands separately). Practise in sections and practise overlaps in order to achieve a sense of the structure. Practise up to speed without the score, checking the score when unsure.
- Try to play through the piece to understand its over all structure. Practice slowly in sections. (hands separately where appropriate). By this stage, 90% of the memorisation is usually completed for me ... be aware of the sections in which my memory is not perfectly secure. Go to that section and memorise using several methods...

B.3 Knowledge acquisition

Table B.7: Open descriptions of ways in which learning and memorisation techniques were acquired, categorised according to three themes emerging from the analysis.

Lack of explicit memorisation training (9 responses)

- It has been a LONG time since anyone has advised me on memorizing. At least 10 years.
- In personal experience is not dealt with much in curriculum …
- … in my experience these things [learning/memorizing techniques] are not given much mention.
- I wasn't really taught how to learn or memorise, I'm just making it up as I go along
- I pretty much taught myself how to memorise. Nobody really ever taught me specific methods.
- I had to work it out for myself (with occasional advice)
- No one really taught me these things, they are just things that are either simply logical or that you pick up from various experiences of learning as you go.
- It is purely an instinctive process
- no one {taught me}, its the way I always do

Methods taught by piano teacher (4 responses)

- My first piano teacher in french conservatoire, she wouldn't let me play at all, before hearing hands apart and by heart
- My current piano teacher. He taught me to 1. analyze the score 2. memorize fingering 3. imagine without the score (the sound of the piece, position of the hands/fingers, touch/articulation, harmony
- my current piano teacher by telling me to memorise it in sections and taking the music away whilst playing
- I used to be terrible at memorizing and I figured that the faster I stop depending on the score, the more secure I am when performing. For this purpose I had to stop memorizing by endless repeating and remember specific details the first time I look at the score. I tutor at college once showed me how to memorize away from the piano, which was very helpful. I read about one of the great pianists that he never moves on to the next page until the current one is perfect. My current teacher pays specific attention to this process…

Methods acquired via reading/other training (4 responses)

- Gieseking and Leimer via their book.
- I taught myself that, in school. I just starting reading one of my mum's books and thought 'hmmm, that exercise looks interesting.' and when I played around with it and found that some worked and some didn't
- A psychology study I participated in talked a lot about visualizing and I've heard masterclass teachers talk about being able to visualize away from the piano as a test of memory.
- … I have also attended/watched/listened to a number of lectures on the subject which have always contained useful information

Table B.8: Table to show % participants who stated that the way they approached learning and memorising had been 'strongly influenced' by each activity (N), and showing mean rating [SD] on 5-point influence scale (where 1= not at all and 5=profoundly)

Activity	% strongly influenced	(N)	Mean	[SD]
Explicit instruction (college piano tutor)	61	(36)	3.68	[1.04]
Individual piano lessons at college	58	(36)	3.79	[1.20]
Individual piano lessons pre-college	56	(34)	3.32	[1.49]
Practice strategies training outside college	50	(10)	0.82	[1.53]
Individual lessons, other	48	(29)	2.74	[1.68]
College piano tutor, implicit	47	(36)	2.85	[1.69]
Listening to expert performer speaking	47	(34)	3.06	[1.46]
Playing/singing informally	47	(30)	2.74	[1.62]
Analysis training (college piano tutor)	46	(24)	2.12	[1.90]
Explicit instruction (pre-college tutor)	44	(34)	3.29	[1.31]
Tutorials outside college	42	(12)	1.00	[1.63]
Choral singing	41	(34)	2.82	[1.38]
Analysis classes at college	39	(33)	2.65	[1.43]
Pre-college piano tutor, implicit	38	(29)	2.53	[1.62]
Watching a masterclass	38	(32)	2.74	[1.58]
Participating in a masterclass	35	(31)	2.44	[1.62]
Aural training (college piano tutor)	35	(20)	1.50	[1.80]
Tutorials at college	33	(18)	1.50	[1.73]
Reading about what professionals do	31	(35)	2.65	[1.12]
Music theory classes pre-college	31	(32)	2.62	[1.44]
Music psychology course at college	31	(16)	1.26	[1.6]
Analysis classes pre-college	31	(26)	2.03	[1.70]
Music theory classes at college	29	(34)	2.65	[1.35]
Improvising	29	(28)	2.24	[1.69]
Aural classes pre-college	29	(28)	2.18	[1.59]
Music psychology course pre-college	29	(7)	0.50	[1.13]
Analysis classes outside college	27	(15)	1.12	[1.57]
Watching a group lesson	26	(23)	1.44	[1.58]
Aural training (pre-college tutor)	25	(28)	2.26	[1.52]
Learning strategies training outside college	25	(8)	0.53	[1.13]
Taking written advice	25	(28)	1.97	[1.42]

Activity	% strongly influenced	(N)	Mean	[SD]
Analysis training (pre-college tutor)	23	(30)	2.35	[1.45]
Practice strategies training at college	23	(13)	1.06	[1.52]
Participating in a group lesson	22	(23)	1.59	[1.60]
Lectures at college	21	(19)	1.29	[1.43]
Practice strategies training pre-college	20	(10)	0.71	[1.31]
Music theory classes outside college	19	(16)	1.18	[1.59]
Tutorials pre-college	18	(11)	0.74	[1.26]
Lectures outside college	18	(11)	0.68	[1.20]
Learning strategies training at college	15	(13)	0.91	[1.38]
Memorisation training outside college	14	(7)	0.41	[0.96]
Aural classes outside college	14	(14)	0.91	[1.36]
Music psychology course outside college	14	(7)	0.44	[0.96]
Doing what other students say they do	14	(36)	2.59	[0.89]
Aural classes at college	13	(32)	2.21	[1.17]
Lectures pre-college	10	(10)	0.62	[1.13]
Learning strategies training pre-college	0	(10)	0.65	[1.12]
Memorisation training at college	0	(11)	0.59	[0.99]
Memorisation training pre-college	0	(10)	0.59	[1.02]

B.4 Skill and strategy choice

Table B.9: Open descriptions of ways in which nine respondents felt they could improve their work, categorised according to three themes emerging from the analysis (n=9).

Increase use of mental strategies (4 responses)

- More work away from the piano.
- More mental practice.
- Do more work away from the piano, especially studying the music without worrying about my ability to play it to get a better overall view.
- I think I should try memorising before I play through or start learning from the score and I think I should start memorising sooner. More chordal analysis might also help me.

Improve focus during practice (4 responses)

- Be more patient, practise more carefully and slowly, find quicker memorisation techniques.
- Focus on improving small quantities of music (anywhere from 4 bar phrases to single pages) at a time, getting a short section, page, phrase, etc, to extremely high level before moving on, instead of reading through entire piece again and again and again.
- Concentrate better. Practise in shorter periods - have more effective breaks. Use metronome less when playing slowly, still use all the expression I want whilst playing at speed.
- … I am sure there are things I could do more efficiently but sometimes you become unaware of them. The basic process works … but there are some things I would avoid.

Find better teaching (1 response)

- … I found out that I know more than I was receiving knowledge here …

Table B.10: Open descriptions of nine respondents' reasons for not adopting strategies that they believed would improve their learning, categorised according to three themes emerging from the analysis (n=9).

Alternative strategies are tiring/difficult/demanding (5 responses)

- I find mental practice extremely tiring.
- Lack of patience, lack of concentration, fatigue.
- Concentration.
- Impatience & boredom…
- I'm impatient and would get bored from lots of analysis and not much playing in my practice.

Time constraints, desire to play/fear of not playing (4 responses)

- Don't get enough time to practise so when I do I just want to play it.
- … time constraints in terms of deadlines and available free time…
- I often need to be able to play things in a short space of time so I would be too worried to spend more time on memorising beforehand.
- … as I find the technical aspects of the piano more challenging, I am unnerved to spend less time actually at it.

Habit (2 responses)

- Old habits die hard.
- It is possible to fall into the trap of playing slowly too much and worrying about trying to secure the notes under your fingers rather than concentrating on the sound and character…

Table B.11: Open descriptions of physical practice, categorised according to 6 themes emerging from the analysis and tabled as 'likes' and 'dislikes'.

LIKES	DISLIKES
playing slowly	**playing slowly**
…playing very slowly at first.	slow practice and such concentration over long period of times
Playing passages slowly with hands separately to reinforce memory	… slow work
I enjoy learning through extremely slow practise. This makes the physical sensation of each sound available to enjoy…	
Slow practice deep into the keys thinking about touch and hand position etc. but ALWAYS with the music and character etc. in mind.	
To trust my ears and rely on what I am hearing. Therefore a very careful slow practice is crucial…	
practise slowly	
repetition	**repetition**
Just playing a piece over and over.	practising something over and over and over and over again in order to memorize it!
REPETITION of a piece	playing old pieces over and over again
playing through my programme every morning before I start practise to see how it is coming along, and what I need to practise that day	repetition in various ways when sections will not stick in the brain
	Drilling technical passages
playing new material	**playing new material**
Learning the notes in the first place.	Learning notes at the very beginning.
practising new pieces	Just starting to learn the piece.
learning a new piece from scratch	
sightreading	**sightreading**
sight reading, playing through with score	sightreading new music.
I am a good sight reader so I enjoy reading large amounts of music even though I can't play it perfectly.	sight reading (!)

LIKES	DISLIKES
working hands separately	**working hands separately**
learn hands separately, and be able to control what each hand is doing...	sometimes hands separately memorising
working in sections	**technical issues/exercises**
just playing little sections then putting it all together … use different ways to memorise a particular sections.... eg, playing on the surface of the keyboard without actually playing notes… Trying out different ways of playing the piece, e.g. Trying different ways of phrasing, or even changing the way I play each phrase...jumpy, smooth...etc	Working out tricky fingering! … playing up to speed when it's not quite ready - this can be essential though as you learn a lot. having to correct any mistakes that have been learnt Getting pieces up to speed. Scales Studies

Table B.12: Open descriptions of mental practice, categorised according to 3 themes emerging from the analysis and tabled as 'likes' and 'dislikes'.

LIKES	DISLIKES
General	**General**
I think mental work, which I do a lot of, is the key, either with or without the score.	I find the first 'mental' practice away from the instrument the most draining part of the process.
Mental practice away from the piano	Taking time outside practice hours (i.e. imagining sound of the whole piece without the score)
mental practising	Visualizing all the notes up to tempo away from the instrument and the score
'mental' practice	
Away from the piano.	
Auditory imagery	
imagining sounds with score	
Visual imagery	
Learning the music visually, away from the instrument	

Table B.13: Open descriptions of techniques for learning and memorising, categorised according to 6 themes emerging from the analysis and tabled as 'likes' and 'dislikes'.

LIKES	DISLIKES
Analysis learning the form of a piece analyse the score etc... Analysing the harmonic structure and similarities between certain phrases, any connections. Analyzing the structure of the piece	**Analysis** Analysis analysing the score before knowing the notes but I sometimes find this necessary when facing technical difficulties.
Automatic memorisation I like to be as instinctive as possible. It feels great when I can play through a piece of music with the score, enjoy playing it, and keep on playing it in this way while I subconsciously committing it to memory as I go. I like it best when memorization occurs naturally mainly because you've practised a section so many times. Playing through until my fingers remember the notes and hearing the music in my head as I play **Working in sections** I enjoy separating sections and memorizing them	**Effortful memorisation: difficult material** Learning fugues. Memorising music that does not easily fall into harmonic or thematic patterns Learning non-tonal pieces without logical, formal structure. Memorising contemporary music with non-conformist patterns in the score making it hard to remember what comes next particularly when a tonal centre is absent. Having to work tediously to memorise something, generally because I do not understand a piece of music well enough at sight to commit it to memory easily. memorise particular difficult parts
Focusing on content I enjoy memorizing like I performing as I find I have no other distractions and helps with communicating the musical content. Getting rid of the score as soon as possible, so I can concentrate on the music. being able to sing the melody and follow the melody instead of notes	**Effortful memorisation: general** practising something over and over and over and over again in order to memorize it! Having to work tediously to memorise something repetition in various ways when sections will not stick in the brain

LIKES	DISLIKES
Using recordings learning with recordings (aurally) often listening while travelling Listening to recordings and memorising it by ear.	I don't like sitting down just for the sake of memorizing, it is a chore for me. memorising the stages in working up to having the piece memorised sometimes hands separately memorising harmony memorising

Table B.14: General open descriptions, categorised according to 3 themes emerging from the analysis and tabled as 'likes' and 'dislikes'.

LIKES	DISLIKES
Working at own pace Working systematically Not being under time pressure to learn a piece - particularly one I enjoy! Able to be given a longer period of time and slowly work my way through the piece Working slowly…	**Time pressure** Learning under time pressure, particularly music by Bach and other contrapuntal music. having to learn piece in short notice and perform. … playing up to speed when it's not quite ready - this can be essential though as you learn a lot.
Expert opinion I like reading professional ideas of memorizing and always try to give it a go myself- and if it doesn't work for me look for other books. I also enjoy going to masterclasses as I am aware to fresh ideas of how to learn and memorize	

Appendix C Supplemental Materials for Chapter Four: An fMRI Study of Expert Musical Imagery

C.1.1 Letter of invitation

INSTITUTE FOR MUSIC IN HUMAN AND SOCIAL DEVELOPMENT **[IMHSD]**

Dear Colleague,

We are conducting new research using a state-of-the-art scanner to find out more about how the brain functions in expert musicians.

We are looking for highly trained pianists to take part in an MR brain imaging study at the University of Edinburgh. If you are in 3rd year (or above) of your undergraduate studies, began piano training by the age of 8 and have played for at least 10 years we would love to hear from you.

If you would like to take part we will arrange for you to visit CRIC (Clinical Research Imaging Centre), Edinburgh, for a morning or afternoon. The scan itself will last for less than an hour. All your travel and out of pocket expenses will be covered. No preparation is required and you will only be needed once.

To take part you also need to be under 65, right handed, a native English speaker with no history of major medical, neurological or psychiatric disorders - and with no unremovable piercings or metal implants.

To register your interest, email your name to k.m.davidson-kelly@sms.ed.ac.uk using the subject line 'pianist study'. We will contact you with more details and to arrange a time for your visit. If you have any questions please email Kirsteen at the address above.

This research is supported by funding from SEMPRE (Society for Education, Music and Psychology Research). Once the results are analysed we will send you a report of our findings.

We look forward to hearing from you.

Yours sincerely,

Kirsteen Davidson-Kelly (PhD student in music)
Katie Overy (Senior Lecturer in music)

C.1.2 Participant information sheet

Clinical Research Imaging Centre (CRIC)
The Queen's Medical Research Institute
47 Little France Crescent
Edinburgh
EH16 4TJ
neil.roberts@ed.ac.uk

Institute for Music in Human and Social Development (IMHSD)
Alison House
College of Humanities and Social Sciences
The University of Edinburgh
12 Nicolson Square
Edinburgh EH8 9DF
k.m.davidson-kelly@sms.ed.ac.uk
k.overy@ed.ac.uk

fMRI STUDY OF MUSICAL IMAGERY: INFORMATION SHEET

Introduction

We are carrying out research at the Clinical Research Imaging Centre (CRIC) in Edinburgh, using non-invasive Magnetic Resonance Imaging (MRI) of the brain to develop ways to find out more about how expert musicians learn. In particular, our objective is to obtain scientific evidence to support the development of effective training methods for musicians.

What is the study about?

It has been suggested that mental rehearsal may be as effective as physical rehearsal for some aspects of learning, which is of interest because replacing or supplementing physical training with mental rehearsal could potentially reduce the occurrence of physical overuse syndromes (e.g. repetitive strain injury) and reduce anxiety.

What is the purpose of the study?

MRI uses a combination of powerful magnets and radio waves to create very high quality pictures of particular parts of the body. MRI does not use X-rays. Our approach is to use functional Magnetic Resonance Imaging (fMRI) to compare brain function in a group of musicians while they imagine and simulate playing. We predict substantial overlap between brain activations produced by imagined and simulated performance. If true this will provide evidence that similar neural mechanisms occur in both conditions, lending scientific support to the validity of musical training using imagined performance.

Why have I been invited?

In order to be able to test the above prediction we are seeking to recruit healthy right-handed native English speaking expert pianists, with no history of major medical, neurological or psychiatric disorders and no long-term medication. As a participant you will have had at least 10 years of continuous training/playing, begun by age 10 and including 1 years' advanced training.

What will happen if I agree to take part?

We will check that it is perfectly safe for you to be scanned. Although MRI is normally a very safe method of taking pictures, we do not scan people who have a heart pacemaker or who have had surgery involving the insertion of metal clips, or people who have metal fragments in their eyes, perhaps as a result of their occupation. Neither will we scan you if there is a chance that you might be pregnant. On the other hand, the metals used in operations such as hip replacements are very rarely a reason not to undergo scanning. The Radiographers will check if you are in any doubt.

When you come to the Centre for your scan you will be asked whether you have read this Information Sheet and if there are any questions which you would like to ask. You will then be asked to sign a consent form.

A changing cubicle will be provided. You will be asked to place any metal objects, such as keys, watches, coins and credit cards, in a locker. Please do not wear any make-up or talc, and be prepared to remove contact lenses if you use them.

What will I have to do?

You will be asked to learn and memorise two very straightforward musical extracts, consisting of 2 bars each, on the day of scanning, and when you are comfortable with your performance it will be audio recorded. Familiarization training will take place on a mock MRI scanner and you will be videoed during learning to provide data on strategy choices.

Subsequently, during scanning you will imagine and simulate performance of the musical extracts. You will be asked to lie on the scanner bed for typically up to one hour, and at most 1 and a 1/2 hours. Usually it takes less time. While you are in the scanner, a series of pictures will be taken of your brain.

Information about your experience during the study and training history will be collected via a post-hoc semi-structured interview and brief self-completion questionnaires.

Will my taking part in the study be kept confidential?
Yes, all the data you provide will be stored, processed and reported anonymously. The only exception to this is the video recording of your learning, for which we will obtain your written consent for specific uses.

As part of this study we will obtain limited series of, so-called, diagnostic scans. Our research studies are designed to improve knowledge of how the brain works, not for diagnostic or clinical purposes. However, a consultant Radiologist or appropriately trained designate will examine these scans and a report will be sent either to your GP or the Principal Investigator of the study in which you are participating if they are clinically trained (or a nominated clinically-trained deputy if not) to document the examination. In order for us to register you appropriately and to allow correct and accurate processing of the information obtained from your scan, you need to give your GP's name and address, as well as your Community Health Index (CHI) to the person who has recruited you into the study. We will not be able to scan you unless we have these details. If you cannot provide your CHI number, it will be obtained on your behalf.

You should be aware that there is a small possibility (about 3%) of a significant abnormality being detected in your scan, which may need to be acted upon in case of any future illness. Any such incidental findings will be notified to your GP. The study investigator or the research centre Radiologist will be happy to discuss this further with you if you wish.

Will my GP be informed that I am taking part?
Yes. Before you take part we will need your written permission to inform your GP of your participation.

Do I have to take part?
Of course you do not have to take part in this study, and **you may withdraw from it at any time**. We are, though, very grateful to you for offering to help us.

Will I receive payment or expenses?
We will pay your travel and other out-of-pocket expenses for your attendance at CRIC.

Are there risks or benefits to taking part?
The scanner makes quite loud noises while it operates. For your comfort, you

will be provided with earplugs and headphones. If at any stage shortly before or during your scan, you become worried, or wish to ask a question, you will be able to speak to one of the Radiographers, who will use an intercom to keep in touch with you.

You will not obtain any specific benefits from taking part in the study. However, your proficiency in music makes you an important subject for the proposed research, which we are confident will provide important information to help make learning and practice more effective and safer for future generations.

What will happen to the results of the study?
Results will be included in Kirsteen Davidson-Kelly's PhD thesis and will, potentially, be published in academic journals. You will receive a brief report detailing the main findings of the study. This will involve a whole group analysis of the functional data. Individual data will not be reported on separately.

The image data obtained during the scan will be stored and processed using computers, and, after the study is completed, these results will be copied onto a permanent record which might be studied again at a later time. Some images are also stored in the NHS x-ray department files where they are protected by NHS data management regulations. Information gathered during the scan may also be made anonymous and shared for research purposes with other medical and scientific researchers, subject to strict laws and University of Edinburgh policies intended to safeguard your privacy.

Who is funding the Research?
Society for Education, Music and Psychology Research (SEMPRE).

Who has reviewed the study?
The study has been reviewed by the West of Scotland Research Ethics Committee and by the lead Sponsor (the University of Edinburgh).

What do I do now?
If you would like to take part in the study you are invited to contact Kirsteen Davidson-Kelly: k.m.davidson-kelly@sms.ed.ac.uk

Who do I contact if I wish to complain?
If you wish to make a complaint about the study please contact NHS Lothian:

NHS Lothian Complaints Team
2nd Floor

Waverley Gate
2-4 Waterloo Place
Edinburgh
EH1 3EG   Tel: 0131 465 5708

Can I find out more?
Further information on Magnetic Resonance Imaging (MRI) is available, if you require it, from Dr. Dilip Patel or Dr. Graham McKillop, Consultant Radiologists at the Royal Infirmary of Edinburgh (Tel: 0131 242 3737/3744) or Dr. Paul Allan, Clinical Director, Radiology, University Hospitals Division, NHS-Lothian (Tel: 0131 537 2042). These persons are not directly involved in this study, and so will be able to give you independent advice. Otherwise, the Centre's Manager or one of the Radiographers will be happy to try to answer any other questions that you might have. They can be contacted at Clinical Research Imaging Centre, Queen's Medical Research Institute, 47 Little France Crescent, Edinburgh EH16 4TJ.

Thank you for reading this – please ask any questions if you need to.

Kirsteen Davidson Kelly/Dr. Katie Overy/Professor Neil Roberts

C.1.3 Screening form for scanning subjects

clinical
research
imaging
centre
EDINBURGH

CLINICAL RESEARCH IMAGING CENTRE

SCREENING FORM FOR SCANNING SUBJECTS

Surname	First Name(s)

Home Address	GP Name/Address

Date of birth	Contact Telephone Number	Weight/Height	BMI (Staff Use)

Do you have a **cardiac pacemaker** or **implanted cardioverter defibrillator (ICD)**?
YES/NO

Do you have an artificial **heart valve**?
YES/NO

Do you have an **aneurysm clip** in your brain?
YES/NO

Have you **ever** had **any** operations of any kind?
YES/NO

Please list operations:

Do you have any **vascular clips**, a **cochlear implant** or a **shunt**?
YES/NO

If you have a shunt, is it programmable? ____________

Have you **ever** had an incident involving **metal fragments** penetrating your eye?
YES/NO

Do you have a metallic **stent, filter** or **coil**?
YES/NO

Do you wear **dentures**, a **dental plate**, **brace**, **hearing aid** or **wig**
YES/NO

(remove before entering the MR room)?

Do you have a **heart condition, asthma** or **kidney disorder**?
YES/NO

Are you wearing a **cardiac**, **HRT** or **nicotine patch**?
YES/NO

Do you have any **metal** or **electrical** objects in your body that you cannot remove,

e.g. body piercings, shrapnel or stimulators?
YES/NO

LADIES: Could you be **pregnant?** Or are you **breast- feeding?**
YES/NO

Do you have an IUD?
YES/NO

Signature of Patient (or Guardian)

Date:

Signature of Radiographer

- It has been explained to me why I may not be able to undergo an MRI examination. I have been given the opportunity to ask questions about them.
- I am satisfied that I have all the information that I require to provide **informed consent**.
- **I have removed all loose metallic objects & credit cards and have placed these in a secure locker before I enter the scanner room.**

C.1.4 Consent form

Clinical Research Imaging Centre
Queen's Medical Research Institute
MRI Scanner
47 Little France Crescent
Edinburgh, EH16 4TJ

Study number:

Participant Identification Number for the study:

MAGNETIC RESONANCE IMAGING
PARTICIPANT CONSENT FORM

Title of Project: **fMRI study of Musical Imagery**

Name of Researcher:

Please Initial to Confirm

Agreement

I understand that my General Practitioner (GP) will be informed of my participation in this study, and know that he/she will be provided with a routine report prepared by a Radiologist. ☐

I know of no reason why I should not undergo Magnetic Resonance Imaging or take part in the study ☐

I understand and agree that medical images obtained during my scan will be stored and processed using computers and, after the study is completed, that these may be copied onto a permanent record which ☐

might be studied again at a later time.

I understand and agree that information gathered during my scan will be shared with other medical and scientific researchers, subject to strict laws and University of Edinburgh policies intended to safeguard my privacy. ☐

I understand that I am under no obligation to take part in the study and that I can withdraw from the study at any time without giving any reason. ☐

I have read the Participant Information Sheet that has been provided to me, and this Consent Form, and have been given the opportunity to ask questions about them. I am satisfied that I have all the information that I need to provide informed consent. ☐

I agree to participate in the study. ☐

Permissions checklist

In this study we have made audio and, in some cases, digital video recordings. Both include audio. Audio recording of the interview will be transcribed, so that we have a complete record of the conversation, but the recording will then be deleted. Audio recordings of your playing will be used to analyse performance timings. Video recordings will primarily be used to analyse your choices while learning the musical pieces (e.g. counting the number of times you played each piece, how much time you spent imagining the pieces).

Please indicate below the way(s) we can use the recordings made during this study. You can select some options and not others--or none at all (option #8). You may also get back in touch with us at any time and alter your permissions.

The recordings will be stored securely for ten years and labelled only with a code number, not your name. The records which connect your recording with your code number are stored separately.

The audio data are anonymous. The digital video data are not anonymous: you would be recognisable to anyone who knows you. However, we will make all reasonable efforts to disguise your identity (e.g. still images may be cropped or blurred).

	AUDIO (interview)	**AUDIO (playing)**	**VIDEO (if applicable)**
1. Viewing and analysis by the researchers involved in this project.	**yes/no**	**yes/no**	**yes/no**
2. Viewing and analysis by these researchers in future, related projects	**N/A**	**yes/no**	**yes/no**
3. Playing excerpts as an example for professional audiences (e.g., at a professional conference)	**N/A**	**yes/no**	**yes/no**
4. As still images in conference slides or publications	**N/A**	**yes/no**	**yes/no**
5. Playing excerpts for other research participants in a subsequent stage of the project	**N/A**	**yes/no**	**yes/no**
6. Available on the Internet on sites targeted at research professionals (i.e. to illustrate publications)	**N/A**	**yes/no**	**yes/no**
7. Available to the public via the lead researchers' websites	**N/A**	**yes/no**	**yes/no**
8. None of the above; please erase the tape	**N/A**	**yes, erase the data no, do not erase the data**	**yes, erase the data no, do not erase the data**

Signature of Participant:

Name: Date:

Signature of Person Taking Consent:

Name: Date:

Name of GP:

Address of GP:

CHI Number (for use by CRIC staff):

C.1.5 Procedure

Introduction (10 minutes)

- Welcome participant and outline session
- Review participant information sheet, discuss key points
- Administer screening form, volunteer consent form
- Discuss questions/concerns

Learning session (40-50 minutes)

- Experimenter reads learning instructions
- Experimenter reads guided analysis of two pieces
- Participant learns pieces (experimenter leaves room)

Learning verification (15 minutes)

- Participant plays pieces to experimenter
- Participant imagines pieces (indicating start and stop points on keyboard)
- Experimenter records participant's actual and imagined performances

Mock scanner (10 minutes)

- Experimenter outlines scan procedure verbally
- Participant enters mock scanner, practices scan procedure (experimenter instructs verbally)
- Discuss questions/concerns

Break (5 minutes)

Scan session (40 minutes)

- Set up
- Audio click on keynote presented through headphones
- Scores of pieces presented on screen
- Training run (3 minutes)
- Main fMRI run (21 minutes)
- T1 (5 minutes)

Post-scan session (20 minutes)

- Semi-structured interview
- Edinburgh Handedness Inventory
- Mental Imagery Questionnaire

Figure C.1: Summary of study procedure including approximate timings (total time 2.5 hours).

C.1.6 Script for learning session

Here are the two scores. Look at the piece called “unison”: notice that it is in G major and begins and ends on the tonic. Both bars begin with the same phrase. The first note of each semiquaver group is G, A, B, A, G, A, B and then back to G to finish.

Next, look at the contour of each semiquaver group. The first two groups rise then fall, the third falls then rises, the fourth begins with a rising fourth and returns back down to the A… then the second bar repeats the initial phrase in which the first two groups rise then fall; this time the third phrase rises a third and then descends to the tonic.

Now have a look at the two-part piece. This is also in G major, with the left hand beginning on the tonic, but the right hand begins on a B. Again, the first phrases of both bars are identical. The first note of each group in the right hand are: B, B, C, C, B, B, C, G…. and in the left hand, the pattern is different: G, D, A, D, G, D, A, B.

So this time the right hand ends on the tonic and the left hand on a B.

Now look at the contour of each semiquaver group in the right hand: the first falls then rises, the second outlines the triad using two falling thirds. Then the next phrase is an imitation of the first. In the second bar the first phrase is exactly repeated, the third group of semiquavers is exactly as before but this time falls to end on the tonic. In the left hand you have a rising scale, three notes going down and then returning to the D, followed by a rising/falling figure and then another descent from the D. The second bar begins like the first, but on the third beat beginning on the A it simply rises up the scale and descends to the B to end.

C.1.7 Interview schedule

1. I hope you found that interesting! Were you comfortable during the scanning? How did you feel?

2. Did you find that the music fitted into the time allowed for each extract in the scanner?

3. Do you think that you managed to keep to the correct tempo throughout, or did it vary at all?

4. When you were imagining the sound of the extracts, did you imagine anything else?

5. What aspect was most vivid?

6. Do you think you imagined the sound more clearly when you were moving your fingers, or when you were not?

7. Did your finger movements in the scanner feel similar to your movements on a real keyboard?

8. Were there any particular times when you knew you had lost concentration?

9. Did you feel that you made any mistakes, forgot anything or found yourself carrying out the wrong task?

10. Can you estimate how many times this happened? OR, can you remember when this happened during the scan?

11. Did you manage not to move a muscle during the imagining conditions, or did you sometimes move your fingers? If yes, what % of the time, would you estimate?

12. What did you think about while you looked at the white cross?

13. When you played the pieces on the real keyboard, how easy was it to play the unison piece? Rate on a scale of 1-10, where 1 is very easy and 10 very difficult.

14. And how easy was it to play the two-part piece by comparison? Rate on a scale of 1-10, where 1 is very easy and 10 very difficult.

15. So how many times harder was it to play the X piece than the Y piece?

16. When you imagined the pieces during the learning session, how easy was it to imagine the sound of the two-part piece? Rate on a scale of 1-10, where 1 is very easy and 10 very difficult.

17. And how easy was it to imagine the sound of the unison piece? Rate on a scale of 1-10, where 1 is very easy and 10 very difficult.

18. So how many times harder was it to imagine the X piece vividly and accurately than to imagine the Y piece?

19. How did you learn the 2 pieces? Did you have a particular strategy?

20. At what age did you begin learning the piano?

21. How old are you now?

22. How much time did you play the piano per day /week
    a. When you began learning?
    b. When you were in secondary school?

c. At college?
d. At the moment?

23. Do you normally use any type of mental rehearsal?

24. Are you right or left handed?

25. Is there anything else you'd like to say about the experiment? We'd be really interested in your comments about the experience.

26. If you think of anything later on you are welcome to email me!

C.1.8 Mental Imagery Questionnaire

1. When learning, memorising or rehearsing music, how important is each of these strategies for you? (Please circle)

		Not at all						Essential
a.	Imagining sound	1	2	3	4	5	6	7
b.	Imagining finger movement	1	2	3	4	5	6	7
c.	Imagining a visual image of the score	1	2	3	4	5	6	7
d.	Imagining note patterns on the keyboard	1	2	3	4	5	6	7
e.	Imagining the structure of a piece/section	1	2	3	4	5	6	7
f.	Other	1	2	3	4	5	6	7

2. How often do you use each strategy when learning, memorising or rehearsing?

		Never						Always
a.	Imagining sound	1	2	3	4	5	6	7
b.	Imagining finger movement	1	2	3	4	5	6	7
c.	Imagining a visual image of the score	1	2	3	4	5	6	7
d.	Imagining note patterns on the keyboard	1	2	3	4	5	6	7
e.	Imagining the structure of a piece/section	1	2	3	4	5	6	7
f.	Other	1	2	3	4	5	6	7

3. How skilled do you feel you are at using each strategy?

		Not at all						Very skilled
a.	Imagining sound	1	2	3	4	5	6	7
b.	Imagining finger movement	1	2	3	4	5	6	7
c.	Imagining a visual image of the score	1	2	3	4	5	6	7
d.	Imagining note patterns on the keyboard	1	2	3	4	5	6	7
e.	Imagining the structure of a piece/section	1	2	3	4	5	6	7
f.	Other	1	2	3	4	5	6	7

C.1.9 Abbreviations

Table C.1: Abbreviations of cortical regions

Abbreviation	Cortical Region
M1	Primary motor cortex
S1	Primary somatosensory cortex
SMA	Supplementary motor area
PMC	Premotor cortex
PrCG	Precentral gyrus
PCL	Paracentral lobule
MFG	Middle frontal gyrus
IFG	Inferior frontal gyrus
INS	Insula
MTG	Middle temporal gyrus
STG	Superior temporal gyrus
FFG	Fusiform gyrus
PoCG	Postcentral gyrus
PCUN	Precuneus
PAR	Parietal lobe
IPL	Inferior parietal lobule
SPL	Superior parietal lobule
LING	Lingual gyrus (occipital lobe)

C.2 Behavioural results

C.2.1 Interview measures

Table C.2: Table showing types of imagery experienced during scanning

Imagery experienced	Participants (n)
Auditory	14
Note patterns (visual)	6
Finger movement (fine motor)	4
General sense of playing (kinaesthetic)	3
Notation (visual)	2
Piano timbre (auditory)	1
Piano (visual)	1

Table C.3: Table showing sample statements concerning task differences (P=Participant)

- [2-part piece] … it was easy to imagine the right hand but harder to imagine the left hand at the same time. [The unison piece] was easier because [left and right hand parts] are both the same obviously. (P4)
- The two part was hard to really hear the sound – just playing it without having to internalize the sound wouldn't be so hard. (P3)
- Physically and in the imagination there is no difference between the difficulty level of the two stimuli. If anything, I would have said that the 2 part piece is slightly easier than the unison – [in] the unison piece I find there is one [difficult] place … (P11)
- When you're moving your fingers you've got access to the muscular memory bit, which is so reliable, and therefore you don't need to work as hard in the brain to do it properly … so I was definitely working harder on the imagined ones than on the playing ones (P9)

C.2.2 Mental Imagery Questionnaire results

Table C.4: showing results of the mental imagery questionnaire, in which participants rated importance, frequency of use and skill for five different types of musical imagery on a scale of 1-7 (where 1 = "not at all" and 7 = "very/very often").

Imagery		Importance	Frequency of use	Skill rating
Auditory	Mean	6.00	5.93	5.79
	[range]	[3-7]	[2-7]	[4-7]
	(SD)	(1.36)	(1.73)	(1.12)
Structure	Mean	5.64	5.29	5.64
	[range]	[2-7]	[2-7]	[3-7]
	(SD)	(1.74)	(2.02)	(1.28)
Note patterns (visual)	Mean	5.36	5.21	5.00
	[range]	[1-7]	[1-7]	[1-7]
	(SD)	(1.65)	(1.63)	(1.52)
Finger moves (motor)	Mean	5.14	4.86	5.21
	[range]	[1-7]	[1-7]	[3-7]
	(SD)	(1.66)	(1.88)	(1.19)
Notation (visual)	Mean	3.29	3.14	4.43
	[range]	[1-7]	[1-7]	[1-7]
	(SD)	(2.3)	(2.38)	(2.28)

C.2.3 Performance measures

Table C.5: Table showing recorded timings (seconds) of imagined and actual performances of the Unison and Two-part pieces (N=14)

	N=14	Imagine (s)	Play (s)
Unison	Mean	12.25	11.86
	[Range]	[11.41 - 14.9]	[10.4 - 14.05]
	(SD)	(0.85)	(0.84)
2-part	Mean	12.46	11.95
	[Range]	[11.56-14.9]	[10.4-13.9]
	(SD)	(0.82)	(0.83)

Table C.6: Table showing mean ratings by 2 independent assessors of recorded performances of the Unison and Two-part pieces (scale 1-5, 1= very poor, 5=excellent)

		Assessor 1	Assessor 2	Mean Rating
Unison	Mean	4.29	4.29	4.29
	Range	3-5	3-5	3-5
	SD	0.83	0.83	0.83
2-part	Mean	4.21	3.86	4.04
	Range	3-5	3-5	3-5
	SD	0.8	0.77	0.79

C.3 fMRI results

C.3.1 Analysis of each condition > rest

The *t*-tests performed for each condition > rest in prefrontal, auditory and motor ROIs (Table C.7) found bilateral activation in MFG, IFG and STG in each condition, and in motor areas including M1, PMC and SMA. In MFG, activation was observed bilaterally in L_MFG (BA 9) & R_MFG (BA 10) in each task; additional activation in L_MFG (BA 10) was observed during Imagine but not during Play (Figure C.2). Activation was greater during Unison than during Two_part in STG (BA 22) bilaterally during imagining, and in R_STG and R_MFG during playing (Figure C.3).

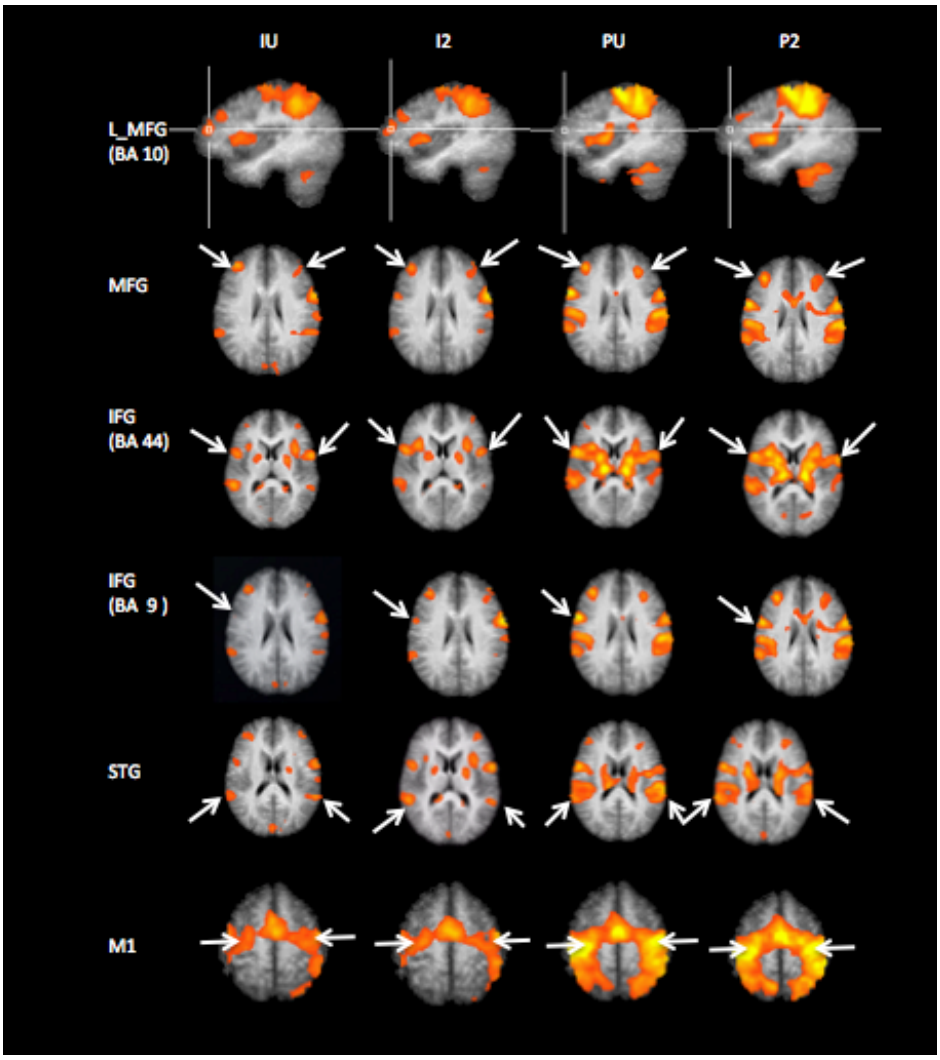

Figure C.2: Volume maps showing activation in each condition > rest ($p<0.05$, FDR corr); L_MFG (BA 10, z = 15); bilateral MFG (L_BA 9 & R_BA 10, z = 25); bilateral IFG (BA 44, z = 11); R_IFG (BA 9, z = 24); bilateral STG (BA22/42, z = 18 except in I2, z = 13); bilateral M1 (z = 54).

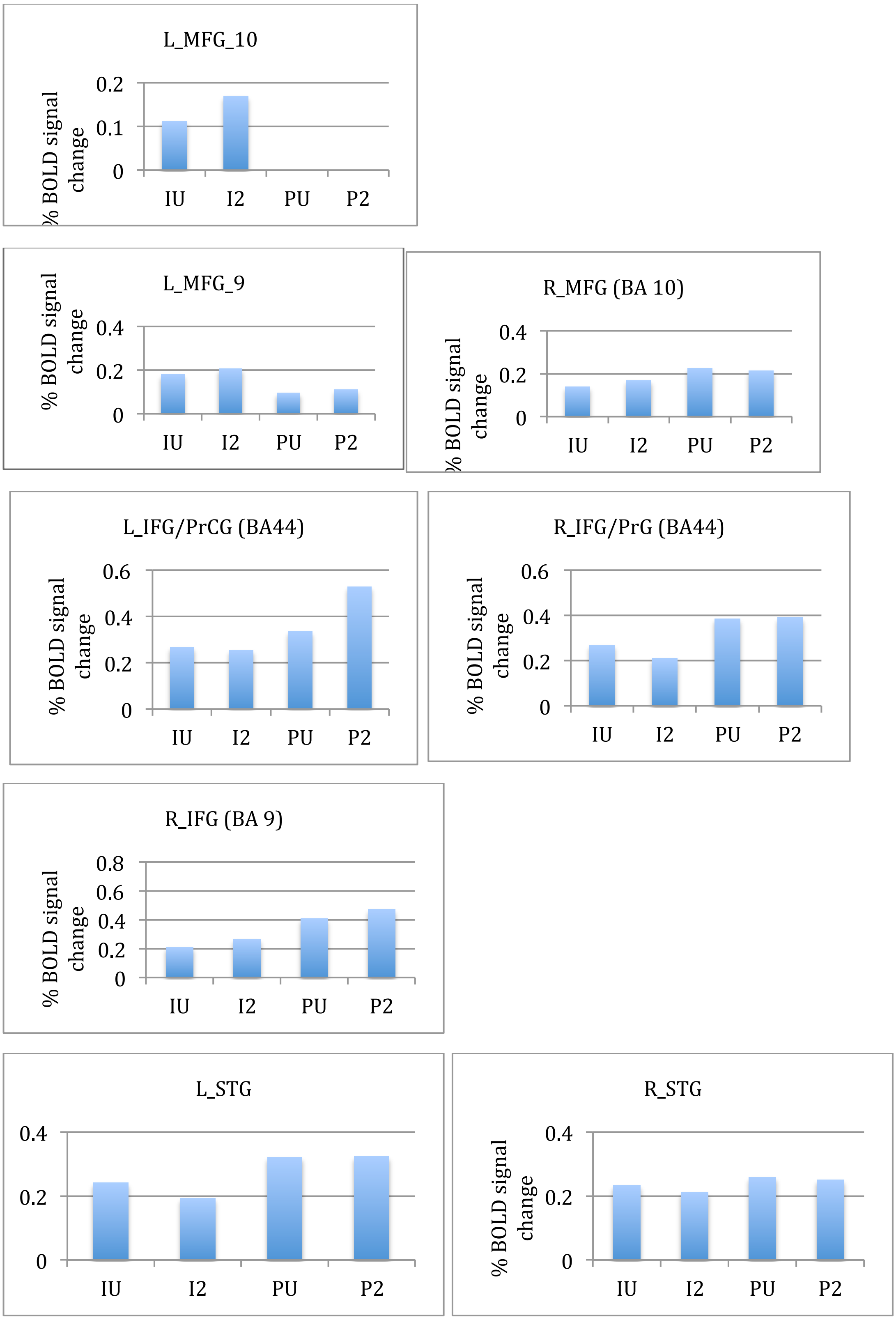

Figure C.3: Bar charts % BOLD signal change in each condition > rest (p<0.05, FDR corr); L_MFG (BA 10); bilateral MFG (L_BA 9 & R_BA 10); bilateral IFG (BA 44); R_IFG (BA 9); bilateral STG (BA22/42); bilateral M1 (BA 4).

Table C.7: Areas of interest activated in each task versus rest (FDR corrected, p<0.05 for the whole brain).

Imagine Unison | Imagine 2-part

Area	BA	mm	*x*	*y*	*z*	*t*	*p*	BA	mm	*x*	*y*	*z*	*t*	*p*
L_M1	4	32	-46	-11	48	7.830038	0.000003	4	31	-46	-8	48	8.623112	0.000001
R_M1	4	36	27	-20	51	4.330361	0.000816	6(4)	30	23	-17	48	5.284291	0.000148
SMA	6	37	-1	-5	57	8.891274	0.000001	6	37	-1	-5	57	8.902144	0.000001
L_PMC	4(6)	33	-29	-20	54	4.179843	0.001079	6	36	-25	-14	51	4.282066	0.000892
R_PMC	6	30	23	-17	48	5.284291	0.000148	6	30	23	-17	48	5.284291	0.000148
L_STG	22	25	-58	-41	21	5.490802	0.000104	22	4	-52	-41	13	2.772781	0.015833
R_STG	22	33	56	-38	9	6.094722	0.000038	22	33	56	-35	9	5.231668	0.000162
L_MFG	9	27	-37	31	30	3.446793	0.004335	9	22	-37	28	27	3.540087	0.003625
L_MFG	10	26	-37	43	15	3.911402	0.001787	10	10	-37	40	15	4.198044	0.001043
R_MFG	10	32	35	40	24	6.025888	0.000043	10	32	35	37	24	5.2459	0.000158
L_PrCG	6	32	-55	1	26	5.946582	0.000049	6	28	-57	1	24	7.870358	0.000003
R_IFG	44 (9)	4	53	7	20	2.525099	0.025359	9	22	53	1	25	4.342566	0.000798
L_PrCG/IFG	44	37	-52	4	10	5.213326	0.000167	44	34	-49	4	9	5.54861	0.000094
R_PrCG/IFG	44	35	50	7	9	4.756014	0.000375	44	34	50	7	12	5.646385	0.00008

Play Unison								Play 2-part							
Area	BA	mm	*x*	*y*	*z*	*t*	*p*	BA	mm	*x*	*y*	*z*	*t*	*p*
L_M1	4	36	-37	-17	54	13.182705	0	4	37	-31	-23	50	11.614712	0
R_M1	4	37	32	-29	54	10.137844	0	4	37	29	-23	57	11.161739	0
SMA	6	37	-1	-8	51	14.675910	0	6	37	-1	-8	51	15.937428	0
L_PMC	6	37	-29	-17	55	7.652631	0.000004	6	36	-31	-17	57	10.877992	0
R_PMC	4(6)	37	29	-21	54	9.221399	0	4(6)	37	29	-21	55	9.938330	0
L_STG	42	36	-58	-32	18	5.722762	0.00007	22	28	-55	-38	15	6.116001	0.000037
R_STG	22	36	56	-35	9	8.85202	0.000001	42	32	56	-32	9	7.33825	0.000006
L_MFG	9	16	-28	31	21	5.154729	0.000185	9	30	-25	34	24	4.829983	0.000329
L_MFG	10	-	-	-	-	-	-	10	-	-	-	-	-	-
R_MFG	10	30	38	37	24	6.482497	0.000021	10	34	35	37	24	7.729698	0.000003
L_PrCG	6	33	-55	1	27	6.497612	0.00002	6	36	-55	1	24	6.495375	0.00002
R_IFG	9	32	53	4	24	10.285764	0	9	35	53	4	24	8.738563	0.000001
L_PrCG/IFG	44	35	-48	4	7	5.486556	0.000105	6	25	-59	1	12	6.139821	0.000035
R_PrCG/IFG	44	37	50	10	6	7.714232	0.000003	44	35	50	10	9	9.564655	0

BA, Brodmann's area; *x*, *y* and *z* represent Talairach and Tournoux (Talairach and Tournoux, 1988) coordinates.

C.3.2 Comparison of M1 activation in Play and Imagine

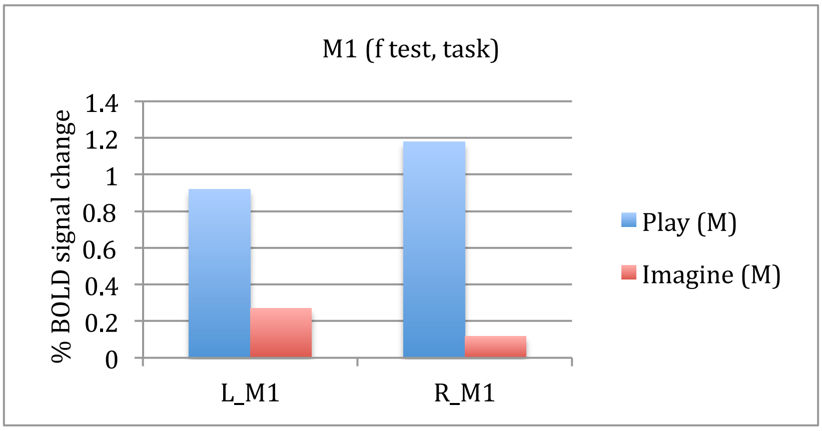

Figure C.4: Bar chart to show mean BOLD signal change in L_ & R_M1 during Imagine and Play (F test, task).