Reading Vocal Music

Eye Movements and Strategies

Timoshenko-Nilsson, Maria

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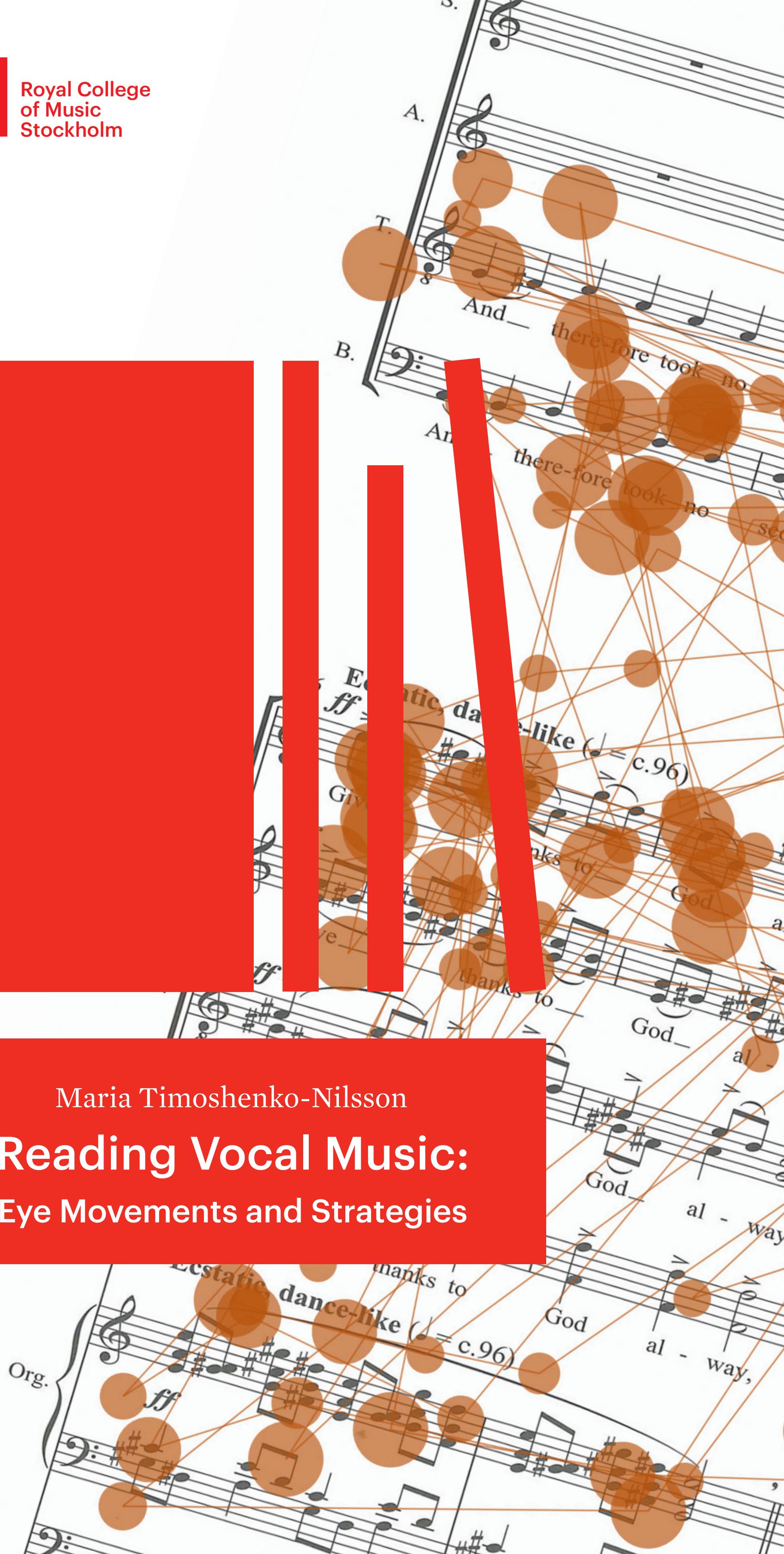

Maria Timoshenko-Nilsson

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MADE IN SWEDEN

Dedicated to my family

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Abstract

In the Western classical musical tradition, proficiency in music reading encompasses complex musical, interpretative, and performative skills. Among these skills, fluency in music reading is considered fundamental in educational contexts. Despite a growing body of research on sight-reading strategies, there remains limited understanding of how experienced choral singers visually and cognitively approach unfamiliar scores.

This dissertation expands the empirical knowledge base on music-reading strategies used by skilled musicians in the Western choral tradition. It identifies key influences on score reading and examines musicians' strategies for navigating vocal scores, from simple to highly complex. The dissertation is comprised of four studies, each contributing to knowledge on vocal music reading expertise. A mixed-methods research design allowed for a holistic assessment of complex research questions, utilizing various methods, including eye tracking, interviews, verbal protocols, and surveys, to compare diverse outcomes, reduce bias, and enhance validity and reliability through triangulation.

The first study investigated the perceptual processes used by skilled singers during music reading. An analysis of the singers' visual attention revealed a distinct prioritization of melody over lyrics. Additionally, the zigzag pattern of eye movements between the music and the lyrics suggested that the lyrics were processed syllabically, potentially causing difficulties in semantic comprehension. The data also showed that the complexity and density of the music significantly influence the visual behavior of choral singers.

The second study shifted the focus to conductors and their conceptions of choral score reading, through two interconnected investigations. The first was a qualitative interview in which conductors described their general conceptions of score reading practices. The second assessed the actual score-reading strategies exhibited by the same conductors. The findings revealed common conceptions and reading tendencies, but also individual cognitive orientations that appeared to inform the conductors' eye movements.

In the third study, the analysis of reading strategies was extended to vocal ensembles. Four quartets performed music excerpts from choral scores while their eye movements were recorded using synchronized eye trackers. The results indicated that experienced choral singers frequently direct their gaze to the neighboring staves in addition to reading their own vocal lines. Participants reported that an overview of the score's features and listening to others sing assisted them in achieving a holistic understanding of the music and supported pitch and rhythm accuracy. These observations suggest that singers visually alternated between sight reading and a parallel information-gathering process.

The fourth study examined the strategies used by music college students with choral background as they learned and memorized three unaccompanied songs. Eye-tracking data was collected to analyze participants' visual gaze behaviors during

memorization. The results showed that students employed a diverse range of approaches, primarily relying on holistic methods (i.e., performing from beginning to end) and segmented ones (i.e., working on segments comprising two consecutive phrases). Additionally, participants used a content-addressable learning technique, relying on structural cues. Overall, combining holistic memorization with content-addressable learning appears to be effective for memorizing short, simple melodies.

The four studies demonstrated that musicians employed a range of music-reading strategies, depending on the complexity of the musical score, the task conditions, and their own cognitive interests. The findings corroborate previous research and underscored the complex interplay between performance mastery, visual processing expertise, audiovisual integration skill, domain-specific knowledge, and contextual awareness. In conclusion, this research contributes to the ongoing investigation of vocal music reading strategies and the development of improved training methods that can promote a more nuanced approach to music reading.

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List of Original Publications

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II. Timoshenko-Nilsson, M., Huovinen, E. & Nyström, M. (2024). Silent score reading: Four Swedish choral conductors' conceptions, processes, and strategies. *Nordic Research in Music Education*, *5*, 160–192. https://doi.org/10.23865/nrme.v5.6133

III. Timoshenko-Nilsson, M., Nyström, M., & Huovinen, E. (2024). Sight-singing in a group context: An eye-tracking study with experienced choral singers. *Journal of New Music Research,* 1–15. https://doi.org/10.1080/09298215.2024.2375557

IV. Timoshenko-Nilsson, M. (2024). Melodic recall: Qualitative insights on singers' memorization strategies. Manuscript submitted for publication.

1 Introduction

1.1 Reading of Vocal Music

Vocal music, a rich and multifaceted art form, has been central to both sacred and secular traditions for centuries (for more information on vocal music, see Koopman, 1999). Choral singers and conductors play a central role in the preservation, maintenance, and transmission of the vocal music tradition, passing on the rich legacy of vocal music through their performances, teaching, and interpretations. Choral pedagogy plays a critical role in fostering the diverse skills necessary for success in this field, from vocal technique and ensemble collaboration to interpretive expression and artistic precision. Among these, fluency in reading music and sight reading are particularly fundamental, as they are key indicators of academic and professional achievement (see Jansson, 2019; Kornelsen, 2005; Garnett, 2017; Kaufman & Flanders, 2020).

Sight reading of a printed score can be challenging, yet it is crucial to developing of musicianship in the Western classical tradition, enabling musicians to learn a broad repertoire and participate actively in various musical events. Sight reading involves the vocal or instrumental performance of non-rehearsed music at sight (Lehmann & Kopiez, 2016) and may occur in three sequential steps: perceiving notation, processing it, and executing (Thompson & Lehmann, 2006). Scholars have observed that sight-reading skills can be improved through the practice of musical analysis, the memorization of complex passages, and the development of inner hearing (e.g., Lehmann & Kopiez, 2016; Zhukov & McPherson, 2022).

Blanka Bogunović and Ida Vujović (2012), in their article "Metacognitive Strategies in Learning Sight-Singing", defined sight singing as "an 'online' activity that asks for quick insight and problem solving in order to maintain fluency and accuracy without interrupting the musical stream" (Bogunović & Vujović, 2012, p. 117). The success in sight singing is considerably influenced by the quality of automatic reaction in creating tone (see Nikolić & Kodela, 2020). Central to this process is audiation, a concept introduced by Edwin Gordon (1977), refers to the ability to hear and comprehend music internally, in the mind, without any external sound being present, commonly called "mind's ear" or "inner hearing". This skill is critical in sight singing, where participants must translate visual symbols into sound mentally before producing the sound vocally.

The process of sight singing becomes more complex when a piece includes accompanying lyrics. Interpreting both musical and textual elements simultaneously requires additional cognitive effort. This dual decoding process demands quick thinking, multitasking, and a deep understanding of both music and language. Therefore, mastering the ability to process both musical and textual elements is essential for singers aiming to excel in sight-singing, as it enables them to deliver a compelling and accurate performance while reading and interpreting music in real time (see Henry, 2015; Mishra, 2016; Fournier et al., 2019).

Over the years, researchers have attempted to investigate and systematize the phenomena associated with sight singing and its connection to various musical skills. Scholars and educators have explored a variety of teaching techniques to address students' individual needs (e.g., Demorest, 2001; Henry, 2004; Potter, 2015). Manuals for ear training and sight-singing skill development (e.g., Karpinski, 2007; Rogers & Ottman, 2019) have provided guidance to optimize practice, thereby enhancing students' reading skill development. Most music education programs in colleges and conservatories in Europe and the United States, include courses focused on aural skills and solfège—a system of syllables used for sight singing and ear training—designed to improve students' music reading and listening abilities (e.g., Karpinski, 2000, 2007).

Despite various practices, educators who supervise choral programs have reported that young singers often demonstrate inadequate sight-reading skills (e.g., Green, 2012; Henry & Demorest, 1994; Henry, 2004, 2015). For instance, Eva Floyd and Marshall Haning (2014) have noted that textbooks commonly used in undergraduate choral methods courses offer a limited guidance on teaching sight singing, with no reference to helping students develop internal sound organization.

However, extensive research has been conducted to clarify the skills involved in music reading and identify the key factors contributing to proficient sight reading (e.g., Arthur et al., 2016; Mishra, 2014; Rosemann et al., 2015; Perra et al., 2024). Scholarly contributions to the music psychology literature on expertise—particularly those addressing expert musicians who can read and perform music accurately at a glance—shed light on the intricate relationship between visual processing expertise and proficiency in music reading (e.g., Lehmann et al., 2018; Lehmann & McArthur, 2002; McPherson & Hallam, 2016). Numerous studies have also explored music reading strategies, which will be discussed in detail later.

1.2 Overview of the Dissertation Structure

Expanding on previous research in music reading, this dissertation examines the strategies used by experienced musicians in reading vocal music, particularly unfamiliar musical compositions. The investigation includes: first, sight singing (performing vocal music without instrumental support) in individual and group settings; second, silent reading (when no performance is required); and third, memorization (reading and learning for recall). This research explores how expertise in music reading is manifested, with a particular focus on the role of visual perception of musical notation.

In Chapter 2, I provide a brief overview of key theoretical perspectives on the complex phenomenon of expertise. These concepts are essential for understanding music reading and memorization skills in the context of expert performance. The chapter also includes a broad review of previous research literature, offering insights into the current landscape of music reading research. Lastly, it explores visual expertise from the point of view of eye-tracking methodology. The original articles were constrained by space, allowing for limited discussion of theoretical perspectives. Consequently, the rationale behind key theories and relevant literature has been expanded in Chapter 2, offering a more comprehensive overview.

Chapter 3 presents an overview of the research aims and introduces the detailed objectives of each study included in the dissertation. Chapter 4 delineates the mixed-methods approach, providing brief information on qualitative and quantitative methods, and eye-tracking methodology. Additionally, this chapter includes a summary of the methods used in the original studies. The results of all original studies will be presented in Chapter 5 separately, with a summary of the main results included at the end. Chapter 6 discusses the findings of the research and aspects of domain-related visual processing expertise, considers the pedagogical implications, and revisits the theoretical perspectives. Chapter 7 reevaluates the mixed-methods approach and addresses issues concerning validity and reliability. Additionally, it reflects on the research limitations and the relevance of the findings, while also proposing directions for future research.

2 Background

2.1 Musical Expertise

The concept of an eminent performer in music refers to individuals who have achieved the highest level of expertise and performance in their field (Mishra, 2020). Musical expertise is often evaluated through objective measures of performance, including technical proficiency, interpretation, expressiveness, and the ability to engage with an audience. The recognition of expertise may manifest in various forms, such as acknowledgment within the musical community, successful performances, awards, and other tangible achievements (Burgoyne et al., 2020).

Jennifer Mishra (2020) has identified a discrepancy in the research literature: scholars define musical expertise in varying ways, making comparisons difficult. Mishra proposed a hierarchy of musical performance expertise, which provides a tool to establish consistency in defining musical expertise. This hierarchical system consists of five key stages for the operational definition of musical expertise: non-performer, student musician, developing expert, expert musician, and influential expert. Here are some definitions: a "developing expert" is a musician who has demonstrated their skills through an audition or public performance but continues to work on technical concerns under the supervision of teacher (e.g., a music major at a university). An "expert musician" is a musician who publicly performs concert repertoire and can prepare this repertoire with little or no supervision from a teacher (i.e., shows musical independence). An "influential expert" is a high-achieving musical expert who sets the standard for the field and influences other experts (Mishra, 2020, p. 578).

Researchers have also examined the effects of genetics on musical expertise, revisiting the long-standing debate between nature and nurture (Burgoyne et al., 2020; McPherson & Hallam, 2016). For example, Burgoyne et al. (2020) discussed the gene-environment interplay among various factors such as ability factors (e.g., intelligence, perceptual speed, music aptitude, perfect pitch), personality factors (e.g., rage to master, passion), experience factors (e.g., starting age, practice, lessons), and physical factors (e.g., hand morphology, lung capacity, strength), along with mechanisms including neural mechanisms (e.g., motor cortex, long-term memory, primary auditory cortex). Researchers have argued that both intelligence (e.g., cognitive ability and working memory capacity) and the role of parents are critical for the development of musical expertise (Burgoyne et al., 2020).

2.1.1 Defining and Evaluating Musical Expertise

Gary McPherson and Susan Hallam (2016) explored musical potential as a multifaceted phenomenon influenced by various factors. They proposed a distinction between gifts—such as intellectual, creative, and sensorimotor abilities, considered innate potentials—and talent, which refers to observable, developed skills. They suggested at least eight distinct types of musical talent—performing, improvising, composing, arranging, analyzing, appraising, conducting, and music teaching—that can be cultivated through systematic practice and training. Additionally, the authors described the skill set that can be acquired in learning to play an instrument, including aural, cognitive, technical, performance, creative, evaluative, and self-regulatory skills. In conclusion, they proposed that "musical potential is best thought of as malleable and ever changing, and a dimension of human experience that takes many forms and occurs at many different levels" (McPherson & Hallam, 2016, p. 443).

Describing the development of musical expertise, Andreas Lehmann, Hans Gruber, and Reinhard Kopiez (2018) proposed that expert performances can be seen as a series of cognitive, physiological, and perceptual-motor adaptations through which individuals progress as they become more proficient in music. According to Lehmann et al. (2018), cognitive adaptation in music encompasses various aspects, such as problem-solving, memory, self-regulation, and self-efficacy, all of which play crucial roles in musical performance and practice. Moreover, Lehmann et al. (2018) suggest that consistent music practice results in physiological adaptations, as the body adjusts to the specific demands of playing an instrument or singing. These adaptations are linked to localized physical changes in musicians, such as increased forearm rotation or enhanced lung capacity, which develop in response to regular use during training. Musicians undergo perceptual-motor adaptations, developing skills and preferences that differ markedly from those of non-musicians. These adaptations may include rapid finger movements, unique preferences, and increased sensitivity to pitch and loudness. Such changes result from extensive, focused practice, which refines both motor coordination and auditory perception to meet the specific demands of musical performance (Lehmann et al., 2018).

2.1.2 The Visual Processing Expertise of Musicians

"Visual expertise" refers to the optimal adaptation of cognitive abilities to tasks that rely heavily on vision (e.g., identification of different types of abnormalities in X-rays or mammograms), where visual material plays a significant role in professional work (e.g., Gegenfurtner & van Merriënboer, 2017). In the realm of music reading research, visual processing expertise is a substantial area of focus (e.g., Arthur et al., 2021; Sheridan et al., 2020) because it accelerates visual information extraction, leading to faster information encoding through high-level knowledge networks (e.g., Perra et al., 2024). Building upon Lehmann et al.'s (2018) description of cognitive adaptation in musicians, visual processing expertise can be seen as an adaptation that furthers an individual's progression in musical proficiency.

The acquisition of expertise in various domains, including music, is an area of research that has long been of interest to scholars seeking to understand the cognitive mechanisms that distinguish experts from novices (see Perra et al., 2022; Puurtinen, 2018; Sheridan et al., 2020). Visual processing expertise involves recognizing and interpreting complex visual patterns that convey meaningful information, rather than focusing solely on individual elements (Sheridan & Reingold, 2017). This capacity results from complex cognitive and perceptual processes, which are developed through extensive practice and training over time (Ericsson et al., 1993; Reingold & Sheridan, 2011).

Reading music involves the comprehending of musical features, their spatial arrangements, and their relationships (e.g., Sloboda, 1976). For example, notes form arpeggios and chords, which contribute to the construction of broader musical structures such as melodies and phrases. Experts can process the score using both holistic processing, which addresses global structural entities, and detailed processing, which focuses on local musical features of the score (e.g., Maturi & Sheridan, 2020). As a result, proficiency in this area depends not only on recognizing visual patterns but also on mastering the domains syntax and the deeper structures that support it (e.g., Sheridan et al., 2022).

Research have demonstrated that expertise can influence eye movements during music reading (for a review, see Sheridan et al., 2020). Visual expertise often entails an exceptional ability to process domain-specific visual information (e.g., Reingold & Charness, 2005; Reingold & Sheridan, 2011). The memory structures of domain-specific visual information, referred to as "chunks" (i.e., a group of related items) (Chase & Simon, 1973a, 1973b; Gobet & Simon, 2000), enable experts to process music scores efficiently by directing their attention relevant features and comprehending underlying structures (Maturi and Sheridan, 2020; Sheridan et al., 2020).

Eye-movement studies on anticipatory looking have found that experienced music readers often look further ahead in the music notation relative to the point of performance compared to less skilled musicians (e.g., Goolsby, 1994b; Penttinen et al., 2015; Huovinen et al., 2018; Truitt et al., 1997; for a meta-analysis, see Perra et al., 2022). Additionally, experts process more information per fixation[1], known as the perceptual span, particularly through greater parafoveal[2] information processing

1 "The state in which the eye remains stationary for a period of time, such as when it pauses momentarily on a word during reading, is referred to as a fixation. This can last anywhere from a few tens of milliseconds to several seconds." (Holmqvist et al., 2011, p.21–22).

2 Parafoveal information processing refers to the processing of visual information located just outside the central focus of the eye, known as the fovea (e.g., Rayner, 1993, 1998). In text reading, parafoveal processing allows individuals to gather information about upcoming words in the peripheral vision, enabling smoother transitions and quicker comprehension when the eyes move to focus on those areas (e.g., Hyönä, 2011).

(Sheridan et al., 2020). More details about parafoveal vision are provided in the following chapters.

Moreover, experts tend to exhibit superior cross-modal integration abilities, allowing them to transition between auditory and visual codes more efficiently, a phenomenon known as enhanced audiovisual processing (Drai-Zerbib et al., 2012). Proficient sight readers also typically display larger eye-hand spans (i.e., distance between eye position and hand position when sigh reading music) compared to those with less proficiency (e.g., Furneaux & Land, 1999; Gilman & Underwood, 2003; Truitt et al., 1997; Goolsby, 1994b). Research on the impact of structural elements in musical notation on eye movements indicates that experts tend to follow the melodic contour, phrases, and moving eyes in a vertical direction aligned with the melody's trajectory (Goolsby, 1994; Sloboda, 1974).

2.2 Theoretical Perspectives on Expertise

Expertise is a multidimensional concept and has been the subject of research in a variety of academic disciplines, such as psychology, education, and sociology. Fernand Gobet (2016), defined expertise as "the ability to consistently demonstrate superior performance in a particular domain relative to one's peers" (Gobet, 2016, p. 2). This definition suggests that expertise involves not only the possession of a high level of knowledge or skill but also the exhibition of superior performance in a specific domain. Furthermore, expertise is not an innate ability but is developed through deliberate practice over time (e.g., Gobet, 2016; Ericsson et al., 1993).

Different theoretical concepts provide perspectives for understanding the complex interplay between domain knowledge, internalized skills, and mastery in performance. The following subsections present theoretical models of expertise and memory that shed light on how experts decode, store, and retrieve information. The presentation begins with a brief review of key theoretical concepts in classical expertise approaches.

2.2.1 Chunking, Schema and Template Theories

Though these three theories focus on slightly different aspects of cognition, they all explore how humans manage large amounts of information efficiently. Chunking theory explains how experts break down complex information into smaller, manageable units or "chunks" to enhance memory and learning. Schema theory, in contrast, addresses how existing knowledge structures, called "schemas," help individuals interpret and categorize new information based on prior experience. Finally, template theory builds on these concepts, particularly in skilled domains, by suggesting that experts rely on detailed mental templates that allow for rapid recognition and response to familiar patterns (e.g., Gobet, 2016).

The chunking theory, developed by William Chase and Herbert Simon (1973a), has been applied across various fields including psychology, cognitive science, linguistics, philosophy, and computer science, to explain how humans process and remember information. In their influential study "Perception in Chess" (1973a), they conducted experiments to understand how chess experts and novices differ in their ability to remember and recognize chess positions. Originally introduced by Miller (1956), this theory suggests that organizing information into "chunks" or meaningful units enables individuals to process larger amounts of information more efficiently. Chase and Simon (1973a) made a significant contribution to the field of cognitive psychology with their research on the expertise and memory of chess players.

The chunking theory has significant implications in music. Musicians, especially experts, use chunking to group notes into meaningful patterns (e.g., Arthur et al., 2016; Lörch, 2022; Maturi & Sheridan, 2020). Through extensive practice, they develop a repertoire of familiar chunks that they can quickly recognize (Sheridan & Reingold, 2014; Sloboda, 1974). In sight reading, the ability to identify chunks allows experts to process music efficiently and accurately by identifying familiar patterns without decoding each note individually (Waters et al., 1998; Waters & Underwood, 1998). Researchers have found that expert musicians have a well-developed domain-specific memory for musical patterns (e.g., Waters & Underwood, 1998). This mode of memory enables musicians to rapidly recall and recognize common musical phrases, anticipate the progression of a piece, and reduce the cognitive load involved in reading music (e.g., Wolf, 1976).

The schema theory, introduced by psychologist Sir Frederic Bartlett (1932) and later developed by Richard Anderson and David Pearson (1984), posits that individuals organize and store knowledge in their minds in the form of *schemas*—"mental abstract knowledge structures" or "internal representations" that help them to understand and interpret new information. Anderson and Pearson described that the reader's schema is a structure that facilitates the planned retrieval of textual information from memory and allows for the reconstruction of unlearned or forgotten elements. Schemas, built upon prior experiences and knowledge, enable new information to be quickly processed and categorized by relating it to existing knowledge, thereby supporting more efficient and coherent understandings.

In the context of music, Bob Snyder (2000) explained that schemas (as a meta-mindset or form of content) help anticipate musical developments, allowing musicians to predict the progression of a piece based on familiar patterns stored in their schemas, resulting in more coherent and seamless performances. Musicians use existing schemas to learn and remember new compositions, finding it easier to grasp pieces that share similar patterns. In addition, schemas encompass knowledge of various musical styles. For example, in improvisation, musicians draw on their schemas to spontaneously create coherent and expressive musical passages (ibid.).

The template theory of Fernand Gobet and Herbert Simon (1996) extends the concept of "chunks," originally defined by Chase and Simon (1973), by introducing the *templates*. According to the template theory, the chunks acquired by experts in a domain evolve through frequent recall into more complex structures of information known as templates. Gobet and Simon (1998) propose that a template not only encompasses information about specific patterns but also includes open "slots" that can accommodate new information.

According to Gobet (2016), templates function as mental representations of familiar patterns, structures, and features within a domain. They allow experts to quickly recognize and process information, supporting storage and retrieval. When experts encounter familiar patterns in a stimulus, they compare these patterns to their stored templates. This alternative theory of expertise and memory explains how experts can rapidly retrieve information from memory while allowing for the flexibility to adapt their knowledge when encountering additional domain-specific information (Sala & Gobet, 2016). Based on the implications of template theory for teaching, Gobet (2005) highlighted the importance of order and segmentation in the curriculum to enhance learning and the development of expertise.

The template theory can explain how skilled musicians leverage their extensive musical knowledge to recognize and interpret musical elements, enhancing their memory and visual search performance (e.g., Maturi & Sheridan, 2020). For instance, a skilled musician may have developed templates for identifying common chord progressions, melodic motifs, or rhythmic patterns. When encountering a new piece of music, the expert can compare the patterns in the piece to their stored templates. If a match is found, they can fast understand the structure and content of the music, facilitating memorization and performance (see Sloboda, 1984 for a review).

Template, schema and chunking theories are cognitive accounts that unpack how individuals process and organize information based on their experience and knowledge. Although these theories share some similarities, they also have important differences. Generally, chunking theory explains how experts break down complex information into smaller, manageable units which enhance proficiency in performance. The schema theory highlights the broader organization of knowledge and the ability to adapt that knowledge to various contexts (Anderson & Pearson, 1984; Bartlett, 1932). While template theory emphasizes precise pattern recognition through exact matches, focusing on how individuals use stored templates to identify and process specific patterns (Gobet & Simon, 1996).

2.2.2 Cognitive processing: WM and LTWM Theories

Two influential theories in the domain of cognitive psychology are the theories of working memory (WM) and long-term working memory (LTWM); each explains different aspects of how information is processed over varying periods. The theory of working memory explains how individuals temporarily hold and manipulate information needed for ongoing tasks, such as problem-solving or learning. The theory of long-term working memory builds on the principles of working memory but extends them to explain how skilled individuals develop strategies to efficiently integrate information stored in long-term memory into their working memory. These cognitive theories are often used in music research to explain the encoding and retrieval processes of musical features. The general principles of these theoretical models are described below.

Alan Baddeley and Graham Hitch (1974) have introduced a theoretical model for conceptualizing the human thought processes through the concept of working memory. Working memory was assumed to be cognitive system which simultaneously stores and processes information, supporting humans in the performance of a variety such complex tasks as comprehension, learning, reasoning, problem-solving, and decision-making.

The working memory model includes four main components: the central executive, the phonological loop, the visuospatial sketchpad, and episodic buffer (Baddeley, 2000). The central executive component, which was assumed to be an attentional-controlling system, directs attention to various types of information and coordinates the activities of the other components. The visuospatial sketchpad manages visual and spatial information, enabling the manipulation of images and spatial relationships. The phonological loop processes verbal and acoustic information, thereby cultivating both spoken and written language. The episodic buffer has been described by Baddeley (2000) as “a limited-capacity temporary storage system that is of integrating information from a variety of sources” (p.421). The episodic buffer functions as a modeling space, storing both visual and verbal information, and organizing it into cohesive chunks or episodes (Baddeley, 2000, p. 421).

The working memory model and its components have been a central focus of research in music education and music psychology. For example, Chenette (2018) explored the complex relationship between approaches to aural skills training and working memory capacity. Maes et al. (2015) studied the role of working memory in the temporal control of cellists’ bowing movements, while Nichols et al. (2018) examined the working memory span of classical and jazz student musicians. Also, Meinz & Hambrick (2010) investigated how working memory capacity influences sight-reading performance.

The common understanding of working memory (WM) is that it assists musicians in managing cognitive demands, such as reading music, by temporarily holding notes, rhythms, and dynamics while enabling them to read ahead on a printed score (e.g., Sloboda, 1974; Thompson, 1987). During learning and memorization process, WM enables musicians to break down complex pieces into manageable chunks, facilitating retention and recall of specific sections (for a review, see Pozenatto, 2020). In ensemble playing, WM supports synchronization by helping musicians remember cues and make performance adjustments (e.g., Nichols et al., 2018).

The long-term working memory (LTWM) theory, introduced by Anders Ericsson and Walter Kintsch (1995) has been effective in interpretation of the experts’ cognitive processes involved in music performances, particularly their ability to execute complex pieces with precision. Music experts draw upon their extensive long-term memory to support and expand their working memory during demanding tasks (e.g., Drai-Zerbib, 2016). Accordingly, musical knowledge can be encoded and retrieved through structured schemas, facilitating quicker access to information stored more permanently in long-term memory (e.g., Snyder, 2016). Moreover, long-term memory is thought to contribute to WM by reducing cognitive load and increasing working memory capacity (Ericsson & Kintsch, 1995; Miller, 1956; Gobet, 2916).

A significant difference between experts and novices has been found in experts' advanced knowledge structures, which facilitate faster processing of musical elements (Drai-Zerbib & Baccino, 2018). Through extensive and deliberate practice, musicians have developed advanced memory structures that enable them to store and retrieve vast amounts of information efficiently over time (Snyder, 2000). Music experts can access complex musical information efficiently through well-established retrieval frameworks, which are integral to their expertise (Drai-Zerbib & Baccino, 2014; Ginsborg, 2022). For instance, when encountering a musical passage, experts can almost effortlessly retrieve relevant patterns—such as groups of notes, chords, arpeggios, and chord progressions—from their well-established long-term memory structures (Ginsborg & Chaffin, 2009; Ginsborg & Chaffin, 2011). This ability enables them to quickly decode and perform intricate pieces during music reading (Williamon & Valentine, 2002). The principles underpinning this process are crucial in music, where pattern recognition, meaningful associations, extensive practice, and structural understanding are central to expert performance (Ginsborg, 2022).

2.2.3 Music Memorization Models

The theoretical framework surrounding memorization in music underscores the multifaceted nature of this key ability, particularly in modern Western classical music, where performances are often expected to be played from memory (see Ginsborg, 2022). Both semantic and episodic memory—forms of theoretical knowledge that assess in storing and recalling musical concepts and experiences—and kinesthetic memory—a type of procedural knowledge that supports the physical execution of music—are essential for reading and interpreting melodies. From an educational perspective, each type of memory holds significant value (e.g., Ginsborg, 2004, 2022; Mishra, 2007). Importantly, these memory systems are interdependent, working together to provide stability of memorization processes (e.g., Ginsborg, 2022).

A substantial body of research has been conducted on the processes involved in memorizing and recalling music from memory (Aiba & Matsui, 2016; Aiello, 2006; Lehmann & Ericsson,1998; Sloboda & Parker, 1985; Snyder, 2000). This research has deepened the understanding of the distinct memory systems engaged and the diverse strategies and techniques employed by musicians to memorize pieces.

Furthermore, research into memorization techniques has uncovered various methods employed by musicians to enhance memory retention. These methods include (a) organizing melodic material into phrases and sections to support mental imagery of the score (Halpern & Bartlett, 2010), (b) using the musical features of the piece as cues for memorization and performance (Ginsborg, 2002; Ginsborg & Chaffin, 2009), (c) memorizing the physical movements required to perform the piece (Chaffin & Imreh, 2002), and (d) utilizing auditory cues to recall parts of the composition (Halpern, 1989). Fine et al. (2015) note that during mental practice, the score often serves as an orientation guide, and reference point for interpretation.

In her theoretical model of music memorization, Mishra (2005) described the complex process musicians undergo when memorizing musical material, developing a framework that explains how music is committed to memory for performance. The process of memorization appears to be dynamic, undergoing changes as practice progresses towards the goal. According to Mishra's theoretical model, the process of memorizing from notation consists of three stages: preview, practice, and over-learning, with each stage further subdivided into distinct steps. For example, the preview stage is subdivided into three components: notational, aural, and performance overviews. The practice stage, in turn, is divided into two parts: notational practice and conscious memorization. The over-learning stage encompasses re-learning, maintenance, automatization, and additional motivation. In 2011, Mishra investigated the impact of processing strategies on the efficiency of memorization and the stability of recall for a technically simple piece of music. The findings indicated that musicians who employed a holistic approach, repeatedly performing the piece from beginning to end, demonstrated superior memorization rates compared to those who segmented the piece. The author attributed this success to forming of a complete mental image of the piece.

Chaffin et al., (2016) reviewed the knowledge about performing from memory, and described several types of memory systems, including associative chaining, content-addressable memory, and multiple memory systems such as auditory, motor, structural, emotional, and visual. According to Chaffin et al. (2016), associative chaining memory is linked to a sequence of cues that remind the musician of what is coming next during a performance. In contrast, content-addressable memory is described as a "mental map" of the piece, providing reference points from which the musician can resume playing if necessary. The authors suggest that content-addressable memory is more likely to be explicit (conscious), while associative chaining tends to be implicit (unconscious). Content-addressable memory is associated with expertise, acting as a safety net that offers flexibility, control, and recovery when associative chaining breaks down (Chaffin et al., 2016). Furthermore, Chaffin et al. (2016) found that performance cues—such as structural, expressive, and interpretive cues—point to different types of memory and serve as landmarks in the mental map of the music that experienced musicians maintain in working memory during performance (see Chaffin et al., 2016, p. 567).

The memorization strategies of classical singers were the focus of a study by Jane Ginsborg (2002). The study involved thirteen participants who learned and memorized a song over six fifteen-minute practice sessions. An intriguing outcome was that experienced professional singers were not necessarily faster or more accurate memorizers than students and amateur singers. In general, participants commenced by practicing the music separately from the words, subsequently progressing to practicing the words and music together. Singers with greater accuracy, in comparison to those with less accurate memorization, were observed to memorize more rapidly. Ginsborg (2002) concluded that the recall of songs from memory required not only fundamental musical skills but also the memorization techniques to complete the task.

Ginsborg and Sloboda (2007) conducted a study to explore the potential for more effective memorization techniques for vocal music. The researchers proposed that it is preferable to memorize the words and melody simultaneously rather than separately for optimal memorization of songs. Their observations indicated that separate memorization of melodies and lyrics was time-consuming and resulted in less accurate performances from memory. Additionally, the researchers observed that the memorized words and melody were intricately connected during storage and retrieval. These authors suggested that memorizing words and melody together is an effective strategy, but perhaps only for singers with high levels of expertise.

After decades of studying music memorization, Ginsborg (2022) emphasizes the interconnectedness of various memory systems. These include conceptual memory (remembering the compositional structure of the music), auditory memory (ability to remember music/pitch contour and to “hear” sounds/melodies in the head), visual memory (remembering mental images of printed music), and kinesthetic memory (involving explicit motor memory, finger/muscle memory, or reflex actions).

As noted by Chaffin et al. (2016) and Ginsborg (2022), if conceptual memory is viewed as a system that facilitates the recollection of abstract knowledge related to compositional structure and its connections to interpretation and association, it can also be suggested that auditory and visual memories—components of working memory—hold information about both pitches and notated symbols. These memory systems facilitate musicians’ ability to read and simultaneously hear music when performing from a score or in their imagination, contributing to the development of musical schemas. Kinesthetic memory enables musicians to recall specific motor skills and perform them without conscious effort. This kinesthetic strategy explicitly supports procedural memory (i.e., tactile, motor, finger, or muscular) in a way that allows musicians to play with a high level of automaticity, thereby enabling them to focus on other aspects of the performance (Chaffin et al., 2016; Ginsborg, 2022). These multiple memory systems collectively support the continuity of performance, even if one memory system becomes unreliable.

Ginsborg’s (2022) pedagogical recommendations indicate that an effective approach to memorizing music involves breaking a piece into smaller subsections (chunks) and memorizing these in several short sessions, rather than trying to memorize the entire piece at once. When music is memorized, it is advisable to practice performing the piece in the concert venue and to be prepared to improvise in the event of memory lapses, as the overall quality of the performance is the key focus.

2.2.4 Deliberate Practice Theory

The deliberate practice theory, established by K. Anders Ericsson and his colleagues (1993), describes deliberate practice as highly structured, goal-oriented learning activities that individuals engage in over extended periods. Notably, expertise in music performance has served as a foundational field in theorizing expert performance at large. In a prominent study conducted by Ericsson, Krampe and Tesch-Römer in 1993, violinists of varying levels of proficiency were asked to rate their deliberate practice since first taking up the instrument and to track their current practice patterns. The results of the study established a direct relationship between musical proficiency and the cumulative time spent in deliberate practice over approximately ten years of study.

According to the theory of deliberate practice (Ericsson et al., 1993), a fundamental requirement for achieving exceptional levels of performance is extensive experience with activities in a particular domain. To be effective, these activities must be performed at an appropriate level of difficulty and monitored by a coach who provides regular and detailed feedback, identifying and correcting weaknesses. Additionally, Ericsson and colleagues identified three constraints that influence the act of practice itself: (1) resource constraints, which refer to access to quality instruction, training facilities, and training materials; (2) effort constraints, which refer to the need for learners to balance their effort with rest; and (3) motivational constraints, which refer to developing and maintaining motivation to engage in deliberate practice.

Ericsson et al. (2007) defined an expert as someone who consistently works to improve and expand their skills through focused practice, often dedicating four to five hours each morning to mentally demanding tasks. Researchers highlighted the importance of skilled coaches in challenging and guiding students’ development. In 2018, Ericsson further noted that experts enhance their abilities through specialized activities such as team training, performance tracking, competition, concerts, and competitive events. By applying these techniques, musicians can pursue superior performance through deliberate practice, which includes increasing purposeful practice hours, breaking complex skills into manageable components, seeking feedback, and pushing beyond comfort zones. Participation in rehearsals, concerts, and competitive events also fosters expertise and the integration of advanced skills.

Research has consistently shown that the most significant predictor of mastery in music reading is the accumulation of deliberate practice hours (e.g., Meinz & Hambrick, 2010), along with experience and repertoire size (e.g., Lehmann & Ericsson, 1996). The effectiveness of sight reading, therefore, results from deliberate efforts and accumulated experience (e.g., Lehmann & Kopiez, 2016). Both the quantity and quality of practice play a crucial role in developing a musician's expertise and ability to employ effective strategies (e.g., Jørgensen & Hallam, 2016). Practicing intelligently by selecting evidence-based strategies is key to enhancing efficiency (e.g., Miksza, 2022).

2.3 Empirical Research in Music Reading

The term "music reading" refers to the mental processes and skills involved in the perception of musical notation to produce a coherent musical performance (Sloboda, 1984, p. 222). Sight reading, also known as *a prima vista* (Italian for "at first sight"), is the ability to read and perform a piece of music on an instrument or vocally without prior exposure or practice (e.g., Penttinen, 2013; Karpinski, 2007). The skills required for sight reading include both practice-related and independent abilities such as pattern recognition, prediction, auditory processing, cognitive speed, and integration of visual and motor skills. Numerous studies have examined these cognitive components, offering insights into how musicians process and perform music from notation without prior familiarity (e.g., Kopiez & Lee, 2006, 2008; Bogunović & Vujović, 2012).

Below, the studies presented in this subsection have investigated music-reading strategies from different research paradigms and are, therefore, presented separately. Eye-tracking studies within the music psychology paradigm provide insights into the relationship between eye movements and the perception of music notation, while studies on reading strategies within the pedagogical paradigm, provide insights into predictors of accomplishing proficiency in music reading.

2.3.1 Research on Sight Reading

To systematize the cognitive skills behind exceptional sight-reading, Kopiez and Lee developed two models that explain this musical skill. A "dynamic model" (Kopiez & Lee, 2006) revealed how the significance of specific predictors changes with the difficulty of sight-reading tasks. Researchers found that while accumulating practice hours is sufficient for achieving proficiency in relatively simple tasks, the importance of psychomotor speed, processing speed, inner hearing, and sight-reading experience increases with task difficulty. At the highest difficulty levels, psychomotor speed emerges as the primary predictor.

In a subsequent publication, Kopiez and Lee (2008) introduced a "general model" of sight-reading skills, which highlighted the relationships between various abilities and sight-reading accuracy, regardless of task complexity. The study identified the most significant predictors of sight-reading proficiency such as psychomotor speed (trilling speed), sight-reading experience up to the age of fifteen, processing speed, and inner hearing. Together, these variables accounted for approximately sixty percent of the variance in sight-reading accuracy. The researchers concluded that excellence in sight reading results from a combination of practice-related and practice-unrelated factors. Trilling speed, for instance, represents an intersection of specialized training and inherent movement speed advantages. This comprehensive model underscores the multifaceted nature of music sight reading, emphasizing that proficiency in this domain relies on a diverse array of skills.

Lehmann and McArthur's (2002) model of sight reading involved four key components: perception (decoding note patterns), kinesthetics (executing motor programs), memory (recognizing patterns), and problem-solving (improvisation and guessing). The researchers argued that sight reading is a trainable skill, shaped by relevant experience, the size of domain knowledge base, and reconstructive processes that engage higher-level mental functions, including conceptual knowledge and specific expectations. Lehmann and McArthur's (2002) further suggested that the perceptual system assist sight reading by allowing memory buffers to organize musical features into meaningful units. It can explain that better sight readers, with a larger perceptual span, can process larger units of information in memory, enabling them to internalize music more efficiently than less-skilled readers. While kinesthetic ability, developed through training (e.g., piano practice), is not a prerequisite for sight reading, yet it can enhance performance. Minimizing unnecessary glances at the keyboard, which interrupt visual contact with the score, may improve accuracy. Musical problem-solving is particularly crucial in sight reading, as not all notes can always be clearly identified. This requires musicians to rely on their expectations and adaptive strategies to maintain the flow of performance (Lehmann & McArthur, 2002). The authors have summarized that, throughout the development of competence, musicians "have come to know [a] large amount of patterns (visual, kinesthetic, aural), have solved countless musical problems (reading, fingering, ensemble coordination), and have developed the ability to manage all situation demands of performing" (Lehmann & McArthur, 2002, p. 148).

Recently, study by Huovinen and Rinne (2024) involving twenty-five professional pianists has demonstrated that the visual expertise of classical musicians is closely linked to their stylistic knowledge of the music. Participants were often able to recognize the style period and composer based on very brief exposure (500 ms) to notated piano music. The researchers have observed that correct responses occurred significantly earlier than incorrect ones, and that they were not preceded by richer verbal argumentation. According to Huovinen and Rinne (2024), success in the task relies on intuitive, holistic integration of information rather than reflective, analytical processing. The stylistic recognition exhibited by participants appeared to follow a pattern-recognition process, with "experience-based intuition" acting as the key mechanism in professional contexts.

2.3.2 Research on Sight Singing

Sight singing is the ability to read and sing music at first sight. This skill involves musician having an accurate mental representation of sounds in order to succeed (e.g., Pomerleau-Turcotte et al., 2022). Much like sight reading on an instrument, sight singing necessitates the singer's ability to interpret the musical notation, comprehend the rhythms, pitches, dynamics, and other musical instructions, and then translate that notation into a sung performance in real time.

Killian and Henry (2005) conducted a study with 198 high school singers. The participants were required to perform two melodies: one with a thirty-second preparation period and another with no preparation. The analysis revealed that sight-singing accuracy scores improved significantly with a thirty-second preparation period for high-accuracy and medium-accuracy singers, but not for those with low accuracy. The most effective practice strategies for the high-accuracy group included using hand signs, singing out loud during practice, isolating problematic areas, maintaining of the beat within the body, and sustaining a steady tempo. The low-accuracy group employed ineffective performance strategies more frequently than the other groups, including abandoning a steady beat, stopping during the melody singing, taking eyes off the music, and shifting the body. The authors proposed that effective training strategies for sight singing should not only involve repetition of testing procedures but also focus on teaching singers both what to do and what not to do when sight singing individually. This approach appears beneficial for singers of all abilities, enabling them to optimize their sight-singing experiences.

In their article on sight-singing ability, Fine, Berry, and Rosner (2006) investigated the effect of pattern recognition on the sight-singing ability of choral singers. The study revealed that when singers observed the musical score and listened to other concurrent vocal parts, they relied more on harmonic cues. The ability to predict the subsequent notes in tonal music was enabled by harmonic expectations, whereas under altered harmony conditions, most participants made errors. According to Fine et al. (2006), less skilled singers relied more on harmonic cues, whereas more accomplished singers, who were better at recognizing and utilizing melodic patterns, demonstrated greater confidence in their interval-singing techniques. Moreover, the study showed that practice had a significant impact on the accuracy of the performance, and an alteration of the underlying harmony in concurrent vocal parts impaired sight-singing ability. Similarly, Nikolić and Kodela (2020) discovered a positive correlation between the level of harmonic hearing exhibited by music students and their success in sight singing.

A comprehensive classification of sight-singing skills was established by Bogunović and Vujović (2012). A questionnaire was administered to 89 music students to ascertain their sight-singing strategies. Three main categories were identified: cognitive (involving mental representations and tonal functions), intuitive (using memory or no active thinking), and no strategy (singing without preparation). The researchers discovered that while less proficient students employed “tone-to-tone” thinking and “bottom-up” strategies in approaching musical material, more proficient students frequently utilized “top-down” cognitive approaches, which encompassed three levels of musical organization: chunking, pattern recognition, and mental representation of melodic, rhythmic, and harmonic structures.

Fournier et al. (2019) conducted an extensive examination of research articles, books, and sight-reading manuals, as well as interviews with students and aural skills instructors. This research resulted in the identification of 72 distinct sight-singing strategies. The strategies were grouped into four main categories: reading mechanisms, sight singing (performance and preparation), reading skills acquisition, and learning support. Each of these categories was further subdivided into subcategories, which encompass various techniques. For example, within the category of reading mechanisms, there are subcategories such as pitch decoding (related to scale degrees), pattern building (grouping notes to form chords or arpeggios), and validation (carefully listening to identify mistakes). Given the absence of a systematic approach to teaching sight-singing strategies, this inventory offers a valuable framework for future research and for aural skills teachers.

Justine Pomerleau-Turcotte med colleges (2023) examined sight-singing strategies employed by students in higher education. The participants were requested to sight-sing a melody and subsequently provide verbal reports about their techniques. Two research cues were used to facilitate this process: video recordings of participants’ eye movements on the musical score and visual representations of their attention distribution on the score, both captured using an eye tracker. Researchers categorized the strategies mentioned by participants into several clusters, such as (1) decoding notation, (2) building mental representations of sounds, (3) using the body to execute the rhythm, (4) relying on automatic skills, (5) using musical knowledge, (6) anticipating upcoming content, and (7) managing attentional resources. This classification covered a range of actions exhibited during the sight-singing task, identifying automatic skills (e.g., intuition, reflexes) as key predictors of performance. Participants with automatic skills likely possessed extensive musical practice, allowing them to perceive musical notation in the form of manageable chunks rather than as individual notes (Pomerleau-Turcotte et al., 2023).

2.4 Eye-Tracking Studies in Music Reading

Visual expertise in music reading refers to the advanced skills and abilities, that musicians develop through intensive musical training, to interpret and understand musical notation efficiently and accurately (e.g., Sheridan et al., 2020). This expertise encompasses a range of cognitive and perceptual skills, including quickly recognizing relevant information, processing complex visual patterns, anticipating upcoming notes, and integrating visual input with motor actions and auditory expectations, all of which contribute to a faster processing pace (for a meta-analysis, see Perra et al., 2022).

Eye-movement studies on anticipatory looking have found that experienced music readers often look further ahead in the music notation relative to the point of performance compared to less skilled musicians (e.g., Goolsby, 1994b; Penttinen et al., 2015; Huovinen et al., 2018; Truitt et al., 1997). Additionally, experts process more information per fixation, known as the *perceptual span*, particularly through greater parafoveal information processing (e.g., Sheridan et al., 2020).

Research on the impact of structural elements in musical notation on eye movements indicates that experts tend to follow the melodic contour, phrases, and moving eyes in a vertical direction aligned with the melody's trajectory (Goolsby, 1994; Sloboda, 1974). Experts usually utilize structural cues to process musical material more efficiently (e.g., Perra et al., 2022; Drai-Zerbib & Baccino, 2014, 2018). Experts tend to exhibit superior cross-modal integration abilities, allowing them to transition between auditory and visual codes more efficiently, a phenomenon known as enhanced audiovisual processing (Drai-Zerbib et al., 2012).

The following is a brief review of the eye-tracking literature focusing on the eye movements of experienced music readers and the factors that influence their ability to process scores efficiently. Studies were grouped according to whether the musician interacted with the score by playing, singing, or reading silently.

2.4.1 Eye-Tracking Studies on Sight Reading

As with other visual tasks, music reading involves a sequence of saccades[3] and eye fixations over time, indicating the reading patterns and comprehension strategies. During instrumental performances based on musical notation, the eyes often move slightly ahead of the point of performance. The distance between the point of fixation and the point of performance is referred to as the *eye-hand span*, which is a standard measure in research on piano players (see Perra et al., 2024). Researchers have historically reported the discrepancies between the note being played and the one currently fixated on in terms of time, the number of beats, spatial distance, or the count of notes (e.g., Huovinen et al., 2018; Madell & Hébert, 2008; Penttinen, 2013; Penttinen et al., 2015; Sloboda, 1974, 1977).

Proficient sight readers tend to exhibit a larger eye-hand span than less proficient ones (Furneaux & Land, 1999; Gillman & Underwood, 2003; Truit et al., 1997). Experts direct their gaze toward relevant note symbols or markings (Gilman & Underwood, 2003). Furthermore, the presence of "structural markers" usually

3 "The rapid motion of the eye from one fixation to another (from word to word in reading, for instance) is called a saccade." (Holmqvist et al., 2011).

influences the eye-hand span and, according to Sloboda (1974, 1977), causes the span to extend precisely to phrase boundaries.

An increase in musical complexity is generally accompanied by a decrease in the eye-hand span (Gilman & Underwood, 2003; Truitt et al., 1997; Wurtz et al., 2009). Complexity of the printed score also affects fixation durations and saccade lengths during pattern-matching tasks (Waters & Underwood, 1998; Waters et al., 1997). Furthermore, incongruent musical endings have been linked to longer fixation durations and a greater number of fixations (for reviews, see Madell & Hébert, 2008; Puurtinen, 2018).

Another measure that often mentioned in research literature is a *perceptual span*, or the region around the fixation point from which useful information is extracted. Perceptual span is typically larger in experts due to their ability to chunk the musical information and look further ahead in the score (e.g., Sheridan & Rheingold, 2014). Proficient musicians process information within their perceptual span during fixations, which typically extend around three to five beats or notes to the right of the fixation point (e.g., Waters et al., 1997; Gilman & Underwood, 2003). Musicians tend to direct their gaze toward note symbols or expressive markings that are relevant to performance (e.g., Gilman & Underwood, 2003).

An interesting study of the conductor's eye movements was carried out by Emmanuel Bigand with a group of researchers (2010). They found that the conductor approached the score by anticipating the upcoming music, often looking two to five seconds ahead of the performance point. The longest distance between the conductor's eye gaze and the sounding music was ten seconds. Anticipatory eye fixations were found to be linked to performance cues, which the conductor described as expressive thematic material critical to the interpretation of the music. For instance, the importance of theme C and its expressive tempo was associated with the duration of the conductor's eye fixations (Bigand et al., 2010). The study highlighted the central role of the score's structural elements, intentions, and conductors' interpretative choices in shaping eye movement patterns.

Several similar patterns in the visual gaze of pianists and conductors highlight how their eye movements respond to the demands of their respective tasks. Their expertise is evident in the tendency to expand their perceptual span, examine notation further ahead in the score, depend on structural cues, and anticipate upcoming material. However, the diversity could be due to performance type and specific cognitive activities in the conductors (e.g., complex and multimodal task involving the reading of the score with multiple instruments, temporal supervision, scene perception) who may distribute time differently.

2.4.2 Eye-Tracking Studies on Sight Singing

Despite the growing body of research on musical performance, eye-tracking studies specifically focused on sight singing remain limited. Therefore, there is a significant need within the scientific and academic community to explore the challenges and cognitive processes involved in prima vista singing.

The act of singing vocal music *a prima vista* involves the simultaneous performance of notated rhythms, pitches, and lyrics, which adds complexity to the task. Proficient singers typically demonstrate an *eye-voice span* (i.e., the distance between the currently fixated point and the point that is presently sung) of approximately four notes. By contrast, less skilled individuals exhibit an average of around two notes when engaging in sight singing melodies, as observed through eye tracking (e.g., Goolsby, 1994b). As previously noted by Sloboda (1977), the eye-voice span correlates with musical structure. Sloboda reported that experienced musicians cover extensive phrases, and sometimes, the eyes must stop to proceed with the musical material. In his succeeding study, Sloboda (1985) employed the "lights-out" technique to examine the eye-voice span of skilled singers. The results indicated that for these individuals, the latency associated with musical phrases was, on average, seven notes.

A similar phenomenon was observed in Goolsby's (1994a) study, in which skilled music readers looked ahead in notation and returned to the singing point to refresh working memory before re-fixating on the performance location. Moreover, Goolsby (1994a) examined the differences in eye movements between two groups of participants in relation to the notational complexity of the stimuli and the effect of practice. Following the practice of the melodies, readers exhibited a reduction in the number of fixations while maintaining a longer duration. Goolsby observed that less-skilled music readers exhibited longer progressive and regressive saccade lengths than their more proficient counterparts. The longer fixation duration observed in less-skilled readers was attributed to difficulties in information processing.

Goolsby's second study (1994b) examined the variations in eye movement measures between two musicians during a sight-singing task, considering their levels of expertise. The findings indicated that a skilled musician read ahead of his performance, with a significant proportion of the visual detail not being the target of a fixation. This indicates that the rhythmic aspect of the notation is perceived within the perceptual span, which expands not only horizontally but also vertically. Notably, during sight singing, musicians exhibited a considerable number of fixations directed toward bar lines and a substantial number of fixations directed towards areas between notes, where no available visual information was present. The author postulated that this may indicate the singer's strategy to determine the interval between two notes, with the intention of comprehending the notation in the parafoveal field of vision.

2.4.3 Eye-Tracking Studies on Silent Reading

While numerous eye-tracking studies have focused on music reading and performance, there has been relatively limited research on silent reading. Silent reading is defined as the act of reading without the involvement of an instrument or voice, and in the absence of performance. Silent reading is recognized as an efficient method for studying musical scores (e.g., Loimusalo et al., 2019).

In a silent reading study by Penttinen, Huovinen, and Ylitalo (2013) involving pre-service teachers, eye-movement measures were assessed alongside participants' verbal descriptions of the notated music. Expertise was demonstrated by shorter fixation durations, linear scanning, and integrative descriptions. The researchers emphasized the importance of investigating eye-movement processes in conjunction with verbal descriptions to assess silent-reading abilities and implicit cognitive strategies for approaching music notation.

Cara and Gómez Vera (2016) examined the differences in eye movement patterns among music students when engaged in a silent reading task involving both music scores and verbal texts. The participants were not engaged in any motor movements (i.e., performance because of playing music). The researchers observed that the duration of fixations was longer for scores than for texts. When reading tonal music and literary texts, participants exhibited longer eye fixations, whereas reading informative texts and contemporary music was linked to a greater number of regressive fixations (right-to-left). The authors concluded that reading contemporary music involves a less linear approach to integrating musical information, whereas reading tonal music follows a more sequential path for music information integration, determined by harmonic tonal relationships.

In a study conducted by Drai-Zerbib and Baccino (2018), the eye-tracking method was employed to examine differences in how expert and non-expert musicians process musical information when presented with stimuli that require them to integrate information from different sensory modalities (like hearing and seeing music). Their results indicated that experts exhibited faster detection of modified notes, particularly in the simultaneous condition where cross-modal integration could be applied. The authors concluded that the main distinction between experts and non-experts lies in the differing knowledge structures in memory, which are developed over time through practice. The study's results validate the theory that experts possess cross-modal integration abilities and support the long-term working memory model of expertise (e.g., Drai-Zerbib & Baccino, 2014; Ericsson & Kintsch, 1995).

The study conducted by Drai-Zerbib and Baccino (2018) examined how expert and non-expert musicians process musical information when presented with stimuli that require integrating different sensory modalities, such as hearing and seeing music notation. Using eye-tracking, the researchers observed that experts were faster than non-experts at detecting modified notes, especially in conditions that allowed simultaneous processing of auditory and visual information. This suggests that experts have a superior ability to integrate different types of sensory input. The authors concluded that the primary difference between expert and non-expert musicians lies in their memory structures, which enable them to access and use musical knowledge more efficiently. The results supported the theory that experts have enhanced cross-modal integration skills, consistent with the long-term working memory model of expertise. This suggests that the organization and retrieval of information in experts is fundamentally different from that of non-experts, contributing to their superior performance.

Silva and Castro's (2019) study investigated how the visual and auditory systems interact during silent music reading. Researchers used eye-tracking data to investigate internal auditory processing, focusing on the concept of the eye-audiation span. This span refers to the relationship between visual attention (eye) and auditory processing (audiation), highlighting a measurable time lag between gaze and the internal processing of rhythm. Silva and Castro tested this novel paradigm and reported evidence for the existence of an eye-audiation span. In their study, this span represents the interval between gaze and the extraction of temporal representations—specifically rhythm—during silent music reading. They further discovered that these temporal representations (internal rhythms) do not coincide with gaze but emerge shortly after it. The researchers suggested that their approach to understanding the relationship between gaze and internal rhythm offers insights into the cognitive processes of silent music reading and provides valuable cues for understanding underlying mechanisms in musical cognition.

3 Research Context and Objectives

3.1 Main Areas of Concern

This section outlines the primary aim of the study by focusing on two interrelated key areas that are essential for understanding the broader context of reading vocal music. The first key area is the study of expertise within the choral context, as expert performance is a highly complex process that is challenging to analyze. In artistic practice, expert musicians often do not systematically reflect on or openly articulate their strategies. They may not publicly share their learning routines, performance methods, or the challenges they encounter. In educational settings, experts—such as professional singers or conductors—may underestimate the difficulty of tasks for novices (Hinds, 1999; Samuels & Flor, 1997) or be unaware of specific aspects of their knowledge that contribute to their superior performance (Sheridan et al., 2020). Additionally, experts may lose conscious control over certain internalized processes, making it difficult to verbalize their approach to reading music (Samuels & Flor, 1997; Reingold & Sheridan, 2011). As a result, interviewing experts about their reading strategies can be particularly challenging.

The second area of focus is the unique nature of the choral genre, which includes two key aspects: singing in a group and using a choral score. Singing in a group with competent, confident singers can be significantly easier than performing alongside less experienced novices who may struggle with score reading (e.g., Zadig, 2017). For experienced singers, the choral score can be highly informative, providing essential musical cues, while for beginners, its complexity can be overwhelming, particularly if they are unfamiliar with how to navigate its structure.

Moreover, choral scores—unlike notations used for solo instrumental performances—present several challenges even for experienced singers. These challenges include visual, notational, and technical complexities (for further discussion, see Sheridan et al., 2020). Choral scores are often written across multiple staves, contributing to notational complexity, which Sheridan et al. (2020) define as the degree of variation in the features that are used to annotate music. A single staff in a choral score may include multiple distinct voice lines, each with different notes and symbols. Visual complexity, defined as the number of items or details present, is evident in elements such as chords with multiple notes stacked vertically or in graphic notations that use visual symbols beyond traditional music notation. Additionally, technical complexity (i.e., the complexity of performing) goes beyond aspects like key signatures and tempo, encompassing elements such as lyrics (Sheridan et al., 2020). Lyrics, which are aligned with the musical composition, are typically positioned beneath the staff but can vary in placement.

While previous studies have explored the music-reading strategies of individual musicians (Pomerleau-Turcotte et al., 2022, 2023; Bogunović & Vujović, 2012), research on music reading within ensemble performance remains underdeveloped. The dynamics of reading music in a group setting and their impact on the strategy development of individual choral singers are still largely unexplored. Furthermore, the question of which strategies experienced singers employ to contribute to successful performances has yet to be fully addressed. Investigating vocal music reading and the strategies of experienced choral singers through mixed-method research is essential for advancing pedagogy and gaining a deeper understanding of the cognitive processes underlying efficient performance in choral context.

3.2 Central Research Question

The primary aim of this thesis was to investigate expert musicians' music-reading strategies, focusing on the techniques that contribute to their mastery, with an emphasis on visual processing competencies. This research sought to identify the specific skills that distinguish highly skilled sight readers from less experienced musicians and to understand the cognitive processes involved in music reading. The central research question was as follows: What strategies do experienced musicians with a background in choral music employ when reading and memorizing vocal music?

This thesis comprises four separate original studies, each addressing specific aspects and research questions. The studies investigate three main forms of music reading: sight reading (*a prima vista* performing), rehearsed reading (performing practiced piece), and silent reading (reading without performing).

3.3 Research Questions for the Original Studies

Each study addresses a different aspect of the music-reading process, aiming to contribute to a broader understanding of experts' music-reading strategies. Study 1, entitled "Eye movements in sight singing: A study with experts," examined the visual gaze patterns exhibited by experienced singers as they engaged in sight reading of unfamiliar songs. This study aimed to examine the distribution of visual attention with a particular focus on singers responses to written music and lyrics. Furthermore, the study investigated the interplay between the complexity of musical stimuli and the corresponding gaze behavior, thereby addressing the dynamics of bottom-up and top-down cognitive mechanisms that are intricately intertwined within the realm of sight-singing performance. The research questions were: (1) How do singers divide their visual attention between written music and lyrics while singing in tempo, *a prima vista*?, and (2) How does complexity in the musical stimulus influence eye-movement behavior in a sight-singing task?

Study 2, entitled "Silent score reading: Four Swedish choral conductors' conceptions, processes, and strategies," comprised two interconnected studies. A combination of interviews and the silent reading of choral score excerpts shed light on the individual reading styles and cognitive conceptions of choral score reading. The main research question of the first study was: How do experienced choral conductors conceptualize their strategies for silent score reading? The research question addressed in the follow-up study was: What visual processes and cognitive strategies do expert choral conductors employ in actual silent reading? The integration of each study's results complemented the overall picture of the cognitive processes involved.

Study 3, entitled "Sight singing in a group context: An eye-tracking study with experienced choral singers," presented a focused investigation of score-reading strategies employed by choral singers, particularly within the context of performing in a group. By addressing two research questions—how choral singers' visual attention was (1) distributed across staff systems and (2) influenced by note density and repeated practice—the study took initial steps toward understanding how choral singers' reading processes might differ from sight-reading a solo piece, given their access to the entire choral score.

Study 4, entitled "Melodic Recall: Qualitative Insights on Singers' Memorization Strategies," was designed to investigate the effective memorization approaches employed by music college students. The research question guiding this inquiry was: What processing and memorization approaches contribute to successful melodic recall? The task of having students read and learn unaccompanied simple songs from musical notation for immediate recall aimed to provide insights into the practical methods they use.

In total, four related studies on vocal music reading were conducted, each using slightly different tasks. Participants recruited for the studies demonstrated their expertise by reading scores with lyrics and of varying complexity. A mixed-methods approach was employed to address the research objectives, combining eye-tracking technology with both quantitative and qualitative methods. The quantitative methods facilitated statistical data analysis, while the qualitative methods have shed light on participants' perspectives. Together, the findings from each study have contributed to a thorough understanding of expertise in vocal music reading.

4 Methods

4.1 General Methodological Principals

In any structured investigation, methodological principles (i.e., objectivity, reliability, systematic approach and precision) serve as the fundamental guidelines that structure how investigation is conducted (e.g., Logarusic, 2021). These principles ensure that the research process is organized, rigorous, and capable of producing reliable and valid result. These principles a foundation for selecting appropriate tools, techniques, and processes while ensuring that the findings aligned with the intended goals (ibid.).

According to Creswell and Creswell (2018), a research approach refers to the overarching strategy that directs how the research problem will be tackled—whether through qualitative, quantitative, or mixed methods. This approach must align with the nature of the research problem and the goals of the study. Once the approach is defined, the research design outlines the plan or structure for the research, detailing how data will be collected and analyzed to answer the research questions. Finally, research methods refer to the specific tools and techniques used to gather data (e.g., surveys, interviews, eye tracking) and analyses of data (e.g., statistical calculation, modeling, hypothesis testing, thematic analysis) (see Creswell & Creswell, 2018). This chapter presents the methods used in this dissertation and the rationale for their selection.

4.1.1 Quantitative and Qualitative Methods

Quantitative research is a systematic approach focusing on numerical data to investigate patterns, relationships, and trends within phenomena (e.g., Creswell & Creswell, 2018). In the scope of this thesis, data analyses were conducted using two prominent statistical tools: IBM SPSS Statistics (Statistical Package for the Social Sciences) and the *R* software for statistical computing (*R* Core Team, 2022). These software packages were chosen for their robust capabilities in handling and analyzing complex quantitative datasets. In addition to eye movement measures, questionnaires with Likert-type scales were designed and analyzed quantitatively. Respondents used numerical scales to express their agreement or disagreement with statements. Closed-ended questions or declarative statements with predetermined response options were incorporated into the quantitative dataset. These methods contributed to the precision of data collection, enhancing the ability to identify trends in a systematic and quantifiable manner.

Qualitative research is a scientific approach that seeks to gain insight into the depth and richness of human experiences, perceptions, and behaviors, and to understand the meaning respondents ascribe to a problem under investigation (Creswell & Creswell, 2017, p. 4). Qualitative research methodology employs a range of techniques, including individual and group interviews, retrospective recall, and inquiries through questionnaires, to delve into the intricate details of phenomena (see Creswell & Creswell, 2017). In this dissertation, interviews provided a platform for participants to share their conceptions and insights, giving voice to their unique perspectives and explicit/implicit skills. Retrospective recall facilitated memory traces, allowing individuals to share valuable memories (e.g., Kaakinen & Hyönä, 2005; Penttinen et al., 2013). The qualitative datasets, obtained through methods such as interviews, retrospective verbal protocols, and questionnaires, enabled me to uncover the nuanced and context-dependent nature of sight-reading strategies employed by musicians. Qualitative data thus supported exploring the underlying dynamics of eye movements across various aspects, including strategy selection, metacognitive processes, perceptual challenges, use of external resources, individual differences, and interactions with the musical context.

The qualitative data were transcribed verbatim and analyzed either inductively or deductively using a thematic analysis approach (Braun & Clarke, 2012). Inquiries through questionnaires enabled the gathering of structured information while still accommodating qualitative aspects, revealing patterns and themes within responses. Through these methods, qualitative, descriptive research goes beyond numbers to capture the essence of human phenomena, fostering a deeper understanding of contexts, motivations, and complexities (see Braun & Clarke, 2012).

Clark and Chalmers (1998) introduced the concept that cognitive processes, traditionally understood as confined to the mind, can be seen as externalized or made portable through means such as verbalization. Accordingly, cued retrospective reporting can be conceptualized as “extended cognition.” To uncover the cognitive processes that may occur during sight reading, retrospective reporting was incorporated into the design of Studies 1, 2, and 3. Ericsson and Simon (1980) characterized these methods as techniques for accumulating a mental representation of problem-solving processes relevant to the specific type of problem. These representations might include the actions taken (“actions”), domain principles (“why”), strategies used (“how”), and self-monitoring (“metacognitive”) (see van Gog et al., 2005, pp. 241–242).

Most participants in original studies were experienced musicians, and the use of above-mentioned methods was intentional to accumulate information on their music-reading strategies and understand the sources of specific actions. Participants were instructed to describe or explain how they engaged in music reading. The explanations received from participants were relevant to the overall research goal and led to a finding of the “whys” and “hows” of efficient music reading. In current research on music reading strategies, the utilization of retrospective verbal protocols has emerged as a useful method for capturing the subtleties and intricacies that characterize the music reading process. However, for future studies, researchers should consider the limitations of the retrospective verbal protocol technique, as these reports may be perceived as more informal or conversational (van Gog et al., 2005).

4.1.2 Mixed Methods Research Design

The third methodological movement, which has emerged alongside the two more traditional approaches, is called mixed methods research (Tashakkori & Teddlie, 2010). Mixed methods research combines qualitative and quantitative research techniques to provide a richer, more comprehensive understanding of complex research questions that cannot be adequately answered by qualitative or quantitative methods alone (ibid.). As described by Tashakkori and Teddlie (2010), the key components of mixed methods research include: (1) triangulation, which involves using multiple methods or data sources to enhance the credibility and validity of findings; (2) design frameworks, such as concurrent, sequential, and transformative designs, each with distinct procedures and rationales for integrating qualitative and quantitative methods; and (3) philosophical underpinnings, which refer to the foundational paradigms of mixed methods research, often rooted in pragmatism or transformative approaches.

Recently, Bazeley (2024) has suggested that the core feature of all mixed methods research is the integration of heterogeneous components, and she has proposed a conceptual model of integration based on a concise list of substantive dimensions. According to her, the selection and integration of different methods should be context-dependent, with some dimensions becoming more prominent than others based on the specific requirements of the project. Furthermore, Bazeley (2024) defines integration in mixed methods research as a dynamic interdependence among different methodological components, characterized by a connected, transactional, transformative, and coherent relationship.

The present study employed a mixed methods design, allowing for more flexible and dynamic research processes. This integration of methods produced broader datasets and a wider range of information for analysis. Additionally, mixed methods facilitated the validation of results by cross-referencing different methodologies, thereby enhancing the research's credibility. The integration aimed to ensure that the components of the study were not viewed in isolation but as interconnected elements contributing to a unified understanding (see Bazeley, 2024).

The integration of the eye-tracking method with both quantitative and qualitative methodologies illustrates the key concepts of Bazeley's (2024) model for mixed methods research. Connection was evident when the data from eye-tracking were linked with musicians' self-reported strategies during music reading tasks (Studies 1, 2, 3). Transfer/exchange was demonstrated when insights from qualitative interviews informed the interpretation of quantitative eye-tracking data. A coherent relationship was achieved when all data sources consistently supported the central research question, "allowing complementary and/or joint analyses of both forms—all of which are supported by regular *conversations* between methods" (Bazeley, 2024, p. 232).

4.2 The Eye-Tracking Method

Eye movements represent a fundamental aspect of human visual perception and cognition (Rayner, 1998). Eye tracking is a technique employed to study eye movements, gaze patterns, and pupil dilation across various research areas, including perception, attention, memory, and reading, among others (for a review, see Duchowski, 2007; see also Holmqvist, et al., 2011; Liversedge et al., 2011; Majaranta, 2011; Noton & Stark, 1991; Rayner, 1998). Traditionally, these studies have focused on two main types of events to understand where, when, and how the eyes collect information from the visual environment (Caldara & Miellet, 2011; Chatelain et al., 2020; Holmqvist et al., 2023). Yarbus (1967) demonstrated that the point, order and duration of the of fixations are "determined by the nature of the object and the problem facing the observer at the moment of perception" (Yarbus, 1967, p. 196). This finding has become a classic in eye movement research and is frequently cited as clear evidence that high-level factors, such as cognitive interest, are essential in selecting where to fixate and can override any low-level, stimulus-driven guidance of attention (e.g., orientation, color) (Nyström & Holmqvist, 2008; Wade & Tatler, 2011).

The utilization of eye-tracking technology enables a comprehensive examination of the reading process, allowing for the analysis of eye-movement measures such as fixation duration, saccades, and fixation locations (see Holmqvist et al., 2011; Rayner, 1993). Saccades include aspects like latency, amplitude, direction, and rate, while fixations encompass their location and duration. Other metrics, like total saccade length and pupil dilation, are also valuable for analysis (O'Shea & Moran, 2016; Hadley et al., 2016; Wyatt, 2010). However, to facilitate comparisons between studies within the music research community, it is necessary to establish standardized experimental procedures and dependent measures (e.g., Fink et al., 2018; Puurtinen, 2018; Sheridan et al., 2020).

Analyses of eye movements during music reading can draw upon established findings in text-reading research, thereby demonstrating the informative value of eye movements in understanding information processing (see Clifton et al., 2016; Rayner, 1986, 1998, 2009; Rayner & Pollatsek, 1997). Results of eye-movement data analysis could answer questions related to the distribution of visual attention, gaze behaviors, and efficiency of gaze strategies involved in music reading (for a review, see Madell & Hébert, 2008; for meta-analysis, see Perra et al, 2022).

Overall, an eye-tracking dataset offers a rich source of information for understanding the cognitive processes and strategies involved in music reading (Pomerleau-Turcotte et al., 2021, Puurtinen et al., 2023), with implications for music education, performance practice, and cognitive psychology.

The following subsections outline the fundamentals of the eye-tracking method and introduce methodological challenges specific to the field of music reading.

4.2.1 Video-Based Eye Trackers

Video-based eye trackers, which use video technology to record eye movements as users view stimuli on a computer screen, are currently the most widely used in psychology, cognition, and human-computer interaction (Duchowski, 2007). Holmqvist et al. (2011) summarized that many contemporary eye trackers generate corneal reflections using near-infrared light. These reflection points are then sent to the eye-tracking software, where they are used to determine the user's gaze location on a particular area or object on the stimulus. Through acquiring and analyzing high-quality data recordings, researchers acquire information about various aspects, such as the duration of fixations on specific objects (ibid.).

Various eye trackers were utilized to address the research objectives, including the Tobii 4C, the Tobii Pro Spectrum, and the SMI RED250. All of these are remote binocular eye trackers with sampling rates ranging from 90 to 600 Hz. A remote eye tracker is a device that monitors and records eye movements from a distance without requiring physical contact with the participant (Mento, 2020). Unlike head-mounted eye trackers, remote eye trackers are typically positioned on a desk or mounted below a computer screen and use infrared light to track the position and movement of the eyes (e.g., Duchowski, 2007; Holmqvist et al., 2011). The distance between the participant and the eye tracker while seated is important to consider during the examination. Most manufacturers of remote eye trackers advise maintaining this distance within a specific range determined by the system's optics, typically centered around 60–70 cm (Chatelain et al., 2020).

Calibration in the eye-movement data collection procedure is a crucial step to ensure the accuracy and reliability of the eye-tracking data (e.g., Hansen & Ji, 2009). During calibration, the participant is asked to fixate on a series of points on a screen. The eye tracker uses these points to map the participant's eye positions to specific locations on the screen, allowing it to accurately interpret where the participant is looking during the actual experiment. The process of calibration is designed to account for individual differences in eye anatomy and movement (Duchowski, 2007).

4.2.2 Eye Movements

Eye movements (i.e., oculomotor behavior) serve a variety of purposes, including scanning a scene for important information, tracking moving objects, reading text, and exploring visual details. Eye movements are rapid in nature and direct the gaze to different locations in the visual field (e.g., Holmqvist et al., 2011). Primary measures of oculomotor behavior include fixation location, fixation duration, and saccadic movements. These measures can be linked to perception and cognition.

A fixation occurs when the eyes remain relatively stationary while focusing on a specific point or object. In tasks requiring focused attention, such as reading or examining intricate visual stimuli, fixations are particularly important (Rayner, 1993; Duchowski, 2003; Holmqvist et al., 2011; Hessels et al., 2018). During fixations, the human visual system gathers detailed, fine-grained visual information, which can be processed by foveal vision. Foveal vision refers to a small region of the visual field that is responsible for sharp central vision. The duration and location of fixations can provide insights into what captures attention and how information is processed. Fixations occur between saccades and are characterized by a stable gaze on a specific point, indicating sustained attention.

Saccades are rapid eye movements that shift focus from one point to another, influenced by the distance covered and lasting between 30 and 80 milliseconds (see Holmqvist et al., 2011; Rayner, 1998). Saccades occur between two fixations, repositioning the fovea to a new location in the visual environment (Duckowski, 2007). These movements are crucial for scanning the visual environment and transitioning between areas of interest (e.g., Yarbus, 1967). However, it is important to note that during these rapid movements, visual information is suppressed (Rayner, 1998, 2009). Gilchrist (2011) suggests that when a scene has several potential targets, the choice of the next saccade is influenced by both the visual characteristics of the locations and the observer's intention. For detailed information on eye movements (key concepts and definitions), see Duchowski (2007), Holmqvist et al. (2011), and Hessels et al. (2018).

4.2.3 The Visualization of Eye Movements

Graphical representations of eye-tracking data, such as heatmaps and scanpaths, are powerful visualization techniques that identify the areas of stimuli which capture the most visual attention (Rayner et al., 2016). Algorithm-generated scanpaths and heatmaps can illustrate the spatio-temporal patterns, duration, and transitions in eye-movement data, enabling direct inspection of the dataset (e.g., Von der Malsburg & Vasishth, 2011).

A scanpath in eye tracking refers to the sequential path the eyes follow when looking at a visual stimulus (e.g., Yarbus, 1967). Holmqvist et al. (2011) defined a scanpath as "the route of oculomotor events through space within a certain timespan" (p. 254) that maps the order and pattern of fixations and saccades

(Holmqvist et al., 2011, p. 254). Scanpaths have long been used to analyze and understand how individuals visually explore scenes, providing insights into their attention, cognitive processes, and behavior (Just & Carpenter, 1976).

Recorded scanpaths are typically visualized by projecting them onto the stimulus, with static or dynamic representations available for analysis (Holmqvist et al., 2011; Noton & Stark, 1971a, 1971b). In a static visualization, dots or circles are used to represent points where the eyes have paused to take in information. The size of the dots can indicate the duration of the fixation. Lines connecting the fixations show the direction and length of the eye movements between fixations (Duchkowski, 2007). Scanpath visualizations can be used for various purposes, including data quality checks, obtaining preliminary impressions of the data (e.g., during piloting), qualitative analysis of data, and even for eliciting cued retrospective reports (e.g., Van Gog et al., 2005; Holsanova, 2001, 2006, 2009). For instance, in their study of pianists' mental practice through music reading, Loimusalo et al. (2019) used scanpath inspection in their analysis to compare eye-movement recordings with post-task interview responses related to specific moments during task execution (i.e., mental practice).

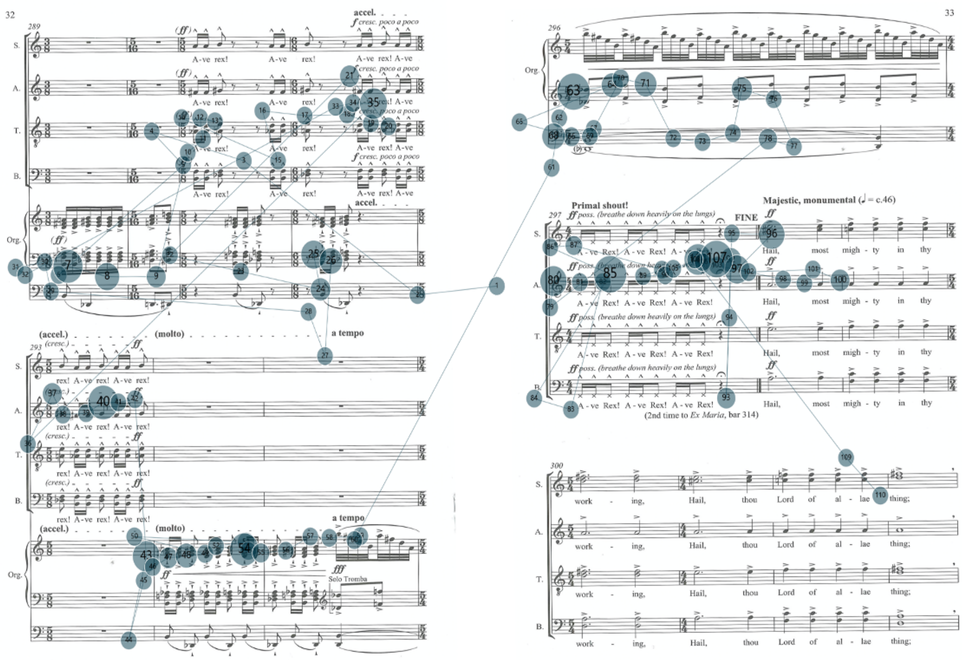

Figure 1. Example of a scanpath.

A scanpath provides information regarding the trajectory of eye movements and the order in which particular musical feature was visited by a choral conductor during the silent reading of a musical score (Tavener, "Ex Maria Virgine", Study 2). The circles represent the fixations' positions with the number of fixation inside of each circle and the lines between circles represent saccades.

Figure 1 illustrates a scanpath from the original Study 2, demonstrating a choral conductor's visual process while inspecting a choral score. The size of the dots and the numbers within them indicate the order and duration of fixations, with larger dots representing longer fixations. The stimulus depicted is an excerpt from John Tavener's choral composition "Ex Maria Virgine," which was used in a silent reading task. In the scanpath, one can observe that the conductor first inspected the choral score in the upper-left stave system before moving on to the organ accompaniment. Interestingly, the conductor chose to focus in detail on the middle voices (tenor and alto) while disregarding the outermost voice lines (bass and soprano).

According to Holmqvist et al. (2011), heatmaps are visual representations that illustrate the intensity and distribution of visual attention across a stimulus. Heatmaps are generated by aggregating fixation data, with areas receiving more frequent and prolonged fixations shown in warmer colors, such as red and yellow, and areas with fewer fixations are represented by cooler colors, like blue and green (for more information on heatmaps, see e.g., Špakov & Miniotas, 2007; Špakov et al., 2017). This method provides a clear and intuitive overview of which parts of a visual stimulus attract the most attention from participants.

Heatmaps are usually used to exemplify and support quantitative results, such as the spatial distribution of data (Holmqvist et al., 2011). In the study by Pomerleau-Turcotte et al. (2023), for instance, heatmaps were utilized during interviews to facilitate discussion around sight-singing strategies. The researchers conducted semi-structured retrospective interviews, using eye-movement videos and attention distribution heatmaps to assist participants in remembering and recalling the strategies they employed. Participants were prompted to complete or correct their previous statements based on their observations of heatmaps.

In Study 3, this visualization technique was useful for analysis individual sight-reading strategies exposed by the singer in a group context. Figure 2 enables a comparative analysis of two heatmaps. The heatmap on the left (Figure 2a) illustrate which part of the score a bass singer engages with and which he ignores during *a prima vista* performance. The data values are represented by a spectrum of colors, providing an immediate visual summary of the areas capturing his attention. The red areas highlight points of interest, indicating where the singer focuses most on the score. The heatmap on the right (Figure 2b) shows how the same bass singer expands his visual engagement by directing his gaze to neighboring voice lines during his third practice session.

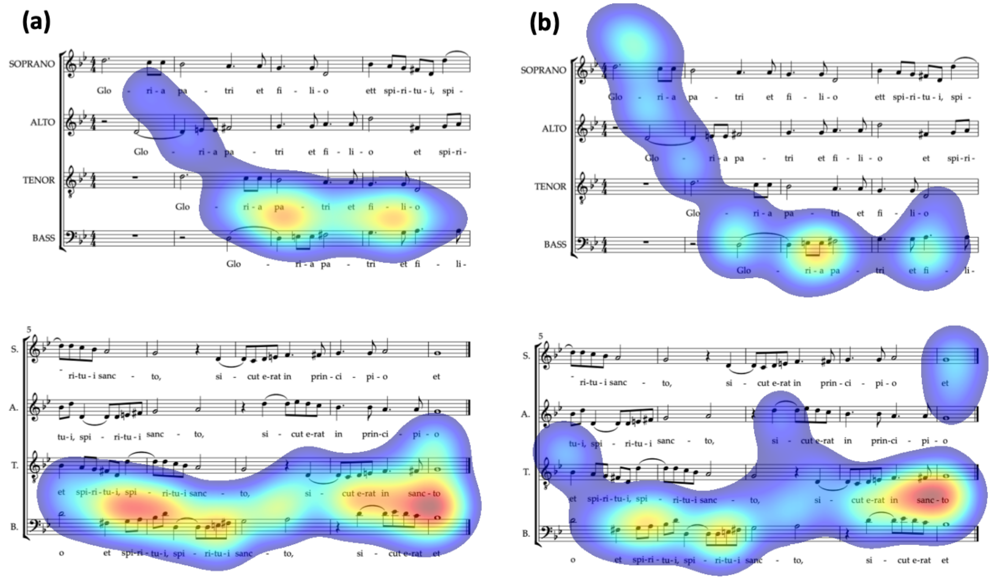

Figure 2. Example of a heatmaps.
Data visualization by heatmaps in Study 3: an individual bass singer's points of fixation in Purcell's "Gloria Patri" (Z. 105): (a) during *a prima vista* and (b) during the third perfromance. The red color represents the most fixated visual areas of the score, and the colder colors represent the less fixated areas. Regions outside of the heatmap were not fixated at all.

In Study 4, heatmaps were employed to investigate memorization approaches among music students. To visualize the distribution of visual attention, I used aggregated heatmaps, which combine fixation point data from multiple individuals or sessions to provide a collective visualization of patterns (see Duchowski et al., 2012). Specifically, the aggregated heatmaps (Figure 3) represent the cumulative visual attention of three low-accuracy performers, allowing for the analysis of common patterns in their performance. Areas where students focused their gaze are shown with warmer colors (e.g., red or yellow), while less-frequent focus points appear in cooler colors (e.g., green). During the initial reading (Figure 3a), participants largely ignored the second line and focused primarily on the first line, with particular attention to the beginnings of the phrases one and two. By the third reading of the same song (Figure 3b), participants could sing through both staves.

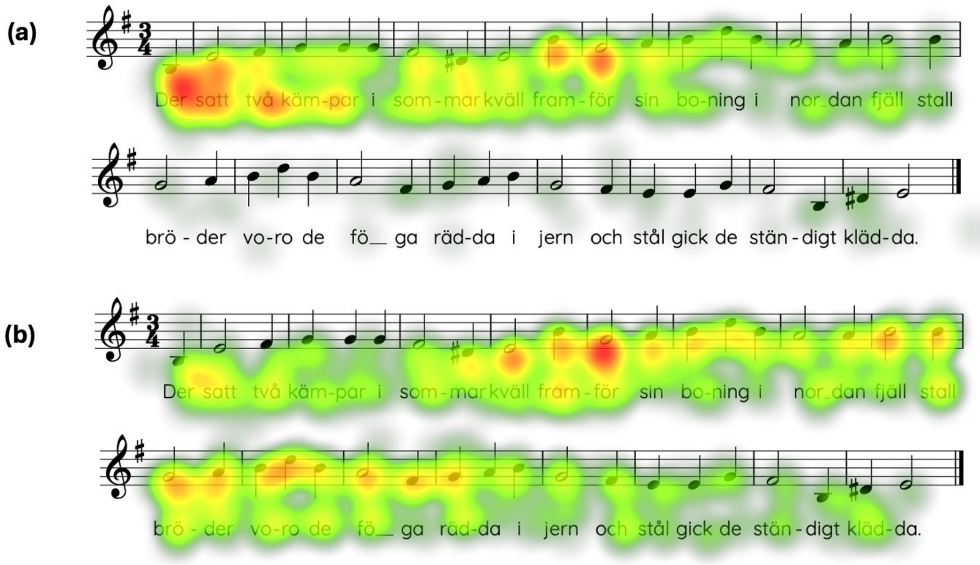

Figure 3. Example of a heatmaps.
Data visualization using aggregated heatmaps from three participants (folk ture, Study 4): (a) the first reading; (b) the third reading of the same song.

According to Holmqvist et al. (2011), Area of Interest (AOI) segmentation defines specific regions within a visual stimulus. Areas of interest are critical tools for analyzing eye-tracking data in various research contexts, used to understand the relationship between gaze behavior and visual stimuli, allowing researchers to quantify and analyze gaze data related to particular features (ibid.). An AOI can be defined as “a segment of a stimulus space that identifies a portion of the stimulus that is meaningful in the experimental design of a study” (Holmqvist et al., 2023, p. 368). This segmentation process provides insights into participants’ eye movements by “simplifying” data recording and facilitating the calculation of fixation counts, start times, duration values, and transition events specific to these areas (Holmqvist et al., 2011). This segmentation should be done before the data collection, since this can be seen as part of the hypothesis. The goal is to simplify the visual input space into a more meaningful and manageable form for analysis (e.g., Caldara & Miellet, 2011).

Researchers employ AOIs to identify which parts of a visual field, such as a portion of a web site or scene, attract the most attention and in what sequence (e.g., Jarodzka et al., 2010). AOI measures include the time spent in specific areas and the number of transitions between them. These measures are vital across various fields, including cognitive psychology, marketing, neuroscience, and education (e.g., Holsanova, 2006, 2009; Orquin et al., 2016; Orquin et al., 2020). Different methods and software facilitate AOI analysis, making it easier to study gaze patterns in contexts like music reading (e.g., Drai-Zerbis & Baccino, 2012, 2014; Penttinen et al., 2015). The specification of AOIs depends on the researcher's needs and interests. Figure 4 illustrates the way AOIs have been variously drawn to capture fixations occurring in visual fields corresponding to bars, staves, and phrases.

Figure 4. Example of an Area of Interet (AOI).
Two examples of music scores with AOI representation: (a) score excerpt (H. Purcell, "Gloria Patri") from Study 3, divided into two types of AOIs: bar-AOI and staff-AOI; (b) score excerpt (folk tune) from Study 4, divided into four phrase-AOIs, encompassing both the musical line and the lyrics positioned beneath the music staff.

4.2.4 Methodological Challenges

In their article, Fink, Lange, and Groner (2018) presented an insightful overview of the current state of applying eye-tracking in music research. The article not only reviewed the field's present status and identified challenges that need to be addressed but also speculated on future possibilities for improvement. Fink et al. highlighted the need for standardized experimental procedures and dependent measures to enhance comparability within the music research community and across other research domains. The authors of the article provided several recommendations for future research, including the need for clearer definitions, the creation of a glossary with labels and definitions for eye-movement variables, linking the utilization of Areas of Interest (AOIs) to specific hypotheses, and integrating a more extensive array of eye-movement parameters for comprehensive comparisons.

Similarly, in a methodological review, Puurtinen (2018) addressed inconsistencies in the methodologies used in eye-tracking research within the music domain. Puurtinen reviewed works published between 1994 and 2017, examining a range of methodological choices related to musical stimuli, conditions of performance (e.g., control of tempo and music-reading protocols), the level of musical expertise among performers, and the treatment of performance errors and eye-movement data. She pointed out that the field lacks methodological coherence or "standardization," particularly concerning the definition of (1) the level of complexity in musical stimuli, (2) expertise levels, (3) task conditions, and (4) the handling of eye-tracking data. This lack of standardized approaches hampers comparing and generalizing of findings across different studies. The reviewer suggested that a thoughtful consideration of previous methodological decisions can serve as a compass for shaping future research inquiries and laying the groundwork for upcoming studies. This approach aims to foster progress towards a cumulative research tradition characterized by the systematic and consistent use of stimuli, research settings, and analytical methods within the field. Likewise, Sheridan and colleagues (2020) examined the outcomes of applying eye-tracking methodology. Among their conclusions, the researchers emphasized the importance of establishing standardized experimental procedures and dependent measures to enhance comparability within the music research community.

In the same vein, discussions on how to increase coherence within the broader eye-movement research field were conducted by Hessels et al. (2018) and Dunn et al. (2023). Hessels et al. (2018), through a survey of 124 eye-tracking researchers, reported confusion regarding the definitions of two main concepts: fixations and saccades. The authors explored potential sources of this confusion and the impact of inconsistent terminology. This confusion often arises when different definitions are used interchangeably. Hessels et al. (2018) suggested that a unified definition would enable eye-movement researchers from different fields to engage in discussions without misunderstandings. Furthermore, Dunn et al. (2023), after reviewing existing eye-tracking literature, underscored the necessity of reporting the quality of eye-tracking data and the obtained eye-movement and gaze measures. As a result, the researchers proposed a flexible, minimal reporting guideline that includes a core set of aspects that everyone should aim to report, which could help unify the field of eye-movement research. Following this discussion, each study in this thesis includes a minimal report according to the guidelines in Dunn et al. (2023).

4.3 Methods in the Original Studies

4.3.1 Participants

The participants in the four studies represented a diverse range of ages, experiences, and educational backgrounds and were actively engaged in choral music life. Many held advanced degrees in music and were employed in professional activities as soloists, university educators, or vocal coaches. Others were students currently enrolled in academic music programs, involved in developing and refining their musical skills. Most of the participants were semi-professional singers and proficient instrumentalists, with comprehensive training in music theory and aural skills. Additionally, a subset of participants was experienced choral conductors with substantial expertise in choir and orchestral conducting, teaching, mentoring young conductors, and guest conducting for esteemed national and international ensembles. In accordance with Mishra's (2020) categorization model for expertise, these participants can be classified as student musicians, developing experts, expert musicians, and influential experts.

The number of participants in each study varied from four in Study 2 to sixteen in Study 3, with mostly equal distribution between genders. In total, the sample (N = 49) included female and male musicians ranging in age from their early 20s to mid-60s (on average 38.9 years old). Between studies, the participants' average years of choir singing experience ranged from 13.0 to 25.6 years.

Participants in Study 1 (seven females and seven males) were tentatively categorized into two subgroups: "professionals" (mean age 46.6 years), who held a master's degree in vocal or instrumental performance, and "learners" (mean age 29.1 years), who either held a bachelor's degree or were pursuing higher education in music and were fluent in music reading. In Study 2, four experienced Swedish choral conductors (two females and two males, mean age 55 years) possessed extensive professional expertise in choir and orchestral conducting. In Study 3, a total of sixteen participants, ranging in age from 20 to 56 years, exhibited a wide variety of choral experiences. Some were semi-professional singers with music degrees from universities, while others lacked higher education in music but had knowledge of music theory, attended aural skills classes, and were trained in musical instruments. Participants in Study 4 were fifteen university-level music students, aged between 22 and 30 years. Nine participants were pursuing choral conducting studies, four were enrolled in the jazz program, and two were engaged in the music teacher program. All participants were skilled in singing, regularly practiced vocal music, and, according to their self-reports, had an average of 15 years of academic music practice and 13 years of choral experience.

It is important to recognize the limitations that come with the small number of participants in each study. With participant numbers as low as four in Study 2, the generalizability of the findings may be limited. Small sample sizes can affect the statistical power in the quantitative parts of the research and the ability to detect significant effects or trends. Additionally, the participants' diversity, while enriching, might not fully represent the broader population of choral musicians. These limitations should be considered when interpreting the results and their applicability to wider musical contexts. However, small groups and individual assessments allowed for the unpacking of unique reading strategies and helped capture the complexity of the sight-reading process.

4.3.2 Music Stimuli

The set of music stimuli included folk songs (Study 4), contemporary choral compositions (Study 1, 2), and Baroque vocal works (Study 3), all presented in modern staff notation, the symbolic system commonly used in Western music. Stimuli exhibited diverse degrees of complexity, featuring melodic variety with different intervals, rhythms, and phrasing, thus providing a spectrum of performance challenges. Each stimulus included lyrics placed below the staff lines (Figure 5). Special attention was paid to the range of pitches to accommodate the vocal capabilities of the singers. To facilitate comparisons, the length of each stimulus was carefully chosen, and the stimulus set was designed to optimize visual consistency in layout.

Figure 5. Example of stimuli.

Examples of notated music used as a stimulus in the research: (a) a song for music reading in Study 1 (composed by author); (b) a score excerpt for the silent reading in Study 2 (Z. Paulinyi, "The house"); (c) a score excerpt for sight singing in Study 3 (A. Lotti, "Missa brevis", Sanctus); (d) a folk tune for memorization task in Study 4.

In Study 1, a collection of ten short songs was used, each comprising eight bars and featuring single-line melodies within a medium vocal range (a comfortable singing range that is neither too high nor too low for the average singer). These songs covered a wide array of textual and musical content. To create an authentic sight-singing situation, the songs were exclusively composed for this study. For the silent reading task in Study 2, notated score excerpts were extracted from choral compositions written between 1997–2013. Each extract consisted of two pages from entire work, intentionally selected to be relatively challenging and less familiar. The excerpts included both *a cappella* compositions and ones accompanied by piano, organ, or flute, to ensure diversity. In Study 3, lesser-known choral compositions in a polyphonic style from the Baroque era were selected, all of them composed for four parts choir (SATB). Some excerpts underwent slight modifications in terms of text or melody to achieve a final cadence. For the memorization task in Study 4, the stimulus set consisted of three simple monophonic songs from the Swedish folk tradition, characterized by predominantly stepwise melodic movement and non-repetitive phrases. Each song comprised 16 bars, presented on two staves with eight bars on each staff.

4.3.3 Apparatus

The following hardware and software were used to record and analyze the eye-tracking data: eye-tracking equipment included the Tobii 4C, the Tobii Pro Spectrum, and the SMI RED250. Stimulus presentation was managed using PsychoPy (Peirce, 2007), SMI Experiment Center™, and Tobii Pro Lab. Visualization and analysis were conducted using Tobii Pro Lab and Python.

Eye-tracking technology was utilized to gather data during various music reading tasks in each of the four studies. While there were some differences in the specific apparatus used, there were also similarities in eye-tracking setups. For instance, all four studies used remote binocular eye trackers to record participants' eye movements. Remote eye trackers employ infrared light and video cameras to capture gaze data without the need for any equipment attached to the participants' bodies. This non-invasive setup allows for natural and unrestricted eye movements during the experiments. However, to minimize head movements, participants were provided with a chin and/or forehead rest.

The studies were conducted in different locations, each equipped with a different eye-tracking device. The eye-trackers used in the studies had varying sampling rates: 120 Hz in Study 1, 90 Hz in Studies 2 and 4, and a higher rate of 600 Hz in Study 3. While a higher sampling frequency allows for more frequent eye position measurements, the 90 Hz rate used in Studies 2 and 4 is generally sufficient for capturing detailed gaze behavior and eye movement dynamics in research on music reading. For illustration, with a 90 Hz sampling rate, approximately 18 samples could be collected during a typical 200 ms on average fixation on the score. The musical stimuli were presented on computer screens with a resolution of 1920 x

1080 pixels and displayed using specific software platforms, such as SMI Experiment Center™, Tobii Pro Lab, and PsychoPy, enabling precise control over stimulus presentation.

4.3.4 Ethics

The design of each study placed a strong emphasis on ethical considerations. Open and honest communication was essential for making the musicians feel comfortable participating. To achieve this, an introductory letter was distributed, briefly outlining the scope of the study and highlighting my interest in their personal sight-reading skills. The introductory e-mail explained the procedures and conditions of participation, including the anonymization of data to ensure privacy and confidentiality. The musicians were also informed about the intention to record their sight-reading performances in audio and video formats. Prior to participating in the sight-reading tasks, participants were informed about their rights, the procedural steps, and the overall aim of the study, in accordance with the ethical guidelines of the Swedish Research Council (2017). Subsequently, participants provided informed consent by signing an informed consent form. They then completed a survey that collected relevant demographic information and details about their musical background, including choral and instrumental experience.

4.3.5 Data Collection

Quantitative and qualitative data were collected for each study. Quantitative data collection, primarily involving eye tracking, adhered to specific protocols. Qualitative data collection included interviews, retrospective recalls, and group discussions to elicit participants' subjective viewpoints. For each participant, data collection occurred in a single session for all studies except Study 2, which involved two phases: phase one, where interviews were conducted via video conferencing tool Zoom, and phase two, where the sight-reading task was performed in person six months later. All four studies shared certain practical procedures: participants were required to familiarize themselves with the setup and procedure, use a stable forehead rest (see Figure 6), and undergo a 5-point calibration before starting the experiment. Additionally, the data collection rooms consistently maintained controlled lighting conditions. Each eye-tracking session began with a short practice session. In studies involving sight-singing performance (Studies 1, 3, and 4), each stimulus appeared on the computer screen, accompanied by metronome clicks that counted in the performance (Study 1, 3) and sounded a tonic triad to give participants a sense of tonality. The data collection sessions lasted no longer than one hour.

Figure 6. Example of the four eye-tracking setups.
The four eye-tracking setups and forehead rests used for data collection in Study 3. Each singer faced their own computer screen during the singing task in group settings.

4.3.6 Data Analyses

All four studies utilized a combination of quantitative and qualitative data analysis methods. The statistical computing environment *R* (*R* Core team, 2022) was commonly used in Studies 1, 2, and 3 for various quantitative analyses, while SPSS (IBM Statistical Package for the Social Sciences) was used in Study 3 to analyze data from eye-tracking sessions and questionnaires. Generalized linear mixed-effects models were used in Study 1 to analyze the main eye-movement measures. Repeated-measures correlation tests ("*rmcorr*") were applied in Studies 1 and 2 using the "*rmcorr*" package (Bakdash & Marusich, 2017) to examine relationships between eye-movement measures and cognitive load. Developed by Bakdash and Marusich (2017), the repeated measures correlation ("*rmcorr*") is a statistical technique designed to assess the overall within-individual relationship between paired measures collected on two or more occasions. This method includes functions for diagnostics, *p*-value calculations, and effect size with confidence intervals. Graphs were produced using the "*ggplot2*" (Wickham, 2016) package in the *R* statistical environment in Study 3 to visually represent data. Study 4 reported descriptive statistics of the eye movement dataset.

All studies incorporated thematic analysis to process transcribed interview data. This approach, following the guidelines of Braun and Clarke (2012), involved coding and identifying themes within the qualitative data. Studies 1 and 2 applied inductive thematic analysis, where themes were developed based on the data itself. Study 3 used deductive coding, where themes were pre-determined and applied to the data. Study 4 employed a qualitative mode of eye movement analysis, using a deductive method to quantify memorization approaches. The deductive coding systems used in Studies 3 and 4 were grounded in empirical research by Bogunović and Vujović (2012), Fournier et al. (2019), and Pomerleau-Turcotte et al. (2023), who systematized sight-singing strategies. Overall, by integrating heterogeneous components (i.e., quantitative and qualitative data) and analyzing them in contextually situated ways, it was possible to address complex datasets and approach the research objectives from a holistic perspective.

4.4 Summary

The methodologies employed in the four articles aligned with the primary aim of investigating expert musicians' music reading strategies. As outlined in Table 1, consistent procedures for data collection were maintained across all studies.

In this thesis, mixed methods research was employed to investigate the multifaceted nature of music reading among expert musicians. By using mixed methods, it was possible to address the research questions from various angles and study the music reading phenomena from a holistic perspective. A crucial aspect of applying mixed methods research was the interdependence between the various elements of the study. For example, in a current dissertation on the reading of vocal music by expert musicians, the use of both qualitative (e.g., interviews) and quantitative (e.g., eye-tracking data) methods allows different aspects of music reading to be explored in ways that support and enhance each other. Qualitative data provided context and depth to the eye-tracking results, while quantitative data validated and refined the insights gained from qualitative methods.

According to Bazeley's model (2024), the interdependence is crucial because it avoids treating different methods or data sources in isolation. Instead, the results from one method can enrich the understanding gained from another, contributing to a more holistic perspective on the research questions. This interdependence ensures that each part of the study is integrated into a larger, unified analysis, leading to a more nuanced and reliable conclusions.

Table 1. Summary of the methodologies.
Summary of the methodologies used in the four original studies.

Research design	Study 1	Study 2	Study 3	Study 4
Rationale	To investigate sight-singing strategies focusing on relationship between music and lyrics.	To explore silent-reading strategies.	To examine sight-singing strategies in a group context.	To investigate sight-singing strategies & memorization for recall.
Participants	Experienced singers (N=14)	Expert choral conductors (N=4)	Experienced choral singers (N=16)	Experienced music students (N=15)
Stimuli	10 newly composed songs written in a broadly classical idiom.	15 choral score excerpts written in contemporary choral style.	8 choral score excerpts written in Baroque style.	3 simple songs written in a folk tune.
Tasks	Sight-singing task: sing 10 songs at the first sight with lyrics, followed by a repetition without lyrics.	Silent reading task: read 15 choral score excerpts, as if preparing to conduct them.	Sight-singing task: sing 8 choral score excerpts at the first sight following by two practices.	Recall task: memorize 3 short songs, following three one-minute practice.
Data	Eye-tracking, Individual interviews, Questionnaires.	Eye-tracking, Individual interviews, Retrospective recall.	Eye-tracking, Questionnaires, Group Interviews.	Eye-tracking, Declarative questionnaires.
Analysis **Mixed methods integration**	Generalized linear mixed-effects models, Thematic analysis of interviews.	Repeated-measures correlation tests, Thematic analysis of interviews.	Generalized linear mixed effects models, Thematic analysis of discussions.	Descriptive statistics, Thematic analysis of memorization approaches.

5 Results

5.1 Study 1

In Study 1, the distribution of singers' visual attention between written music and lyrics was examined. The results of the study showed that participants prioritized melody over lyrics, which was supported by interviews and eye movement analysis. The data obtained from the eye-tracking analysis revealed that the participants spent a greater proportion of their time fixating on the music than on the lyrics. They entered new bars more often by glancing first at the music. Notably, despite making fewer errors with the lyrics, participants invested a greater cognitive effort in decoding musical notation than in processing the lyrics, as especially indicated by longer fixation times on the melody compared to lyrics. The observed zigzag movement between music and text indicated a potential syllabic processing approach for the lyrics, which could explain the participants' informally reported challenges in semantic comprehension.

Furthermore, the study investigated the effect of stimulus complexity on singers' eye movements. The results demonstrated that increased local complexity (the number of notes and accidentals in a bar) led to a greater fixation time on a bar. Pupil dilation was found to be influenced by the number of accidentals, indicating the cognitive effort required to process notated music with chromaticism. The temporal distance between fixating and singing a note, which is referred to as the eye–voice span, was found to be best predicted by phrase structure and the note density of previous melodic material. The interviews indicated that the most effective approaches were those that allowed for flexibility to move between different sight-singing strategies.

To the best of my knowledge, at the time Study 1 was published, there were no previous eye-tracking studies investigating the sight-singing strategies of experienced singers, with a particular focus on the role of lyrics in a tempo-controlled situation. In current study, singers processed the two different streams of information simultaneously, with increasing cognitive load as the number of notes or accidentals in a measure increased. The singers' strategy was to allocate more reading time to the music, while the performance pace was regulated by a metronome, compromising the semantic comprehension of the lyrics. One explanation could be that the reduced attention to lyrics could be partly due to familiarity with the lyric reading style, and the longer fixation duration on the music than on the lyrics could be explained by the musical complexity of the stimulus.

The results of this study are consistent with previous eye-tracking studies that have examined the visual gaze of expert musicians during score reading. For example, Goolsby (1994), Huovinen et al. (2018), and Sloboda (1977) have discussed the influences of score complexity and highlighted the critical role of structural elements in skilled reading. The current study contributes to the broader issue of visual attention and cognitive load of singers by addressing eye-voice spans, aspects of strategic thinking and singers' metacognition. A salient finding to emerge from the data is that singers do not look far ahead in the notation, but instead manage the task by responding to immediate challenges.

5.2 Study 2

Study 2 addressed conceptions of score reading and approaches to concrete silent-reading tasks among four Swedish expert choral conductors. In substudy 1, interviews with the conductors revealed four distinct themes regarding their approaches to silent reading: gaining an overview, examining harmony or potential challenges, and shaping a so-called conducting line (i.e., a selective script or annotations in the score for organizing one's actions around the score). The subsequent eye-tracking study (substudy 2), revealed that silent reading progressed mainly from start to end in a mostly linear manner both within and between staff systems, and that relatively quicker scanning through the score tended to lead to more holistic verbal accounts (i.e., retrospective verbal reports).

Furthermore, the verbal accounts of each conductor revealed slightly different cognitive interests, such as aesthetic interest, practical interest, harmonic interest and interest in choral compositional structure. These cognitive interests appeared to influence their eye movements. For instance, the conductor with "aesthetic" interests exhibited relatively low local linearity and few vertical saccades. Given that this specific participant also described the music in a relatively holistic manner, it can be hypothesized that holistic statements may often take place at the cost of information about the vertical aspects of the music (e.g., detailed analysis of harmony or choral structure). In contrast, another participant frequently described harmonic progressions and exhibited relatively few transitions between staff systems yet showed many vertical saccades and a locally linear reading style.

Thus, the two substudies highlight that, regardless of shared models of professional practice, individual reading styles or cognitive orientations may influence reading strategies. Remarkably, without hearing the excerpts during the 30-second task, all of the conductors were able to extract glimpses of the music's aesthetic meaning solely from the notation. For illustration: "a carpet of sound over which the soloist seems to float, […] and what is false and what is true is painted on the sheet music" (Participant 1); "it becomes like an ecstatic dance-like explosion" (Participant 3). This ability can be attributed to their musical expertise, visual processing skills, and high level of professionalism. However, due to the small sample size and limited generalizability, these connections should be interpreted cautiously.

An interesting aspect of the results of Study 2 is that, although all four conductors participated in the study as apprentices of the Eric Ericson Swedish choral tradition and share similar conceptions regarding how to study a new choral piece, they still exhibited subtle variations in their score reading styles, prioritizing different musical elements. This could be explained by different "problem-setting" approaches (Schön, 1983), or it could be related to the research by Corbalán et al. (2019), who found various types of score processing and music teaching among conductors. Comparing these results with previous research (e.g., Corbalán et al., 2019; Emerson et al., 2019, Jossberger et al., in press), it becomes evident that while there are shared models of professional practice, individual reading styles and cognitive orientations play a significant role.

5.3 Study 3

Study 3 investigated choral singers' gaze behavior during a group performance in an SATB ensemble. Eye-movement measures were analyzed in conjunction with the singers' views regarding their music reading, obtained through questionnaires and group discussions. The study shows that participants often directed their gaze to the neighboring staves directly above their own voice lines in the score. As an exception, sopranos, as the highest voice, looked instead below their line at the alto voice. Instead of visually connecting their own performances with structurally significant lines (melody and bass), participants thus focused on the nearest voices, possibly also due to difficulties in reading another clef or challenges in monitoring distant voices in peripheral vision.

The results of the analysis underscore the substantial influence of note density in a bar on total and average fixation durations on one's own lines, but not on other voices' lines. Practice, on the other hand, exhibited effects only on average fixation duration for one's own lines, with no significant impact observed on other lines. Fixations on other voice lines were shorter than those on singers' own lines, and their duration was unaffected either by note density or practice. Data from questionnaires and group discussions revealed that singers actively utilized both audio and visual cues, to grasp similarities between voices, match their own pitches against other voices, and enhance their performance when working with choral scores. This approach is particularly significant in a choral context as it allows singers to coordinate their individual parts with the overall musical structure. In essence, the study reports on the interplay between musicians' gaze behaviors, the complexity of the score, repeated practice, and group context.

Notably, no prior research has been conducted on the specific topic of sight singing from a full score in a group context. This presents an exciting opportunity to explore singers' eye movements, especially considering how experienced singers excel at multitasking while working with choral scores. Results showed that while singers focused on their own lines (melody and lyrics), they also spent time gathering information to support their comprehension of the entire score. Singers used domain-related knowledge, audio and visual cues, and parafoveal reading. This behavior may differ from those reading "one-staff music," partly due to the group context and the complexity of the information-rich score. These findings align with those reported in prior studies examining the eye movements of conductors working with string ensembles and clarinet-piano duos (Bigand et al., 2010; Bishop et al., 2019).

5.4 Study 4

The objective of this descriptive study was to investigate the memorization approaches that contributed to successful melodic recall. Fifteen music college students were tasked with memorizing three unfamiliar folk tunes following a 60-second practice period. To identify changes in visual attention throughout the practice sessions, participants' eye movements were recorded. Results showed that some students achieved accurate recall as early as the second minute of rehearsal, despite the brief three one-minute practice sessions.

Based on recall accuracy, the sample was divided into two subgroups: high-accuracy performers and low-accuracy performers, each representing 20% of the total sample. Both subgroups applied structural cues when rehearsing challenging sections. High-accuracy performers revisited phrases more often, demonstrated better music reading skills, and processed the music faster. This observation suggests a link between fluency in music reading and effective memorization. Differences in total fixation duration indicated shifts in visual attention over time.

The results indicate that all participants employed four memorization approaches—Holistic, Segmented, Additive, and Serial (see definitions in Paper 4)—and adapted them interchangeably. This result supports Mishra's (2005) theoretical model, which identified four distinct strategies for the practice stage. In the current study, the definition of the memorization approaches builds on Mishra's model but includes modifications to better address specific aspects relevant to empirical research. For instance, the Additive approach involves participants processing larger segments of three phrases. The slightly modified interpretation of the Additive approach enhances the flexibility of assessment. Although my definition differs slightly from Mishra's theoretical model of memorization (2005), the study is still fundamentally grounded in her theoretical framework.

The Holistic and Segmented approaches were used more frequently than the Additive and Serial approaches. High-accuracy performers tended to prioritize the Holistic approach (i.e., practicing the entire score from beginning to end), while low-accuracy performers used both approaches in roughly equal proportions, with a slight preference for the Segmented approach (i.e., practicing selected segments). Despite these variations, the Holistic approach, favored by high-accuracy performers, could be considered the most effective for memorizing short and technically simple melodies written in a conventional music style. This interpretation aligns with Mishra's (2011) statement that memorization efficiency could be influenced by the strategy employed.

The findings of Study 4 are interesting in several respects: (a) both Holistic and Segmental approaches have been most used by students in memorization tasks under time constraints; (b) bars near system breaks or challenging melodic intervals caused greater visual and cognitive attention, similar to the process of reading text (e.g., Just & Carpenter, 1980); (c) efficient reading skill may assist in processing and retention of melodies. Overall, these results align with earlier studies emphasizing the importance of visual, auditory, conceptual, and kinesthetic memory types, as well as self-monitoring through brief memory checks (e.g., Killian & Henry, 2005; Loimusalo & Huovinen, 2018; Parkes, 2022; Pomerleau-Turcotte et al., 2023).

5.5 Summary of Main Results

This section presents a concise summary of the key findings and their relevance to the broader context of existing research.

(a) In all studies, musical experience, particularly in choral singing, influenced participants' visual processing expertise. Expert singers, conductors, and music students demonstrated gaze patterns that reflected their level of mastery, such as the ability to quickly identify domain-relevant musical features and anticipate upcoming elements. These skills positively impacted their performance accuracy and visual processing expertise. Similar findings have been highlighted in recent meta-analyses of domain expertise by Perra et al. (2022), Puurtinen (2018), and Sheridan et al. (2020).

(b) Participants adapted their eye movements based on the complexity and density of the musical material (Study 1). As the density and complexity of the stimuli (such as the number of notes and accidentals) increased, the fixation duration often also increased, reflecting the need for more cognitive resources to process intricate musical elements. Experts prioritized melodic lines and omitted lyrics when they had difficulty processing melodies.

Previous research has shown how factors such as the complexity and density of musical material, as well as visually disrupted scores, influence eye movement patterns (e.g., Arthur et al., 2016; Kinsler & Carpenter, 1995; Wurtz et al., 2009; Waters & Underwood, 1998; Drai-Zerbib & Baccino, 2011). For a recent meta-analysis, see Perra et al. (2022), and for a review, see Madell and Hébert (2008).

(c) The results indicated an interrelationship between holistic and detailed processing when reading musical scores. Experts scanned the score horizontally to focus on upcoming details, while simultaneously inspecting it vertically to understand harmony and overall structure (Study 2, 3). Previous research has also linked holistic perception with visual processing expertise, as shown in studies on medical image perception (for a review, see Sheridan & Reingold, 2017; Kundel et al., 2007).

(d) Conductors' individual cognitive orientations in reading and interpreting choral scores were evident during silent reading (Study 2). The emphasis on artistic individuality in interpretation and performance has been explored by researchers such as Corbalan et al. (2019), Morrison and Silvey (2022), and Price and Byo (2002).

(e) In group performances (Study 3), singers synchronized typical sight-reading processes with additional information-gathering strategies, utilizing both auditory cues (e.g., the sound of the ensemble) and visual cues (e.g., structural elements, notated symbols) to enhance their understanding of the musical content and coordination with the group. The importance of audio and visual cues in supporting music reading was also demonstrated in studies, such as those by Silva and Castro (2019) and Drai-Zerbib (2018), on multisensory information processing.

(f) Repeated practice was linked to improved accuracy (Study 3, 4). The practice variable was examined in other studies; for example, in Mishra's (2014) meta-analysis of factors associated with sight-reading accuracy, practice was a strong predictor. Overall practice time or years of practice (but not short practice phases) were associated with eye-hand span (e.g., Rosemann et al., 2016). The influence of a short practice phase (rehearsal) affected the perceptual span, increasing it from 4–5 notes to a span of 11 notes (Burman & Booth, 2009). In the study by Iorio et al. (2022), both mental and physical practice appeared important for improving performance, with accuracy gradually increasing.

(g) For memorizing shorter, technically simple folk tunes, the combination of holistic and segmented memorization approaches was found to be beneficial (Study 4), as also suggested by Mishra (2011). Adapting the learning process to the structural cues facilitated easier memorization. Earlier studies, such as those by Goolsby (1994) and Sloboda (1977), provide partial support for the role of structural units in determining visual processing.

The results of these studies indicated that various components, including musical expertise, visual processing expertise, music reading strategies, and performance outcomes, are closely interrelated. This highlighted the dynamic nature of the sight-reading process. Expert musicians, perhaps due to their greater working memory capacity, were able to keep more elements active in their memory for a brief period between visual intake and performance of the score. This indicated that expert musicians process visuomotor information in a more structured way compared to those with less expertise (e.g., Pomerleau-Turcotte et al., 2022; Perra et al., 2024). Some of these skills may be directly related to the audiation of musical intervals (i.e., hearing the music internally before performing it), while others may relate to visual processing expertise, which involves the domain-specific knowledge to understand the organization of choral scores.

6 Discussion of the Results

6.1 Highlights of the Thesis

To address the central research question concerning the strategies employed by experienced musicians in the reading and memorization of vocal music, a synthesis of results from four original studies was conducted. The outcomes highlight the cognitive effort musicians experience when decoding and performing musical notation. Furthermore, the challenges associated with the simultaneous processing of music and lyrics necessitate the ability to manage multiple elements concurrently, understanding both musical and textual components. Moreover, reading the choral score and performing in group settings required domain-related processing skills. The results indicated that while performing their own lines (melody and lyrics), singers also gathered additional information to enhance their understanding of the entire score. Besides, singers integrated audio and visual cues to enhance music reading accuracy. This approach may differ from reading “one-staff music,” as the coordination of one’s own part with those of others in the context of an information-rich score may present greater demands. Ultimately, the ability to effectively manage multiple streams of information is crucial in choral settings.

In this dissertation, experienced singers and conductors demonstrated a range of strategies that can be categorized as domain-related knowledge and skills. The knowledge component includes understanding fundamental concepts of music theory, compositional structure, harmonic relationships, and choral score organization. Domain-related skills encompass audiation, automatized sight-singing techniques, the ability to manage multiple streams of information, and self-monitoring abilities. These sets of knowledge and skills are deeply interrelated, each reinforcing and complementing the other in the context of music performance. This list represents only a small portion of the broader set of competencies essential for effective reading vocal music, analogous to the visible tip of an iceberg.

Taken together, these findings have underscored the complex interplay among visual processing expertise, performance mastery, audiovisual integration skill, domain-specific knowledge, and contextual awareness. Experienced musicians exhibited flexibility by using these skills interchangeably, thereby enhancing their ability to read and memorize vocal music effectively.

6.2 Aspects of Domain-Related Visual Processing Expertise

Scholars classify musical expertise into areas such as performance, composition, memorization, conducting, sight reading, playing by ear, and improvisation, reflecting the wide range of skills and knowledge within the field of music (e.g., Haston & McPherson, 2022; Zhukov & MacPherson, 2022; MacDonald, 2022; Ginsborg, 2022; Morrison & Silvey, 2022). Within this framework, expert performance can be defined as the ability to deliver musical pieces with exceptional technical precision and expressive depth, reaching a standard comparable to international-level performances (e.g., Ericsson et al., 1993; Sloboda, 1985; Sloboda, 1991; Ericsson & Lehmann, 1996; Mishra, 2020).

Visual processing expertise is a key component of overall musical expertise (see Perra et al., 2024). It is a cognitive ability developed through extensive practice. Visual processing expertise involves a collection of skills, such as recognizing patterns, interpreting visual information (like musical notation), and efficiently processing visual stimuli specific to the demands of performance (e.g., Ericsson et al., 1993; Lehmann et al., 2018). Musicians' visual processing expertise encompasses the advanced capacity to accurately decipher musical notation with or without performing it, selectively focusing on relevant elements within the visual field during the reading process (e.g., Sheridan et al., 2020).

In Study 1, participants successfully performed a complex stimulus set by deciphering notation and focusing on relevant elements while reading prima vista. In Study 2, the visual processing expertise of conductors was exhibited through their gaze patterns, which were influenced by their cognitive interests. In Study 3, choral singers' visual processing expertise was demonstrated by the distribution of visual attention between their own and other vocal lines. In Study 4, visual attention to structural units supported learning outcomes. Just as visual attention in music reading involves actively processing notated music, attentional focus in music performance refers to mental concentration on aspects such as sound quality. In a study by Atkins (2017), trained singers improved sound quality when they adjusted their attentional focus. Visual attention in music reading and attentional focus in music performance may be related, as both involve managing cognitive resources to optimize performance.

The role of parafoveal vision is particularly relevant to visual processing expertise in music. Parafoveal vision allows musicians to process visual information beyond the central focus of their gaze, which is essential for tasks like reading ahead in musical notation. Research has shown that experts in various fields process domain-specific visual features as larger patterns, engaging in more parafoveal processing to integrate information across a broader visual region (e.g., Sheridan et al., 2020). This phenomenon is not unique to music; it has been supported by evidence from other domains, such as medical image perception (e.g., Kundel et al., 2007; Nodine

& Kundel, 1987), chess (e.g., Gobet, 2016; Reigold & Sheridan, 2011), and text reading (for a review, see Schotter et al., 2012).

Sheridan and Reingold (2017) discussed the perception of medical images, noting that experts utilize their parafoveal and peripheral vision to process large regions of an image in parallel. Additionally, they highlighted that experts benefit from a rapid initial glimpse of the image. The question of how musicians process parafoveal information has not yet been answered. One hypothesis is that while maintaining fixation on a specific point in the score, musicians might divide their visual and cognitive attention to a broader area around the foveal vision, enabling more holistic understanding of the material in both vertical and horizontal directions.

A choral score is usually more widely spaced and larger in size than a single staff for a solo instrument. When reading a choral score, experienced conductors and singers tend to have fewer fixations and a deeper understanding of both the horizontal and vertical dimensions of the notated music than novices. It could be suggested that as a result of their extensive experience in professional practice, experienced choral conductors engage in more parafoveal processing when looking at the score (similar to medical image perception). With this visual processing expertise, conductors and choral singers may be able to perceive the interconnectedness of individual elements of the score, anticipate upcoming sections earlier, gain a clear overview of the overall structure of the page, and focus on specific points while understanding the broader context (for conductor performance, see Bigand et al., 2010).

In reading choral music, both foveal and parafoveal processing may be important. Foveal vision, which is responsible for sharp central vision (Holmqvist et al., 2011), allows choristers to accurately identify individual musical features directly in their lines. This precise visual focus is essential for immediate and accurate music reading and performance. On the other hand, parafoveal vision, which occurs just outside the direct line of sight, supports a broader awareness of elements such as the compositional structure of a choral score (for parafoveal processing in text reading, see Hyönä, 2011). It could enable choristers to gather additional contextual information from surrounding lines without moving their gaze.

Experienced choral singers, through practice with choral scores, may develop the ability to process larger musical configurations in their parafovea during each fixation, which may lead to longer fixation durations (for a discussion of parafoveal vision, see Sheridan et al., 2020). Visual processing expertise may be critical for coordinating their singing with others, which may require directing subsequent fixations to salient aspects of the score beyond one's own vocal line. This ability to process information outside of fovea helps in the overall understanding of the musical structure and harmonies, facilitating smoother transitions and better preparation for upcoming passages (similar to text reading, for a review, see Schotter et al., 2012). The integration of foveal and parafoveal vision may support experienced choristers and choral conductors in the effective use of chunking and rapid transitions between individual details and larger musical patterns (for visual expertise in chess, see, e.g., Reingold & Sheridan, 2011). This type of reading could be considered a part of singers' domain-related visual processing expertise of singers and conductors (for visual search in music, see Maturi & Sheridan, 2020). However, the ability to consciously comprehend information in parafoveal vision is a skill that needs to be understood and intentionally studied. This is because it is not typically included in standard curricula but could be of interest in achieving proficiency.

6.3 Complexity of Musical Stimuli and Tasks

In the scope of this research, it was evident that more challenging elements of a musical score, such as wide intervals, accidental keys, complex harmonies, or intricate lyrics that include metaphors, necessitate greater visual and cognitive engagement. The results demonstrated that not only complex musical features could contribute to longer fixation durations, but also an increased density, defined as the number of notes within a given bar. The effect of "complexity" was observed even in cases where the content consisted of mere repetition of a single note.

In contrast, the data obtained from interviews suggest that singers typically found lyrics, such as repetitive phrases from traditional liturgical texts, to be more manageable due to their familiarity with the text and the predictability of successive words. Though, complex and less familiar texts demand increased attention and great effort. Music and lyrics collaboratively contribute to the formation of a complete song; however, they represent distinct elements of a composition and necessitate the competence of cross-modal processing (e.g., Drai-Zerbib, 2016). Thus, the complexity of each component may influence how the score is processed.

In informal discussions, participants indicated that the task felt more complex when they heard defined metronome beats while sight singing or when sitting in front of a computer instead of standing in the traditional choral semicircle. Related discussions upon the effect of complexity of musical stimuli and task conditions on gaze patterns have been discussed by Perra et al. (2022), Puurtinen (2018), and Sheridan (2020).

To manage the complexity they faced, participants in Studies 1, 3, and 4 employed a range of strategies. Singers utilized discrete body movements, such as mimicking the playing of an imaginary instrument with finger motions, clapping on their laps or a table, or stamping their feet to assist with sight reading and memorization tasks. These strategies can be explained in terms of kinesthetic memory, as they appeared to be partially automatic and were used without conscious control. Maes et al. (2015) suggested that continuous body movements provide temporal control information to performers under high cognitive load conditions. Furthermore, Pomerleau-Turcotte et al. (2023) found that strategies involving body movements were positively correlated with rhythm score execution. This suggests that bodily engagement not only helps manage cognitive demands but also enhances rhythmic accuracy in performance.

Incorporating kinesthetic motoric body movements results in the formation of memory traces that can be retrieved and serve as links to memory reconstruction, thereby enhancing the robustness of the performance. The idea is that these movements, once internalized, provide a reliable foundation that supports and stabilizes performance, especially under challenging conditions (e.g., Ginsborg, 2020; Lehmann & McArthur, 2002). This speaks to the efficiency of long-term retention and chunking strategies among experienced musicians (e.g., Sheridan & Reingold, 2014).

The following is a concise overview of the strategies used by participants to facilitate their reading processes. Informal observations during task performance indicated that each participant employed at least one of the strategies listed below: (a) incorporating motoric body movements to maintain pulse and rhythm steadiness; (b) prioritizing the melody and accepting the exclusion of lyrics (humming instead); (c) improvising the melody when it was forgotten while using body movements to indicate tempo; and (d) moving their fingers as if playing a keyboard or other instrument. Additionally, singers described using muscle memory during the singing task, particularly in the following way: (e) relying on vocal cord memory as part of their muscle memory during sight-singing.

In interviews, participants also emphasized the importance of instrumental practice, mastering improvisation, and listening to various styles of music in developing their aural skills. Interestingly, a few participants mentioned that they adjusted their strategies based on the complexity of the score, highlighting that flexibility and adaptability are essential traits in music reading skills. These findings underscore the multifaceted nature of “an art of practice” (Schön, 1983) and could be viewed as signs of utilizing visual, auditory, conceptual, and kinesthetic memories, as described by Ginsberg (2022), Killian and Henry (2005), Loimusalo & Huovinen (2018), and Pomerleau-Turcotte et al. (2023).

Another strategy actively employed in reading tasks was the use of audio cues. Qualitative data reveal that many participants performing in a group relied on audio cues as navigational support during the performance (Study 3). Conversely, those who performed individually (Study 1) pointed out that they missed the harmonic support achievable only in a group context. There were also indications that, in general, singing in a choir is helpful for sight singing on various levels. However, the effectiveness of audio cues can be influenced by factors such as a singer’s knowledge of music theory, experience, and sight-singing skills. Incorrect singing by one individual can negatively impact the entire group. These findings align with previous research on cross-modal integration, which explores how musicians combine audio and visual stimuli during performance (Drai-Zerbib & Baccino, 2014), and benefits from harmonic support, as also noted by Fine et al. (2006) and Nikolić and Kodela (2020).

6.4 Pedagogical Implications

Throughout history, mentors and masters have underscored the significance of effective sight reading as a foundational skill in musicianship. Their teachings have consistently highlighted the importance of domain knowledge and deliberate practice as essential components of musical development—principles that remain relevant in contemporary education (Demorest, 2001; Ginsborg, 2022). This dissertation employed eye-tracking methods to illuminate the reading strategies of expert musicians, making their processes "visible" (see Sheridan et al., 2020). The findings from four original studies may offer valuable insights for music education, presenting approaches that can enhance the score study curriculum and foster visual processing expertise among students.

Based on the results of the first study, which indicated that melodic content requires more cognitive resources than lyrics, it can be suggested that novice singers should start with the more accessible part—lyrics—and incorporate the melodies later. Several approaches to working with lyrics could be considered: (a) reading the lyrics separately from the melody, (b) singing the lyrics together with the melody while reading in a "zigzag" manner (as suggested by Ginsborg, 2002), and (c) practicing "reading" and comprehending the lyrics in parafoveal vision to minimize zigzag eye movements. The latter method may involve longer fixations on the space between notes and lyrics. These varied approaches offer a range of options that depend on singers' individual preferences and skills. However, no single approach should be regarded as the only "correct" one (see Loimusalo et al., 2019; Loimusalo & Huovinen, 2021).

All conductors in the second study were trained in the Eric Ericson choral tradition, where the concept of "conducting lines" (i.e., a script for organizing actions around the score) was valued as a tool for interpretation and practice (Ericson et al., 1974). In interviews, all conductors mentioned that in different degrees they employed conducting lines for various aims during studying scores. Thus, this method could be included in the curricula and be a research object in future studies. Moreover, introducing singers to the concept of a conducting line can be beneficial, potentially enhancing their understanding of the music and the conductor's intentions, thereby fostering greater agency and responsibility in rehearsal. Moreover, sharing examples of how experienced conductors organize their score reading could support the pedagogical training of young conductors. The results can be a good reminder that students may need to be guided differently depending on the reading task. (e.g., first accounting reading vs. deeper digging for interpretive clues) (e.g., Bigand, et al., 2010).

The results of the third study suggest that sight-singing and parallel information-gathering processes are often used in tandem. This dual approach to perceiving and processing the printed score is valuable for experienced singers but may be devastating for novices. Conductors can emphasize the benefits of maintaining a comprehensive overview of the entire score, particularly regarding neighboring vocal lines, and can train novices to frequently observe the musical lines of their peers, especially during pauses or less dense sections in their own parts. Utilizing available time to familiarize oneself with the score and identify similarities can facilitate score reading and enhance performance. Importantly, the results indicated that the most effective way to optimize gaze patterns for the information-gathering process during performance is to focus on the neighboring voice line above in the notated score.

The next valuable skill for reading music is the ability to rely on auditory cues. In learning environments like choral rehearsals, instructing singers to actively listen and distinguish individual pitches within the harmony, using them as auditory cues, may further improve their proficiency. By following harmonic progressions and tuning into the pitches sung by others, singers can adjust their performance to better align with the group's needs (e.g., Fine et al., 2006; Nikolić & Kodela, 2020; Zadig et al., 2017). Music educators can support novice singers by explaining what to look for and listen to during rehearsals with the score, demonstrating this method through gaze patterns of experienced singers (e.g., using scanpath visualization), and incorporating targeted ear training exercises. A short, focused session during rehearsals can further help students develop these listening skills, enhancing their ability to integrate their parts into the ensemble.

Another observation in the third study was the extended fixation durations which was attributed to the parafoveal vision, likely assisting choristers in processing larger sections of the score. This type of score processing would potentially allow for an understanding of the relationships between voices, structural cues, and guide to some location of interest. Sheridan et al. (2020) pointed out that experts rely more heavily on parafoveal vision than novices, allowing them to detect broader visual patterns rather than focusing solely on individual features (Sheridan et al., 2020, p. 126).

It could be suggested that the efficient functioning of the oculomotor system to identify relevant information and determine its location through parafoveal reading is a trainable skill. As with other skills, this could be developed by starting with a simple musical composition, practicing at a slow tempo, and engaging in deliberate practice. By implementing the "method of parafoveal reading" into music education, it is possible to develop the necessary skills to master sight reading and understand the boundary conditions of the visual processing expertise (see also in Sheridan et al., 2020). Further research on parafoveal vision within an educational context is still needed.

For improved memorization, students might benefit from thoughtfully applying Mishra's (2005) four memorization approaches, understanding when and how to use each for optimal results. For instance, the holistic approach can be effective when learning a new song, as it helps maintain a complete view of the piece, or at the end of rehearsal to sing all memorized passages together. Additionally, engaging different types of memory—visual, conceptual, auditory, and kinesthetic—can enhance memorization by accommodating diverse learning styles and reinforcing information through multiple channels (for more on types of memory, see Chapter 2; see also Chaffin et al., 2016; Mishra, 2011).

One pedagogical implementation could be to take advantage of the "primacy effect"—the phenomenon where initial information is better retained, likely due to cognitive priming—observed in the fourth study. This aligns with the theoretical assumption that memory retention is often stronger at the beginning of a musical piece (see Chaffin & Imreh, 2002; Finney & Palmer, 2003; Mishra, 2010). To enhance their memorization skills, it might be reasonable to recommend also using other strategies that intentionally break with this tendency, such as the "backward-chaining strategy" (e.g., Ginsborg, 2022), which involves rehearsing vocal music starting from the end. This approach encourages working backward, either section by section or focusing on the more challenging parts first, ensuring stable retrieval and reinforcing difficult passages.

Choral directors aiming to perform concert repertoire without scores can initiate effective memorization practices. During each rehearsal, singers can be challenged to memorize a short section of the song within a limited time frame (3 minutes). By systematically developing singers' deliberate memorization and sight-singing skills—prioritizing "chunking" as a key strategy—choral directors can build a strong foundation for musicianship (e.g., Chaffin et al., 2016; Gobet, 2016). Singers can also be encouraged to employ both content-addressable memory and the holistic memorization approach (e.g., Chaffin et al., 2016; Mishra, 2011). Furthermore, introducing metacognitive strategies such as evaluation, planning, concentration, and self-monitoring can enhance students' awareness of their memorization processes and equip them with self-directed learning strategies. This approach aligns with earlier observations by Hallam (2001) and Parkes (2022).

6.5 Revisiting the Theoretical Perspectives

In this section, the theoretical frameworks presented earlier (e.g., chunking, schema, and template theories, WM, LTWM) will be re-examined considering the current findings, with attention to their relevance and applicability to research in the music domain. The discussion will also explore how these frameworks intersect with other relevant models introduced previously. Although the current research did not directly examine the relationship between music reading and memory structure, the findings are consistent with these theoretical frameworks and may indirectly support the applicability of theories such as schema, templates, or LTWM in explaining expert behavior.

Expertise in music performance is multidimensional, involving a combination of cognitive, perceptual, and motor skills (Kopiez & Lee, 2006, 2008). The previous studies reveal that expert musicians employ a wide range of cognitive strategies and processes, including pattern recognition, anticipation, problem-solving, and metacognition, to perform at a high level (see Perra, 2022, 2024; Penttinen, 2018). According to research literature on the musical expertise, schema and template theories help explain the memory structures that musicians develop through extensive practice (e.g., Snyder, 2000; Gobet, 2016). For instance, it could be suggested that as musician became proficient in reading of musical notation and familiar with the different conventions of musical styles, they may develop a more extensive system of slots in working memory and form "larger" long-term memory schemas that supported schematic understanding of musical notation and enhance memorization (see Baddeley, 2007). The "procedural templates" established through practice facilitated the automated sequence of actions (Land & Furneaux, 1997). In addition, during the memorization task, students utilized several components of working memory–the visuospatial sketchpad (used to comprehend e.g., musical score), the phonological loop (used to comprehend e.g., melodic passages), and the episodic buffer (used to integrate several different chunks into a larger memory representation)–which might contribute to increased memory span during the recall (see Baddeley, 2000).

The long-term working memory theory (Ericsson & Kintsch, 1995) positions itself as a framework that integrates various theoretical models, offering a comprehensive approach to understanding musical expertise. This theory suggests that long-term memory can function as an extension of working memory during performance, storing and retrieving schemas and templates developed through extended practice. These schemas facilitate efficient information processing and recall during tasks like music performance (see Drai-Zerbib & Baccino, 2018; Gobert, 2016; Reingold & Sheridan, 2011; Maturi & Sheridan, 2020).

Below are examples that illustrate the applicability of the above-mentioned cognitive theories to the research on musical reading expertise. The tendency of singers in Study 1 to focus more on the melody than the lyrics suggests the potential for differences in the cognitive demands of processing these two types of information. This observation aligns with theories of cognitive load and attentional allocation, which posit that individuals allocate greater cognitive resources to tasks that are perceived as more challenging or critical for task performance (e.g., Gobet & Simon, 1996; Gobet, 2016; Lehmann & McArthur, 2002). Additionally, syllabic processing of lyrics during sight reading could support the theory of cross-modal processing, where musical and linguistic information influence each other (cross-modal processing, e.g., Drai-Zerbib, 2016; Drai-Zerbib & Baccino, 2005; Williamon & Valentine, 2002).

The gaze patterns of choral conductors in silent reading (Study 2) may be attributed to their well-developed working memory capacity and well-established retrieval processes from long-term working memory (e.g., Baddeley, 2003; Cara & Gómez Vera, 2016). Following a brief 30-second reading period, the conductors were able to generate interpretive suggestions for previously unfamiliar choral excerpts. The conductors' reading strategies were found to be closely linked to their personal intentions in identifying specific events in the choral score. This allowed them to make interpretative decisions by quickly accessing information stored in a well-established long-term working memory system. These findings may support the applicability of the long-term working memory theory in explaining interpretive expertise.

The visual processing expertise of choral singers who participated in Study 3 can be attributed to the mental frameworks (schemas and templates) developed for specific contexts, e.g., Baroque musical style (see Snyder, 2000). Singers' expertise in working with the choral score can support a model in which multiple action sequences are conceptualized as a "chain," where one action triggers the next. For instance, skilled choral singers may first fixate on and perform their own voice line. Then challenges may prompt them to search for visual cues in others' voice lines, guiding their eye movements to examine notation across multiple lines, and return back to own voice line. Thus, the continuum of reading and information-gathering processes exhibited by skilled choral singers provides evidence for the "action schema" theoretical model. (i.e., a chain of simple action modules) proposed by Land and Furneaux (1997).

Furthermore, the observations of the utilization of visual and audio information during performance are consistent with the existing theoretical perspectives on working memory theory (see Baddeley, 2000). This highlights the presence of a developed system in choral singers that enables the temporary storage of information in a multimodal code, which is capable of binding data from subsidiary systems and from long-term memory into a unified episodic representation (cross-modal integration, Drai-Zerbib & Baccino, 2012).

The theoretical model of memorization proposed by Mishra (2005) has been employed to explain the results of Study 4. The findings indicated that students used different memorization approaches in varying proportions to encode and recall notated material. Participants divided the material into four equal units (phrases), and the memorization process relied on this division (see Chaffin et al., 2016), suggesting that structural boundaries facilitate interaction within working memory and serve as cues for retrieval. These findings support the theoretical assumption that expert musicians rely on structural cues and working memory retrieval structures in tasks such as memorization.

It is essential to recognize, however, that no single theoretical model can comprehensively explain all aspects of expert musical performance. Rather, various findings may refine existing theories or provide evidence that a theoretical framework can be applied to enhance understanding of the underlying mechanisms of musical expertise.

7 Methodological Discussion

7.1 Multifaceted Approach

Researching expertise in vocal music reading requires a multifaceted approach, as no single research method can adequately address the various dimensions of the investigation (see Bazeley, 2018, 2024; Creswell & Creswell, 2018). One aspect of this complexity relates to the nature of music itself—an intangible art form that demands meticulous interpretation. The cognitive process of reading music necessitates the translation of musical symbols into motor actions (e.g., Kopiez & Lee, 2008; Sloboda, 1985). Diverse factors, including musical genre, style, tempo, and the complexity of the notated material underscore the necessity for a "multifaced" analytical lens. Additionally, the musicians themselves—practitioners of different musical schools—represent the development and utilization of a diverse array of practice strategies, further adding to the study's intricacy. This blend of abstract and concrete challenges highlights the complexity of studying music reading within the vocal context.

To address this complexity, the methodological design incorporated both qualitative and quantitative approaches. A mixed-methods research design framework (Bazeley, 2024) was employed to capture the quantitative aspects of eye movements alongside the qualitative dimensions of cognitive processes. This methodological synergy aimed to provide a deeper understanding of the phenomena under investigation, adding depth and breadth to the previous knowledge. The study utilized various methods, including eye-tracking, interviews, and surveys to compare diverse outcomes, reduce bias, and enhance validity and reliability through triangulation. Quantitative eye-tracking data provided insights into visual gaze patterns, while qualitative interviews uncovered participants' perceptions of their strategies. The integration of the method during analysis and interpretation phases provided a more holistic understanding of cognitive processes, with qualitative data contextualizing and elaborating on quantitative findings, shedding light on the cognitive mechanisms that guide singers and conductors.

The concept of integration between methodological approaches was fundamental to four original studies. For example, in Study 2, the results of the initial interviews were integrated with those of the subsequent investigation, which included eye-tracking data and conductors' retrospective reports. Results from the interviews informed the analysis of eye movement patterns and the interpretation of the retrospective reports. In the final phase, all interdependent components were combined, resulting in a coherent and comprehensive answer to the research question. This integration demonstrated how different types of data can interact, enrich, and complement each other during different stages of the research, leading to a more nuanced understanding of the findings.

The following explains how mixed methods research, as presented by Bazeley (2024), was implemented in current research on reading strategies. Bazeley's cohesive framework recognizes the interdependence of different concepts, which is critical in distinguishing mixed methods from a monomethod. If the phenomenon of music reading is understood as multifaceted and multidimensional, then the use of multiple sources and types of data is essential to a holistic investigation. In original studies, each "monomethod" contributes interdependently to the overall research goal. By viewing the whole as an integration of its parts, this research has achieved a richer, more complete picture that transcends simplistic, one-dimensional views of individual methods.

One of the Bazeley's (2024) concepts, *integration,* was established between various elements of the research—such as methods, contexts, sample, or stimuli—to ensure that each component was connected and relevant to the overall investigation. For instance, linking quantitative eye-tracking data with qualitative interviews was crucial for understanding how different reading strategies were applied and perceived by participants (e.g., Studies 1, 2, 3). This approach provided a comprehensive view of the strategies used, where insights from one method supported and enriched the findings from another.

The concept of *transfer* in this context involved exchanging data, information, and insights between different research methods (ibid.). For example, the findings from one study, where participants elaborated on their concept of music reading, informed the eye-tracking examination, thereby deepening the understanding of the cognitive processes involved (e.g., Study 2). Additionally, the participants' feedback on the overall design influenced future studies' design. Although some feedback may have been general, this exchange was crucial for creating a robust, interdependent research framework that advanced the whole study's objective.

Reconfiguration occurred by fusing different data sources and methodologies (ibid.), resulting in a dynamic and unified understanding of the music reading process. The integration of various methods—such as surveys, eye-tracking, interviews, participants retrospective reports, and researchers' observation—created an inseparable whole, comprehensive understanding of reading strategies that could not have been achieved through a single approach alone.

Coherence was achieved by ensuring that all research components aligned logically and synergistically. This alignment was crucial for effectively producing a cohesive set of findings that addressed the main research question effectively. By integrating various aspects of the investigation, the research reached a level of synergy where diverse methods and data sources supported each other, leading to a nuanced understanding of vocal music reading strategies.

This methodological synergy provided valuable support throughout the research process. The range of integration varied from study to study, linking the different approaches used at a particular point in time, or linking the different strands that occurred at each stage of the study (see Bazeley, 2024). It would be almost impossible to obtain the same results using only one methodological approach. The integrative nature of the mixed methods design opens new perspectives for future research.

7.2 Validity and Reliability of Findings

When discussing the validity and reliability of this research, several aspects must be addressed to ensure the consistency and trustworthiness of the findings. This research established validity by thoroughly defining and systematically exploring music-reading strategies, aligning with existing literature. The key constructs, such as the music reading strategies of experts and the mechanisms of reading music scores of different complexities were central to the research focus and were rigorously examined to reflect both theoretical and practical dimensions.

To further enhance validity, the study employed a mixed methods approach (Bazeley, 2024) with multiple sources and types of data collection and analysis, allowing for triangulation, which supports the credibility of the results. Previous studies provided a foundation for comparison and context, ensuring that the research aligned with and advanced current knowledge in the field. Additionally, the research process incorporated expert review (e.g., peer-reviews assessed the quality of the manuscript before it was published) at various stages, confirming that the study measured what it intended to measure.

One challenge was selecting research tasks and stimuli that appropriately matched the participants' level of expertise. Tasks that were too simplistic might not capture the full range of participants' skills, while overly complex tasks could lead to frustration or disengagement. This balance was crucial for maintaining the validity of the results, as it directly impacted how well the tasks reflected the participants' reading strategies. Thus, the experimental tasks were designed to replicate authentic musical interactions as closely as possible within the controlled conditions of a "laboratory setting". Recruiting participants with the highest level of expertise and maintaining their engagement throughout the study required additional effort, especially, when they were supposed to perform together (i.e., choral singers in group investigation).

A notable strength of the study was its ability to bridge "laboratory settings" and real performance contexts by using ecological stimuli. To capture their music reading strategies, participants were engaged in tasks involving different scores of varying complexity, effectively simulating real-world scenarios. In the context of silent reading strategies, conductors interacted with excerpts from contemporary choral compositions. It was critical to establish "standards" for executing tasks resembling the real-time decision-making processes that occur when leading a vocal ensemble. Within the context of group performance, the polyphonic style of music in the choral excerpts ensured a consistent set of musical elements within each individual voice line. The memorization scores were written in a traditional folk tune, whose simplicity made them easier to recall.

Reliability in this study refers to the consistency of measurements and data over time and across different conditions. To ensure procedural reliability, the measurement instruments were calibrated, data quality was closely monitored, and strict adherence to the experimental protocol was maintained (e.g., Dunn et al., 2023). Furthermore, pilot testing was conducted in Study 4 to verify that our experimental procedures were functioning as intended and producing consistent results. In all studies, control of data quality was implemented to identify and correct errors or inconsistencies in the eye-tracking data. To ensure the integrity and reliability of the qualitative analysis, inter-coder agreement was established in Study 2. The agreement between multiple coders was reported as a coefficient (Cohen's kappa). Additionally, the results of these studies were compared with findings from existing eye-tracking research on music cognition, reading, and performance.

As the experimenter, I completed a training course to familiarize myself with the eye-tracking equipment, protocols, and guidelines for interacting with participants. The course covered the technical aspects of the procedure and emphasized the importance of consistent communication and delivering instructions clearly and unambiguously. During data collection, uniform instructions were provided to all participants, ensuring that everyone received clear and identical guidance throughout the experiments. Additionally, consistent lighting conditions were maintained across sessions to create a standardized environment, thereby minimizing potential confounding factors.

In addition to eye-tracking, the current studies employed other methods of data collection and analysis. Firstly, the accuracy of the performances was analyzed both objectively, using Melodyne 4 software, and subjectively, through professional evaluation of errors during listening. While the software in Study 1 provided precise and standardized measurements, minimizing subjective bias, it proved ineffective in evaluating the accuracy of individual voice lines in *a cappella* group singing (Study 3). Since the goal was to analyze the accuracy of each voice line performance rather than the perfection of intonation for each melodic interval, subjective analysis was essential for complementing the limitations of the objective measurements.

Secondly, the retrospective report and interview approaches helped address the challenge faced by proficient musicians in articulating their strategies. Due to the internalization and automatization of their expertise, some musicians found it difficult to explain the processes involved in task completion. This highlights the complexity of capturing expert strategies solely through eye tracking. By encouraging participants to verbalize their thoughts, the retrospective reports and interviews allowed for a deeper exploration of their reasoning and problem-solving strategies (e.g., van Gog et al., 2005; Ericsson & Simon, 1980). This provided qualitative data that complemented the quantitative eye-tracking metrics. Participants' reflections contributed to the ecological validity of the study by bridging the gap between controlled experimental settings and real-world situations. However, there is a risk that participants may provide "fabricated" explanations afterward, known as off-line reporting, that may not accurately reflect their actual thought processes (see van Gog et al., 2005). Awareness of these issues can improve the accuracy and reliability of decisions.

Thirdly, surveys and questionnaires were utilized to garner self-report data on musicians' reading strategies, metacognitive awareness, and background information. These research instruments provided access to participants' individual experiences and beliefs regarding music reading approaches (van Gog et al., 2005; Creswell & Creswell, 2017), contributing to an understanding of the subject matter.

7.3 Limitations and Future Research

While the four studies generated interesting findings, several limitations should be mentioned. All studies had relatively small sample sizes, which restricted the generalizability and comparability of the results. These limitations became evident when considering statistical support. Statistical analysis necessitates a more extensive collection of empirical data; therefore, the findings of this study with a small sample size cannot be applied to the wider population or provide conclusive results. Although the participants were predominantly experienced musicians, with their mastery of music reading enabling them to efficiently interpret and perform vocal music, individual differences in experiences, skills, and expertise levels introduced challenges, particularly for comparisons within and between studies.

However, the benefit of research on small groups of participants is that it informs the research community of findings on a particular topic before committing to larger and more resource-intensive research projects. This work could address whether the research question requires further exploration, while also identifying potential challenges, gaps in the literature, and logistical obstacles. In addition, these studies with limited samples of participants can serve as pilot tests for the chosen methods and provide a basis for potential collaborations with other researchers interested in music reading in the choral context.

A potential limitation of this thesis is the absence of control groups. In psychological studies of expertise, a common approach is to include a control group of novices, such as non-musicians, to identify the characteristics that distinguish expertise by comparing their behaviors across groups under specific task conditions. However, this research focused on the description of strategies used specifically by experienced musicians with a choral background. Moreover, the complexity of the stimulus set presented to the experts would have been beyond the capacity of novices to process, making a comparison with novices unfeasible.

It should also be noted that using only excerpts from larger choral compositions (within the same musical style) could be a limitation, as excerpts may not fully capture the complexities of an entire score, potentially leading to misconceptions. Even though the tasks in the studies were carefully controlled to ensure reliable results, certain factors—such as performing in a “laboratory setting”, using excerpts from larger choral scores, utilizing a metronome throughout the task, and positioning participants with a forehead rest—may have influenced their performances. However, no issues were reported by any of the participants.

Future research could address the limitations outlined above by conducting larger-scale studies with diverse participant groups, including musicians of various skill levels and experiences. Longitudinal studies that track the eye movements of musicians over time may provide additional information about the development of expertise, starting at the novice level. Furthermore, wearable eye-tracking glasses could provide a first-person perspective in a real-life setting. Participants would not need to alter traditional choral routines, ensuring an authentic representation of their eye movements during music reading related tasks. This approach could contribute to the exploration of a dynamic process, beginning with their initial familiarity with the score and culminating in the concert performance without scores.

Furthermore, researchers could explore the potential for integrating eye movement modeling examples into music training, offering a pedagogical approach that leverages insights from the observed visual strategies of skilled musicians (e.g., Jarodzka et al., 2017; Gegenfurtner et al., 2017). Incorporating eye-tracking techniques into practice and providing accessible feedback may enhance the effectiveness of music education, offering valuable tools for both instructors and students to refine their music reading skills and acquire higher levels of musicianship (e.g., Jarodzka et al., 2017). It would be valuable to examine the impact of visual communication among choir members on the coordination and engagement of performers during choral performances. In addition, it would be worthwhile to investigate how visual cues—body movements and facial expressions—of fellow singers contribute to this engagement.

8 Conclusion

This research, comprising four interrelated studies, systematically investigated the strategies employed in reading vocal music. The studies assessed the influence of expertise, practice, and musical complexity on reading, memorization, and performance. Through rigorous analysis of both qualitative and quantitative data sets, the research sheds light on the complex relationship between visual processing skills and musical performance expertise.

This dissertation highlights the effectiveness of a mixed-methods design and its integrative approach in addressing the complexities of music reading. Eye-tracking technology bridges music cognition and musical performance, enabling a micro-level exploration of the relationship between music reading expertise and visual attention. This interdisciplinary approach underscores the value of applying eye-tracking in the study of music reading.

The findings offer a unique perspective on the synergy between visual processing expertise and performance mastery, revealing the intricate interrelationship between these two integral aspects of musical proficiency. It is evident that visual and performance skills should be developed in tandem, reinforcing one another to enhance overall musicianship. Following the results of these investigations, it is now possible to move beyond speculation and provide evidence-based insights into how music reading occurs in the choral context. While these findings offer a valuable starting point, they represent only the initial phase of exploration, with much more to be examined in this area in future studies.

Based on the studies conducted, it can be inferred that deliberate practice and intentional memorization are fundamental strategies for developing music reading expertise. By providing a practical perspective grounded in choral settings, this study addresses a gap in the existing literature and explores phenomena relevant to those involved in choral ensembles. The findings have the potential to inform and enhance pedagogical practices in choral education, inspiring educators, conductors, and fellow researchers. The aim of studying vocal music reading strategies is to contribute to the broader discourse in choral music, ensuring that the findings reach a wide audience of choral professionals and educators who can directly benefit from the research. This approach seeks to extend the discussion beyond the confines of music psychology, making it relevant and accessible to practitioners in the field.

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Maria Timoshenko-Nilsson is an experienced choral conductor with over two decades of practice. She has led more than ten choirs and taught music at Åbo Akademi University in Vaasa, Finland. Through her work, Maria discovered the need for more pedagogical support to assist singers in enhancing their music-reading skills. Her doctoral research focuses on identifying effective strategies that could facilitate the advancement of training methods and stimulate future research in the domain of choral music.

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