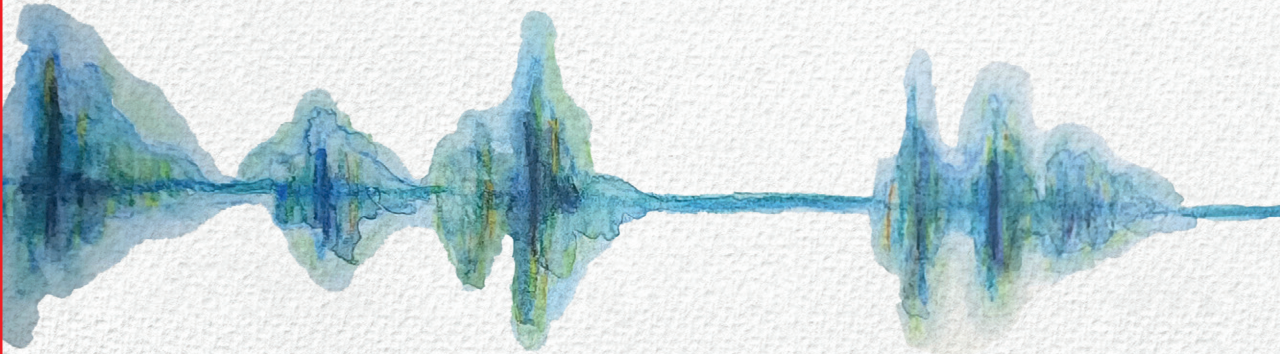
‘Now I know my ABC, next time won’t you sing with me?’

Effects of musical mnemonics on memory performance in healthy adults, ageing, and individuals with cognitive impairment



Marije W. Dijkman

DONDERS
SERIES

RADBOUD
UNIVERSITY
PRESS
Radboud
Dissertation
Series

‘Now I know my ABC, next time won’t you sing with me?’

Effects of musical mnemonics on memory performance in healthy adults, ageing, and individuals with cognitive impairment

Marije W. Dijkman

‘Now I know my ABC, next time won’t you sing with me?’ Effects of musical mnemonics on memory performance in healthy adults, ageing, and individuals with cognitive impairment
Marije W. Dijkman

Radboud Dissertation Series
ISSN: 2950-2772 (Online); 2950-2780 (Print)

Published by RADBOUD UNIVERSITY PRESS
Postbus 9100, 6500 HA Nijmegen, The Netherlands
www.radbouduniversitypress.nl

Design: Proefschrift AIO | Annelies Lips
Cover: Proefschrift AIO | Guntra Laivacuma
Cover Image: The aquarel of the audiowave was painted by the author of this dissertation.

The quotation on the cover page of this dissertation is from the ABC-song.

Printing: DPN Rikken/Pumbo

ISBN: 9789465152196
DOI: 10.54195/9789465152196

‘Now I know my ABC, next time won’t you sing with me?’

Effects of musical mnemonics on memory performance in healthy adults, ageing, and individuals with cognitive impairment

Proefschrift ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. dr. J.M. Sanders,
volgens besluit van het college voor promoties
in het openbaar te verdedigen op

donderdag 2 april 2026
om 10.30 uur precies

door

Marije Wilhelmina Dijkman
geboren op 8 juli 1986
te Velp

Promotor:
Prof. dr. R.P.C. Kessels

Copromotor:
Dr. R.S. Schaefer (Universiteit Leiden)

Manuscriptcommissie:
Prof. dr. H. Bekkering
Prof. dr. A. Postma (Universiteit Utrecht)
Dr. M. Sadakata (Universiteit van Amsterdam)

‘Now I know my ABC, next time won’t you sing with me?’

Effects of musical mnemonics on memory performance in healthy adults, ageing, and individuals with cognitive impairment

Dissertation to obtain the degree of doctor
from Radboud University Nijmegen
on the authority of the Rector Magnificus prof. dr. J.M. Sanders,
according to the decision of the Doctorate Board
to be defended in public on

Thursday, April 2, 2026
at 10:30 am

by

Marije Wilhelmina Dijkman
born on July 8, 1986
in Velp (the Netherlands)

PhD supervisor:
Prof. dr. R.P.C. Kessels

PhD co-supervisor:
Dr. R.S. Schaefer (Leiden University)

Manuscript Committee:
Prof. dr. H. Bekkering
Prof. dr. A. Postma (Utrecht University)
Dr. M. Sadakata (University of Amsterdam)

Table of contents

Chapter 1 | General introduction **11**

Chapter 2 | A novel model on the effects of musical mnemonics on memory performance **23**

Chapter 3 | Effects of musical mnemonics in ageing **67**

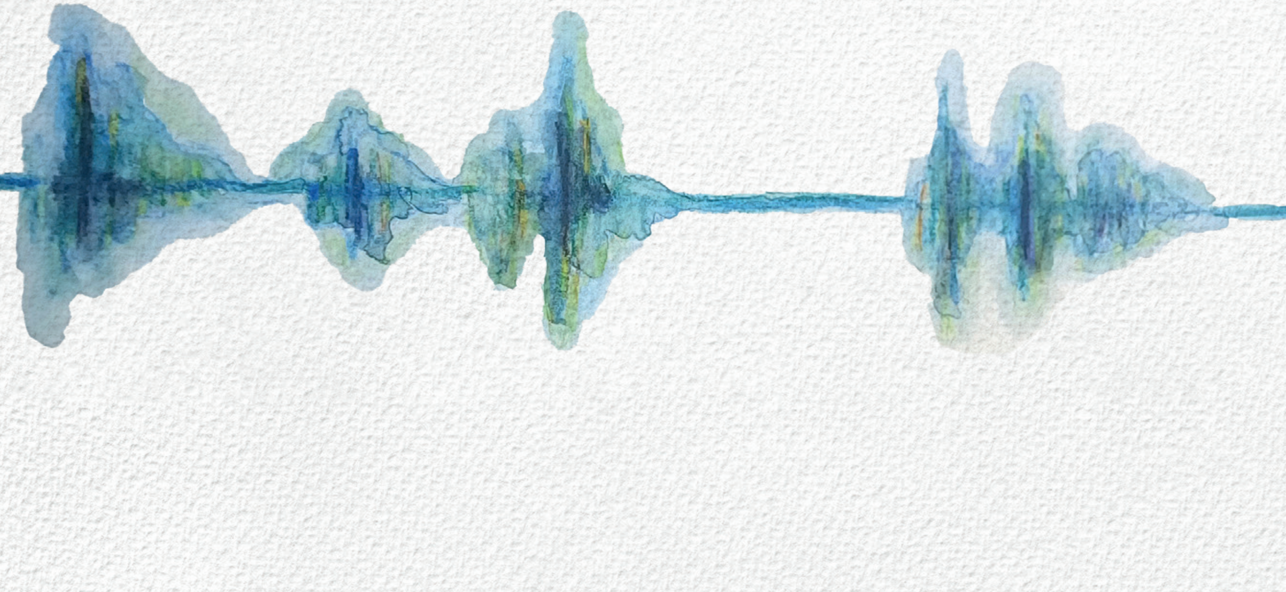
Chapter 4 | Effects of musical mnemonics in people with amnestic Mild Cognitive Impairment **83**

Chapter 5 | General discussion **101**

Appendices
References **117**
Appendix **127**
Research data management **135**
Dutch summary **137**
Portfolio **146**
Curriculum vitae **147**
List of publications **149**
Dankwoord **151**
Donders Graduate School **157**

“Muziek en ritme vinden hun weg tot in de geheime plaatsen van de ziel”.

Plato



Chapter 1

General introduction

Introduction

Our memory plays an important role in daily life, and consists of different systems, of which the distinction between temporarily keeping information active (i.e., short-term, or working memory, Baddeley, 2000) and a permanent store (i.e., long-term memory, Squire, 2004) is the most important. Everyday memory function (e.g., remembering what you have eaten yesterday, and remembering older events such as a holiday a few years ago), is referred to as *episodic memory* (EM), itself a part of declarative (explicit) long-term memory (Tulving, 1972). In ageing-related cognitive decline, different memory systems are unequally affected, and the largest degree of memory decline is generally seen in EM (Nyberg et al., 2012). In addition, *working memory* ([WM], i.e., the ability to maintain and manipulate a limited amount of information for a brief period of time, Baddeley & Hitch, 1974; Baddeley, 2000) also deteriorates with age (Nyberg et al., 2012). WM is involved in, for example, mentally rehearsing a phone number until writing it down. However, despite the age-related decline in both EM and WM, typically ageing older adults by definition perform within the normal range on formal memory tests (compared to age- and education-adjusted normative data).

In contrast, in persons with *mild cognitive impairment* ([MCI], Petersen et al., 2014), cognitive performance on neuropsychological tests is by definition impaired compared to age- and education-adjusted normative data, and substantiated by a subjective report of cognitive decline in everyday life by either the person with MCI themselves or their loved ones. MCI can be present in one or more cognitive domains. However, in people with MCI, functional independence is largely and by definition preserved, in contrast to the diagnosis of dementia (Petersen et al., 2014). Furthermore, persons are classified as having the subtype of *amnestic* mild cognitive impairment (aMCI) when the cognitive impairments affect the memory domain. Impairment can be restricted to the memory domain (aMCI*, single domain*) or accompanied by impairments in other cognitive domains ([aMCI*, multiple domain*], Petersen et al., 2014). Persons with the aMCI subtype, that is, showing EM impairments on validated tests, are most at risk for subsequently (i.e., within a couple of years) progressing to Alzheimer's dementia ([AD], Albert et al., 2011). However, there is increasing evidence that in aMCI, not only EM, but also WM is compromised (Kirova et al., 2015).

Currently, no proven effective pharmacological treatment options for (a)MCI are available (Petersen et al., 2014). There is some evidence for possible beneficial effects of non-pharmacological interventions such as physical exercise or cognitive training (i.e., ‘restorative approach’, aimed at improvement of memory functioning, see van Heugten et al., 2016), but there is a need for larger RCTs (Petersen et al., 2014). However, the memory problems that cognitively impaired individuals experience in daily life, even in the absence of functional decline, may be ameliorated by the use of memory strategies (e.g., Joosten-Weyn Banningh et al., 2011; De Wit et al., 2021) – that is, using strategies with the aim of improvement of memory performance – which may promote their independent living (Ross et al., 2022). In older individuals with subjective memory complaints (SMC), the use of memory strategies may also improve memory performance in daily life (Frankenmolen et al., 2018b). Likewise, in cognitively unimpaired older adults who show normal ageing, the use of memory strategies may ameliorate memory-related affect, memory ability, memory self-efficacy and their wellbeing, and quality of life (Hudes et al., 2019).

Memory strategies

Memory strategies (referred to as *mnemonics*) are used to improve the recall of information. Some memory strategies are well-known to many, such as the use of an agenda to remember appointments as an example of an external memory strategy, and making a visual association with an aspect of a person’s appearance or name to aid the learning and recall of their name, as an example of an internal memory strategy (see, e.g., Eikelboom et al., 2020). Advancing age is generally associated with decreasing internal strategy use and increasing external strategy use (Pizzonia & Suhr, 2022). The use of external memory aids is the most commonly reported strategy in older adults, regardless of cognitive status (Ross et al., 2022).

Across the spectrum of cognitive functioning (i.e., older adults without cognitive impairment, with SMC, MCI or dementia), older adults use a variety of memory strategies, including internal, external, and behavioural strategies (e.g., reducing expectations, acceptance of support), to compensate for everyday memory problems (Ross et al., 2022). However, behavioural strategies are mostly reported by cognitively impaired individuals, and internal strategies (e.g., verbalization, active remembering, systematic thinking, visualizing) are more frequently reported by cognitively unimpaired participants (Ross et al., 2022).

More specifically, with regard to WM strategies, Chevalère et al. (2020) report that one of the memory strategies cognitively unimpaired older adults spontaneously use, is making use of music, for example relying on rhythm or melody (e.g., making a melody with to-be-remembered separate words) or the association of words to music keys.

Musical mnemonics and aiding mechanisms

Indeed, the use of music is also an example of a mnemonic strategy. The idea that music may enhance cognitive functions is long-held and widespread, with 'the Mozart Effect' as a well-known example (although shown to not necessarily be related to Mozart, cf. Thompson et al., 2001). The use of music with the aim to improve neuropsychological problems was, for example, applied in Melodic Intonation Therapy ([MIT], e.g., Albert et al., 1973, for a recent overview, see Zhang et al., 2022) in aphasia. In stroke patients (e.g., Särkämö et al., 2008), but also in other brain diseases affecting cognitive performance (e.g., Multiple Sclerosis), music is also used to support (among others) memory, also called musical mnemonics training, also used in the framework of neurological music therapy ([NMT], Gardiner & Thaut, 2005).

In their review on benefits of music on verbal memory, Ferreri and Verga (2016) divide previous research into studies that use listening to background music versus studies that use a sung presentation of to-be-learned verbal information. They argue that between the existing different research paradigms (i.e., sung presentation versus background music), the complexity of the music that is used differs (substantially) and, as a consequence, the beneficial mechanisms of music on memory performance may possibly also differ (i.e., temporal-scaffolding-attentional mechanisms on the one hand, and arousal and mood and emotional-reward mechanisms on the other hand). Furthermore, Ferreri and Verga (2016) also mention that *musical expertise* (i.e., an umbrella term referring to the history of musical activity and training of the individual) may play a role. Although in previous research the participants' musical expertise has been frequently operationalized in different ways and was often not systematically examined, it appears relevant to be systematically considered, given the possible moderating effects it may have on the effects of musical mnemonics on memory performance (cf. Baird et al., 2017).

Using music in which the to-be-learned material is embedded (as is the case in sung presentation), with the aim of facilitating memory performance, has also been referred to as 'music as a structural prompt' (Madsen et al.,1975; Wolfe & Hom, 1993). *Musical mnemonics* have often been applied in educational settings, for teaching academic and social skills, as for example in the ABC-song, in which school-aged children learn the alphabet sung to the familiar melody ‘Twinkle, twinkle, little star’ (Jellison, 1976; Wolfe & Hom, 1993), to support the acquisition, recall and correct sequencing of letters. Another recent example of the use of a musical mnemonic facilitating motor sequence learning is ‘the handwashing song’, that was designed during the COVID-19 pandemic to teach and help children remember the six steps of the WHO-approved handwashing routine, with the aim of reducing the spread of the infection (Thampi et al., 2020). The near omnipresent – across various cultures known - nursery rhyme ‘Frère Jacques’ (or ‘Brother John’) was used and the lyrics were translated into 28 languages (among which Dutch). This highly familiar melody was chosen as it not only matched the recommended duration of the handwashing routine (20 s) and is easy to sing for children, but also involves very simple melodic patterns, which possibly (after familiarization through repetition and rehearsal) facilitated the (self-)monitoring of errors in the routine as missed steps were immediately noticed. Finally, musical mnemonics are also used for other purposes, such as to support the storage of information from a television commercial (e.g., Yalch et al., 1991).

Despite the widespread use of musical mnemonics, the empirical evidence on the effects of musical mnemonics in people with or without cognitive impairment is still limited (e.g., Rainey & Larsen, 2002; Silverman, 2012). Previous studies regarding the effects of musical mnemonics on WM performance have largely been conducted in cognitively unimpaired younger adults, and only a few studies have systematically assessed the possible facilitating aspects of separate musical components for memory. Furthermore, research methods differed substantially with regard to the verbal materials and musical embedding, and these studies showed mixed results regarding the specific contribution of separate musical components.

However, Silverman (2007, 2010, 2012) systematically assessed the effects of separate musical components, and consistently reported a significant beneficial effect of rhythmic presentation on WM performance in undergraduate students, possibly through *chunking mechanisms* (i.e., the grouping of several presented stimuli into a single familiar unit, or *chunk*, and recoding with a concise name [with the goal of reducing WM load], e.g., Thalmann et al., 2019, see also e.g., Miller, 1956, and Cowan, 2001), facilitated by the rhythm or time structure added (Silverman, 2007). Furthermore, melodies (that is, combinations of both pitch and rhythm patterns) that were previously unfamiliar negatively affected WM performance, possibly causing WM overload (Silverman, 2007). From these findings, it can be inferred that specific musical components (e.g., pitch, rhythm, melody, familiarity) and their combinations may affect WM performance differently.

Only recently, specific studies have been conducted on the effects of musical mnemonics in cognitively unimpaired older adults and cognitively impaired participants, such as persons with AD, especially focusing on EM (e.g., Simmons-Stern et al., 2010; Ratovohery et al., 2018, 2019). However, it can be argued that it is also important to focus on WM performance, as this also declines with ageing (Nyberg et al., 2012), can be compromised in aMCI (e.g., Gagnon & Belleville, 2011; Kirova et al., 2015), and is pivotal in long-term EM encoding and retrieval (e.g., Baddeley, 2012). To our knowledge, no previous studies have focused on the effects of musical mnemonics to improve WM performance in ageing, (a)MCI or AD to date.

Musical digit span task

Verbal working memory capacity is typically measured with span tasks (e.g., digit span or word span, see Conway et al., 2005). In clinical practice, the WAIS-IV Digit Span subtest is widely used to assess verbal WM, in which digit sequences of increasing lengths have to be memorized in the same or reverse order (Wechsler, 2008). In this thesis, a newly developed paradigm, the musical digit span task, will be introduced. The musical digit span task consists of prerecorded digit sequences that are either presented in a sung or spoken manner. The task is partly based on a previously described digit span paradigm (Silverman, 2007), but combined with increasing span lengths, as is the standard procedure applied in the WAIS Digit Span subtests (Wechsler, 1955, 2008). The task measures WM performance in spoken presentation and varying musical conditions (A. spoken, B. ‘pitch’, C. ‘rhythm’, and D. ‘melody’, see Figure 1.1 for the musical notation of the digit sequences in the different conditions). The administration phase is followed by a free recall, in which the participants have the choice to sing or speak back the digits in the same order as presented.

In the musical digit span task, 32 digit sequences of increasing lengths (5, 6, 7, 8 digits) are presented, with two different digit sequences per span length. Dissimilar to the WAIS-IV Digit Span subtests (Wechsler, 2008) that start with a two-digit sequence, the musical digit span task starts with two 5-digit sequences, as shorter lengths typically result in a ceiling performance in many participants. The digit sequences are presented in the four different conditions right after each other (e.g., spoken, pitch, rhythm, melody, eight spans in total).

Thereafter, two 6-digit spans are presented in the four different conditions, following with the 7- and 8-digit sequences (32 digit-spans in total).

Figure 1.1

Musical notation of the digit sequences in the four different conditions of the musical digit span task for all sequence lengths

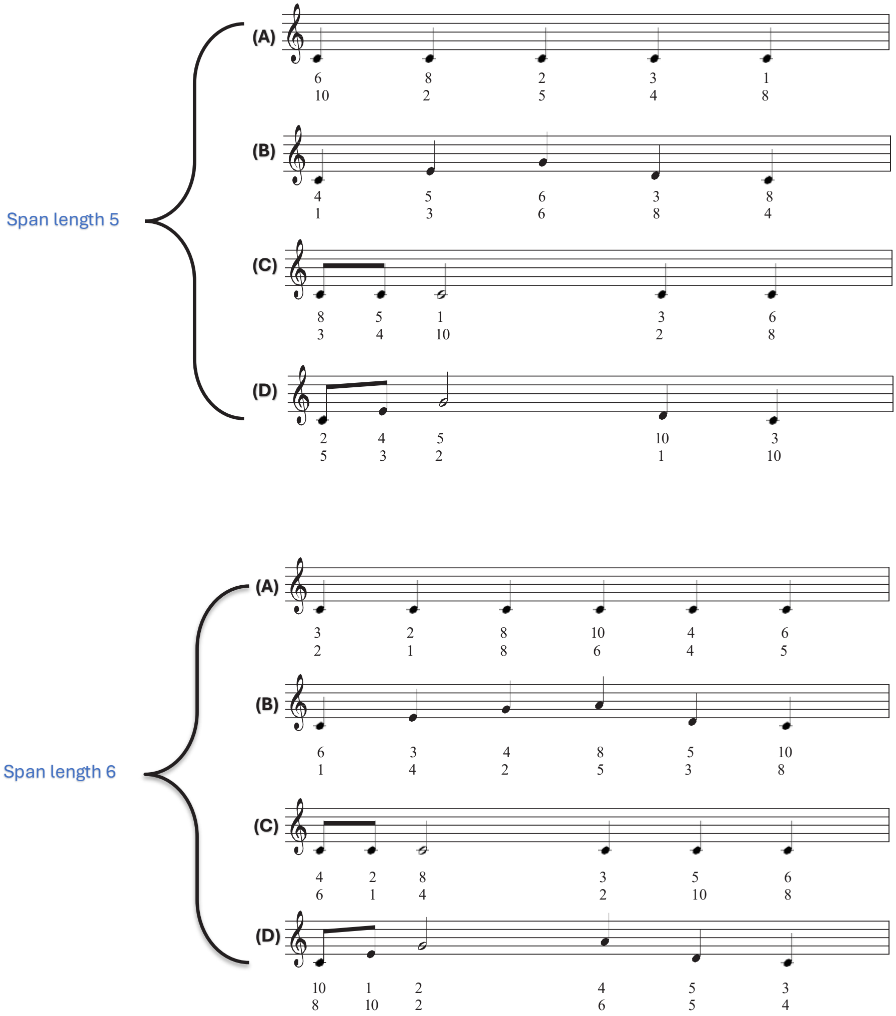
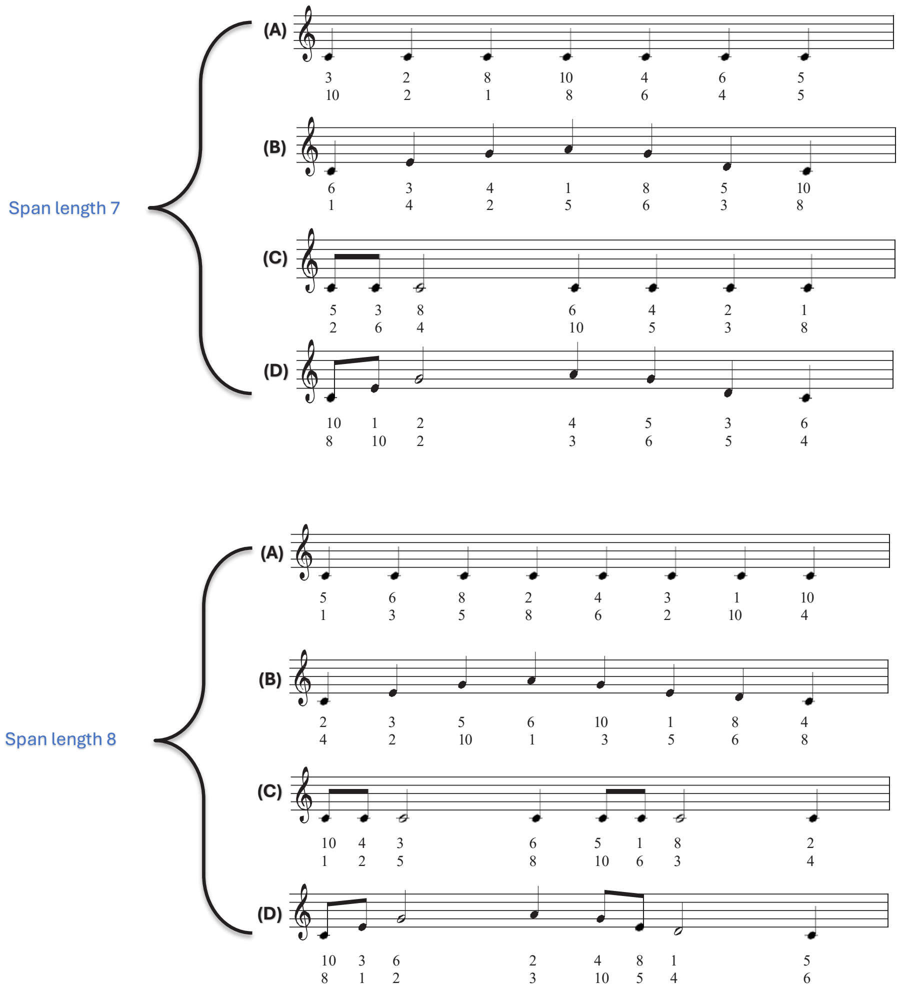


Figure 1.1 Continued



Note. The task starts with two different digit sequences with a length of 5 digits, presented in the four conditions (directly one after the other, with a fixed order in which the four conditions are presented within each participant, although counterbalanced between participants), and then continues with two different digit sequences with a length of 6 digits presented in the four conditions, and so on. The digit sequence length is written in blue next to the accolade at the left. The musical conditions are shown in capital letters, (A) = spoken, (B) = pitch, (C) = rhythm, (D) = melody.

With regard to the musical embedding, that is, the composition of the musical presentation, the method as described by Silverman (2007) is mostly followed. In the spoken condition, the digits are presented ‘as usual’, that is, with a 1 digit-per-second pace, using only quarter notes and with no pitch varying (only C). In the ‘pitch’ condition, the digits are sung to an unfamiliar simple five-tone pitch sequence also using only quarter notes (so isochronously), based on the pitches C, D, E, G and A (C major key, starting on a C, moving upward and returning back to C, pitch intervals where possible restricted to a major third or less, cf. Silverman, 2007). In the ‘rhythm’ condition, the digits are spoken to an unfamiliar rhythmic pattern with varying durations (eighth, quarter, and half notes), with no pitch varying (only C). In the ‘melody’ condition, the digits are sung to an unfamiliar five-tone pitch sequence, with a rhythmic pattern with varying durations added (with the same tonal and rhythmic principles used as in the ‘pitch’ and ‘rhythm’ conditions respectively).

Aims and scope of thesis

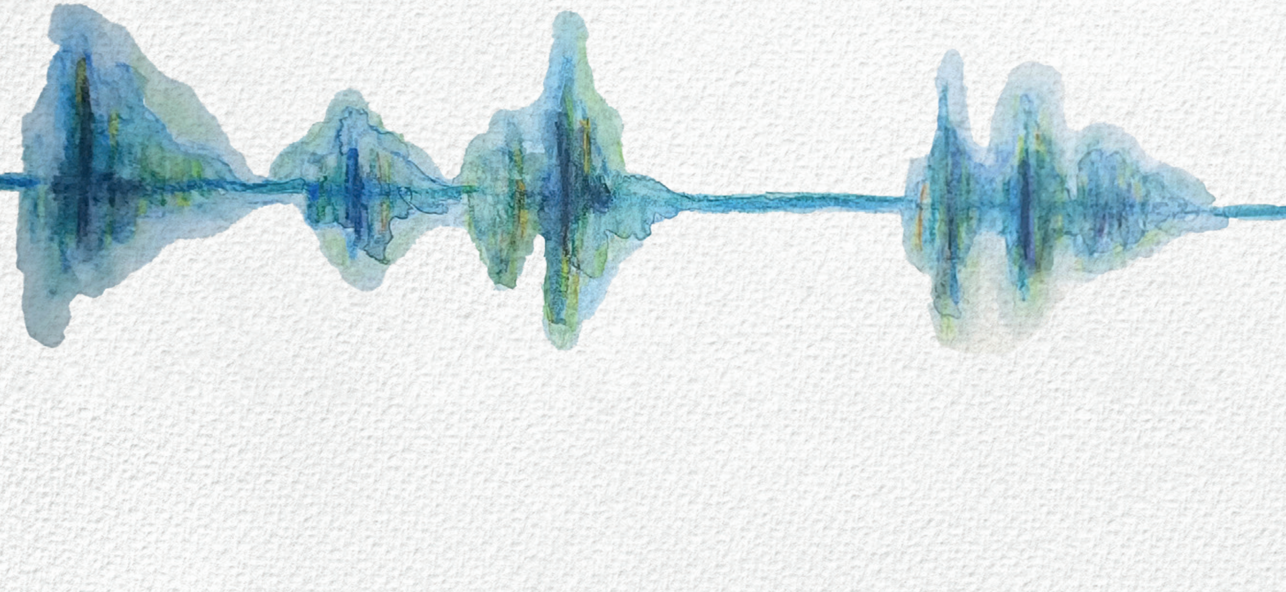
In this dissertation I aim to investigate whether musical mnemonics affect (working and episodic) memory performance in ageing with or without cognitive impairment. I intend to answer these research questions through a systematic review of the literature on the use of music as a mnemonic aid in children, cognitively unimpaired young and older adults, and older adults with cognitive impairment (i.e., MCI and AD). In the empirical studies, I aim to answer whether and how WM performance in cognitively unimpaired young and older adults and persons with aMCI might be enhanced by musical presentation (differently) and whether and how the degree of benefit is possibly moderated by their musical expertise. In general, I hypothesize that cognitively unimpaired younger adults will outperform cognitively unimpaired older adults in their overall performance in general on the musical digit span task (cf. Ratovohery et al., 2018). Similarly, I hypothesize that cognitively unimpaired older adults will outperform individuals with aMCI on the musical digit span task, regardless of the musical condition (cf. Ratovohery et al., 2019).

Chapter 2 addresses the existing literature on effects of musical presentation of verbal information to enhance memory performance, which I studied through conducting a systematic review. The aim of this review was to investigate whether musical mnemonics affect WM and EM performance in cognitively unimpaired children and young adults, and in ageing with(out) cognitive impairment, including persons with MCI or AD. Furthermore, I aimed to answer whether there was a moderating role of musical expertise on degree of benefit of a musical mnemonic. Also, I intended to gain insight into mechanisms through which music as a structural prompt might aid memory performance, and aimed to answer which specific aspects of music play a role in memory enhancement. I will provide a possible theoretical framework, explaining the insights on the effects of musical mnemonics gained. Finally, I intended to elaborate on the implications for the future design of music-based memorization strategies, and to provide reporting guidelines for future research on musical mnemonics and clinical use (e.g., in memory rehabilitation in persons with cognitive impairment including MCI or AD).

Chapter 3 describes an experiment in which the effects of musical presentation of verbal information on WM performance in cognitively unimpaired young versus older adults were investigated. The purpose of this study was to determine whether and how musical mnemonics affect WM performance in both groups (differently), using the novel musical digit span task. Also, I was interested in whether specific aspects of music (i.e., rhythm, pitch, or a combination of rhythm and pitch) would contribute differently to being an effective mnemonic. Lastly, musical expertise was assessed with two perceptual tests (Beat Perception and Melody Memory) and the Self-Report Inventory of the Goldsmiths Musical Sophistication Index v1.0 (Gold-MSI, Müllensiefen et al., 2014). Regarding the effects of musical presentation, I hypothesized that both groups would perform best in the rhythm condition and worst in the conditions including pitch. Furthermore, I hypothesized a relatively larger benefit of rhythm in older adults and diminished performance in the pitch-varying conditions, based on the findings of previous studies and WM theory.

Chapter 4 consists of a follow-up study that builds on the study discussed in chapter 3. In this study the effects of musical mnemonics on WM performance in cognitively unimpaired older adults versus persons with aMCI were assessed. Again, I employed the musical digit span task, this time to investigate whether cognitively impaired persons could also benefit from musical presentation. I was interested whether the same or different musical presentations (i.e., rhythm, pitch, or a combination of both) would lead to optimal benefit in persons with cognitive impairment (i.e., aMCI) as compared to cognitively unimpaired older adults. Finally, musical expertise was again taken into account, as a possible moderating variable with regard to the possible benefits of musical mnemonics. Based on the findings, implications for the future design of music-based memorization strategies in (a)MCI were discussed. Again, I hypothesized that both groups would perform best in the rhythm condition and worst in the pitch and melody conditions. Also, aMCI patients were hypothesized to benefit more from rhythm as compared to OA and to experience faster WM overload in the two conditions with pitch (among others based on expected differences in executive resources as a consequence of their condition).

To conclude, in **Chapter 5**, a summary of the main findings on musical mnemonics is provided and the strengths, limitations, and clinical relevance are discussed. These findings are highlighted from different theoretical perspectives and discussed in the light of the novel theoretical model as presented in the systematic review. Finally, recommendations for future research are given and implications for the future design of music-based mnemonics in therapeutic settings are discussed.



Chapter 2

A novel model on the effects of musical mnemonics on memory performance

---

Published as:
Derks-Dijkman, M. W., Schaefer, R. S., & Kessels, R. P. C. (2024). Musical mnemonics in cognitively unimpaired individuals and individuals with Alzheimer's dementia: A systematic review. *Neuropsychology Review, 34*, 455–477.
https://doi.org/10.1007/s11065-023-09585-4

Abstract

Based on the idea that music acts as a mnemonic aid, musical mnemonics (i.e., sung presentation of information, also referred to as 'music as a structural prompt'), are being used in educational and therapeutic settings. However, evidence in general and patient populations is still scarce. We investigated whether musical mnemonics affect working and episodic memory performance in cognitively unimpaired individuals and persons with Alzheimer's dementia (AD). Furthermore, we examined the possible contribution of musical expertise. We comprehensively searched the PubMed and PsycINFO databases for studies published between 1970 and 2022. Also, reference lists of all identified papers were manually extracted to identify additional articles. Of 1,126 records identified, 37 were eligible and included. Beneficial effects of musical mnemonics on some aspect of memory performance were reported in 28 of 37 studies, including nine on AD. Nine studies found no beneficial effect. Familiarity contributed positively to this beneficial effect in cognitively unimpaired adults, but requires more extensive investigation in AD. Musical expertise generally did not lead to additional benefits for cognitively unimpaired participants, but may benefit people with AD. Musical mnemonics may help to learn and remember verbal information in cognitively unimpaired individuals and individuals with memory impairment. Here, we provide a theoretical model of the possible underlying mechanisms of musical mnemonics, building on previous frameworks. We also discuss the implications for designing music-based mnemonics.

Introduction

There is a popular and long-held belief that music can serve as a mnemonic device by setting information that has to be learned and remembered to music (Moussard et al., 2012; Rainey & Larsen, 2002). The strong statement of Sloboda (1985; p.268) that ‘music is of immense benefit as a mnemonic aid’ has been adopted by various authors (Rainey & Larsen, 2002; Silverman, 2010), and the use of music for the facilitation of memory performance has been called ‘music as a structural prompt’ (Madsen et al., 1975). In educational and therapeutic settings, music has often been paired with social and academic skills to be learned (e.g., Jellison, 1976; Jellison & Miller, 1982; Ludke et al., 2014; Wolfe & Hom, 1993). In primary school, children learn the ABC-song, whereby the alphabet is sung to a familiar melody (i.e., ‘Twinkle, twinkle, little star’), to support the acquisition and recall of letters and their proper order in the alphabet (Jellison, 1976; Wolfe & Hom, 1993). Furthermore, children learn for example to identify body parts by singing the lyrics “Head, shoulders, knees and toes” (Wolfe & Hom, 1993). Others have offered a fun and innovative approach to learning physics through the use of karaoke (Dickson & Grant, 2003). Moussard et al. (2012) asserted that music is also used for other purposes related to memory and association, for example in advertisements on television (e.g., Yalch, 1991). Moreover, more general claims about the effects of music listening and cognitive performance are widespread (e.g., Schellenberg & Weiss, 2013, see also Box 2.1 on the ‘Mozart Effect’). Empirical evidence on the beneficial effects of using musical mnemonics is, however, limited (Rainey & Larsen, 2002), and studies so far have largely been conducted in cognitively unimpaired individuals (Moussard et al., 2012).

Box 2.1

Music and its influence on cognition

The number of publications on the assumed positive effects of music on cognitive functioning has increased considerably after the publication of Rauscher and colleagues (1993), presenting the 'Mozart Effect'. After listening to Mozart's piano sonata K448, the researchers observed a brief improvement in reasoning skills solving spatial problems in cognitively unimpaired individuals. Although the specificity of Mozart's music was subsequently invalidated, and the finding identified as an effect of mood and arousal on cognition (Thompson et al., 2001), various studies evaluating this contextual effect of music (i.e., mere listening) on cognition have been carried out, also using other cognitive tasks, and music of other composers. For example, Mammarella et al. (2007) showed better working memory performance in cognitively unimpaired older adults on digit span tasks after listening to Vivaldi. The mood-arousal hypothesis is also supported by neuroimaging evidence. In an overview of studies using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), Pauwels et al. (2014) argued that listening to pleasurable music, due to evoked emotions, gives higher arousal (among other things in the amygdala and hippocampus and the orbitofrontal cortex, para-hippocampal gyrus and temporal lobes) resulting in temporarily enhanced cognitive performance in multiple domains. While the specific 'Mozart Effect' is now generally considered a neuromyth (MacDonald et al., 2017), it appears that listening to music can indeed affect cognition through arousal mechanisms. However, these studies focused on the contextual (transfer) effects of listening to music before the performance of a cognitive task, which is not the same as the use of musical mnemonics, and thus beyond the scope of this review.

Musical Mnemonics: A possible tool for cognitive rehabilitation in memory-impaired individuals?

The question whether musical mnemonics may have clinical relevance for memory rehabilitation was posed by Moussard et al. (2012) in their case study in a person with mild AD. They reviewed the two only existing studies at the time in participants with memory impairments due to AD (Prickett & Moore, 1991; Simmons-Stern et al., 2010) and showed an advantage of a sung presentation in persons with AD despite methodological or task-specific issues. Simmons-Stern et al. (2010), for example, referred to an anecdote in which the daughter of a person with AD successfully taught her non-musician father about current events through singing the new stories to the melody of a popular song, suggesting that AD non-musicians may also benefit from music. Silverman (2010, 2012) described that prior studies on musical mnemonics focused on familiar types of verbal information (i.e., multiplication tables, phone numbers, random numbers and types of text) and unfamiliar and novel types of verbal information in various populations (i.e., young children, children diagnosed with learning impairment or with cognitive impairment, persons with Multiple Sclerosis (MS), dysphasia, and nursing-home residents with memory loss due to Alzheimer's disease (AD)). However, despite the widespread informal use of music as a mnemonic aid in both general and patient populations, the research on this topic in this patient group is still limited (Simmons-Stern et al., 2010) and there is a clear need for future research to unravel mechanisms through which musical mnemonics might aid episodic memory functioning in AD. Furthermore, research in AD to date has mainly focused on the functioning of long-term episodic musical memory (Moussard et al., 2012, 2014; Simmons-Stern et al., 2010, 2012). To our knowledge, no research was reported on the use of musical mnemonics in working memory paradigms in persons with AD, focusing on the ability to keep information active for a brief period of time in order to manipulate it (Baddeley, 2000), or provide additional structure to allow transition to long-term memory for those with impaired working memory (Rainey & Larsen, 2002).

Music as a mnemonic aid: Possible underlying mechanisms

Music is not a unitary concept, but is made up of diverse components such as melody and rhythm. These and other single or combined components have been identified as possible facilitating aspects of music as a mnemonic aid. When music is used as a mnemonic, rhythm was found to increase the ability to chunk information in order to increase the likelihood of encoding and recall (Silverman, 2012). Schön et al. (2008) concluded that pitch may even be effective without addition of rhythm. Others concluded that the melody, which also includes pitch structure, is more effective than only rhythmical information (Ludke et al., 2014; Wallace, 1994). In addition, the complete musical context has also been identified as a facilitating aspect of music as a memory enhancer. Schellenberg and Moore (1985) for example, found that the complete musical context, including pitch (e.g., scale, mode, contour) and rhythm (e.g., beat, meter) contributed to a meaningful musical context, making a passage easier to learn. They also proposed that pitch and rhythm are two aspects of an interactive system, and that removal of one of these parameters might strongly weaken the meaningful context, or the aiding component. McElhinney and Annett (1996) concluded that the integration of text, melody and rhythm, provided by the musical presentation, could have promoted better organization of information and thus might have enhanced recall. The relevance of the complete context is also supported by the notion of a "joint accent structure" in music (Jones, 1987), that is an integrated combination of the pattern of perceptual accents in pitch, rhythm, and other musical characteristics, that can function as cues for memory by inducing enhanced attention to specific time points in the music. Rainey and Larsen (2002) suggest that a basis to predict successful memory enhancement through music can be derived from research findings on the storing process of the music and lyrics of songs (separately, or integrated in a single representation).

In their review on the effects of music on verbal learning and memory, Ferreri and Verga (2016) discussed several potential mechanisms. First, music may function as a temporal scaffold, thereby selectively directing attention, and thus reinforce and facilitate learning and memory. Next, music enhances arousal and mood, which has been shown to benefit aspects of cognitive function. Finally, music may activate the reward system through induction of emotional responses. Ferreri and Verga (2016) were the first to review studies on the specific benefits of music on verbal learning and memory, dividing them into studies using a 'sung vs. spoken' encoding paradigm or those using background music. They furthermore proposed a model on effects of music on learning and memory in order to explain how different mechanisms might be involved in the previously described paradigms (i.e., sung vs. spoken or background music).

Ferreri and Verga (2016) hypothesized that recruitment of these different cognitive mechanisms (i.e., temporal scaffolding, arousal-mood, emotions-reward) critically depends on the complexity of the musical stimulus such as tempo, mode, arousal, and length, and the experimental paradigm used (sung vs. spoken or background music). This results in either a direct action of the musical stimulus on the verbal material (i.e., temporal scaffolding mechanisms allow anchoring between the verbal and musical stimulus thus resulting in attention direction and possible improvement of memory performance) or, with more complex musical stimuli (e.g., classical background music) in an indirect action via general-purpose mechanisms (attention, arousal-mood, emotions-reward). Finally, Ferreri and Verga (2016) mentioned that their model does not consider familiarity of the melody, but they argued that it possibly could modulate the proposed combined effects of the musical and verbal stimulus.

Emotion and general arousal have also been suggested as possible mechanisms for enhanced verbal memory seen in an AD population (Moussard et al., 2012; Ratovohery et al., 2019). Another notion, put forward by Moussard et al. (2012), is that shared syntactic processes for music and language may aid memory for songs in AD through enhanced connections between the melody and the lyrics. Finally, Ratovohery et al. (2019) also discussed the deeper and richer encoding (Craik & Lockhart, 1972), and the role of the spared musical processing in AD in contrast with language processing deficits. Furthermore, they noted that aspects inherent to music such as complexity, tempo and harmonic structure, may also contribute to the assumed effect of music as a mnemonic aid.

Aim of our systematic review

Here, we examined whether the use of musical mnemonics (i.e., sung presentation of verbal information) leads to enhancement of working and episodic memory performance in both cognitively unimpaired individuals and in patients with AD (in which working or episodic memory impairments typically occur, Kessels et al., 2015; Kirova et al., 2015). We performed a systematic review anticipating that most studies would have small sample sizes, have heterogeneous and varying methodological approaches, and without standardized outcome measures precluding formal quantitative meta-analysis. Also, we explored which aspects of music may be relevant in memory enhancement (e.g., familiarity of the melody) and where possible, also taking into account the effect of musical expertise (i.e., an umbrella term referring to musical background and training of the participants, operationalized in different ways in the included studies, ranging from regular informal music activities to formal music studies or professional musicianship) on degree of benefit of musical mnemonics. We synthesized our findings into a theoretical account of the underlying mechanisms building on the model of Ferreri and Verga (2016), to help set up a framework for future empirical studies to clarify how music (i.e., aspects of the musical stimulus, stimulus complexity, paradigm) could contribute to the processes of memory in terms of encoding, maintenance and retrieval, also taking into account personal aspects (e.g., cognitive ability, musical expertise). Finally, we provided recommendations for future research through a list of guidelines of what specific information future researchers should report regarding the musical and verbal stimulus and for clinical use (e.g., for memory rehabilitation in people with cognitive impairments including mild cognitive impairment (MCI) and AD).

Methods

Search strategy

A systematic search of the literature through the following *information sources*, that is, the PubMed and PsycINFO databases simultaneously, was completed on May 9, 2022, using a *search strategy* with combinations of the following search terms (or truncated versions): 'music', 'working memory', or 'episodic memory', in accordance with the PRISMA guidelines (Page et al., 2021a, b). Because of the limited amount of literature on musical mnemonics, we decided not to narrow the search results in advance by already searching with the search terms MCI and AD. As we did not find studies on musical mnemonics in persons with MCI, we here describe the results in the general population and for those with AD.

Study selection

For this review only original research articles published in scientific journals were selected when the following *eligibility criteria* were met, namely: a) using musical mnemonics in an experimental setting, and b) measuring the performance on a memory test (i.e., a test measuring a specific memory process such as encoding, retrieval or recall) as an outcome measure. Musical mnemonics were defined as a musical presentation (i.e., sung (using pitch) digits or words). Furthermore, when musical expertise (umbrella term referring to musical background and training of the participants, ranging from regular informal music activities to formal music studies or professional musicianship, specified in various ways in different papers) was included as a covariate these results were also reviewed. Reviews (or articles) not containing original data, studies not published in English, studies published before 1970, studies concerning music therapy not specifically aimed at remembering verbal material, or using music as a context, studies on evoked musical autobiographical memories, studies on tonal working memory, patient studies that did not focus on MCI or AD, and animal studies were excluded. Regarding the *selection process*, first, these criteria were examined by careful screening of the titles and abstracts by one author (MWD, with assistance from RPCK). Subsequently the full-text papers were screened to assess whether they met our inclusion criteria by one author (MWD, with help from RPCK). For each identified paper in the review, the reference list was also manually extracted to identify additional articles. Finally the reference lists of the additional articles were also manually extracted to identify additional articles by one author (MWD, with assistance from RPCK). The *data collection process* consisted of collection of the data from the included reports by one author (MWD) with critical input from RS and RPCK. No tools on *study risk of bias assessment* were used.

Data-analysis

For each paper only the paradigms of interest (i.e., comparing the performance on a verbal memory test after musical vs. spoken presentation as *data items*) were considered in accordance with our inclusion criteria (for instance, when papers reported multiple experiments) and the corresponding *effect sizes* were recorded. We collected data on the report (e.g., author, year), participant characteristics (i.e., population, number of participants and age (mean and standard deviation/range), musical expertise) and the research design (item characteristics, i.e., materials for memorization and musical stimulus embedding (paradigm, learning phase and testing phase), and memory domain). If data were missing (for example regarding age), this was noted with 'not reported' (N.R.)(See Table 2.1). For the studies included in which effect sizes were not reported, effect sizes (Cohen's *d*) were computed based on the available data comparing the intervention (i.e., sung) versus control (e.g., spoken or for example rhythmically spoken) conditions. Furthermore, when other effect sizes or statistics were reported, we converted them into Cohen's *d*, where possible, using available calculators (Lakens, 2013; Lenhard & Lenhard, 2016; Lin, n.d.; Lipsey & Wilson, 2001; Uanhoro, 2017). We interpreted Cohen's *d* in line with common guidelines (i.e., 0.2, small; 0.5, medium; 0.8 large) (Cohen, 1992). The study effect sizes are listed in Table 2.1. If possible, the effect sizes were averaged across sub-experiments, but when different paradigms were used within a study for different sub-experiments, the effect sizes were calculated separately.

Results

Study characteristics

The search resulted in a total of 1,126 articles published between 1971 and 2022. A total of 1,091 articles were excluded after reviewing the titles and abstracts for eligibility. Full-text articles were retrieved for 35 studies, 14 of which were eligible for inclusion. Forty-seven additional studies were assessed after searching the reference lists, of which 17 additional articles were eligible for inclusion. Finally, fourteen additional studies were assessed after searching the references lists of the additional studies included, of which six articles were eligible for inclusion, which resulted in a total of 37 included papers.

Table 2.1

Characteristics of the studies examining effects of music on memory functioning

Article	**Participant characteristics**				**Item characteristics**
	Population	***N* of participants**	**Age *M* (*SD*) [Range]**	**Musical expertise**	**Materials for memorization**
Baird et al., 2017	AD	5	79.0 (11.1)	Mu	Sentences: day, time, task
		6	72.5 (7.7)	NMu	
	OA	15	74.9 (7.3)	Mu	
		7	70.0 (1.6)	NMu	
Calvert & Billingsley, 1998	Exp. 2: Ch	39	4.7	N.R.	Exp. 2: Telephone number
Calvert & Tart, 1993	Exp. 2: YA	28	19.6	N.R.	Prose
Chazin & Neuschatz, 1990	Ch	26	8	N.R.	Mineral names
	YA	20	[18-21]		
Deason et al., 2012	OA	12	76.3 (7.7)	NMu ME (y/n)	Lyrics
Gfeller, 1983	Ch	30	9-11	N.R.	Multiplication tables
	Ch learning impairment	30	9-11		
Good et al., 2015	Spanish-speaking Ch	38	9-13	Some ME	Novel English song lyrics
Jellison, 1976	YA	34	N.R.	ME/NME (17/17)	Digit span
Jellison & Miller, 1982	YA	46	N.R.	ME/NME (23/23)	Digit span Word span and/or pitch sequences
Kilgour et al., 2000	YA	Exp. 1: 78	19.8 (3.2)	ME/NME (39/39)	Lyrics
		Exp. 2: 40	20.4 (3.2)		
		Exp. 3: 120	19.3 (2.4)		

Item characteristics			Memory domain	Summary music effect	Effect sizes (Cohen's *d*)
Musical stimulus embedding					
Paradigm	**Learning phase**	**Testing phase**			
	Familiarity	**Modality**			
Sung vs. spoken	F	Spoken + passive Re	EM	M- AD NMu	-0.84
				ME+ AD	0.99
Exp. 2: Sung / prose / combination	Exp. 2: UF	Exp. 2: Spoken	WM	Exp. 2: M-	-1.24
Sung vs. spoken	F	Written	WM & EM	Exp. 2: M= SE STR & LTR	0.17
				Exp. 2: M+ RE STR & LTR	1.63
Sung vs. spoken	F	Written	WM & EM	M+ IR	0.60
				M= DR	0.00
Sung vs. spoken	UF	Passive Re	EM	M=	0.69
Sung vs. spoken	UF	Written	WM	M- SR	-0.48
				M+ ER	1.72
Sung (Acc guitar) vs. spoken poem	F (UF repetition)	Sung or spoken	EM	M+ IR	1.84
				M+ IT	0.77
				M+ IP	1.86
				M+ DR	1.92
				M= DT	0.96
Sung vs. spoken	UF	Written	WM	M+	1.22
				ME+	0.87
Sung vs. spoken	UF	Sung or spoken	WM	M- DS	I.D.
				M= WS	I.D.
Exp. 1: Sung vs. sung with piano prelude or spoken	UF	Spoken	EM	Exp. 1: M+ IR & DR	0.75
Exp. 2: Sung vs. spoken equated presentation rate				Exp. 2: M-	-0.81
Exp. 3: Sung vs. spoken slow, medium or fast presentation rate				Exp. 3: M-	-0.32

Table 2.1

Continued

Article	Participant characteristics				Item characteristics
	Population	***N* of participants**	**Age *M* (*SD*) [Range]**	**Musical expertise**	**Materials for memorization**
Lehmann & Seufert, 2018	YA	108	16.2 (1.3) [12-19]	ME NGD	Six rhymed verses and a refrain
Ludke et al., 2014	YA	60	21.7 [18-29]	N.R.	PAP English & Hungarian
Ma et al., 2020	YA	42	19.3 [17-22]	NMu	Chinese words
McElhinney & Annett, 1996	YA	20	21.9	N.R.	Lyrics
Moussard et al., 2012	Mild AD	1	68	NMu	Lyrics
Moussard et al., 2014	AD	8	77.8 (5.2)	NMu	Lyrics
	OA	7	75.7 (7.4)		
Oostendorp & Montel, 2014	AD	21	N.R.	N.R.	Word list
Palisson et al., 2015	AD	12	82.8 (8.9)	ME NGD (high ME excluded)	Text
	OA	15	77.1 (7.2)		
Prickett & Moore, 1991	AD	10	75 [69-87]	N.R.	Life-long F material (songs/ psalm) vs. first presented material
Purnell-Webb & Speelman, 2008	YA	Exp. 1: 100	17-52	ME NGD	Poetry verses
Racette & Peretz, 2007	YA	Exp. 1: 36	25 [20-37]	ME/NME (18/18)	Lines French folksongs

Item characteristics			Memory domain	Summary music effect	Effect sizes (Cohen's *d*)
Musical stimulus embedding					
Paradigm	Learning phase	Testing phase			
	Familiarity	Modality			
Sung (accompanied by monophonic piano) vs. spoken or visual	UF	Spoken + C	EM	M− R (vs. visual)	-0.78
				M= R (vs. spoken)	I.D.
				M+ C (vs. visual)	0.40
				M= C (vs. spoken)	I.D.
Sung vs. spoken or rhythmic spoken	UF	Spoken + Passive Re	EM	M+ IR & DR	0.49
Sung vs. spoken (IDS or ADS)	UF/F	Passive Re	EM	M+ WL (vs. ADS) Sung = IDS	0.64
				M+ DR (vs. ADS) Sung = IDS	0.47
Sung vs. spoken	UF	Written	EM	M= SE	0.56
				M+ RE (trial 2 & 3)	2.15
Sung vs. spoken	UF/F	Sung or spoken	EM	M- IL UF	I.D.
				M+ RL UF + F	I.D.
Sung vs. spoken	UF/F	Sung or spoken	EM	M= IR	I.D.
				M+ DR: OA F AD UF + F	I.D.
Sung vs. spoken	F	Sung or spoken	EM	M+ CR & FR	I.D.
Sung melody + IA vs. spoken/SME	F	Spoken	EM	M+ IR (vs. spoken)	1.13#
				M+ IR (vs. SME)	0.87#
				M+ DR (vs. spoken)	0.78#
				M+ DR (vs. SME)	0.30#
Sung vs. spoken/ rhymed speech	UF/F	Sung and spoken	EM	M+*	I.D.
Sung (F/UF melody/ unknown/ known Rhy) vs. spoken	UF/F	Written	EM	Exp. 1: M+ Rhy	I.D.
Sung vs. spoken (melody in background)	UF	Sung (on melody) or spoken (lyrics alone)	EM	Exp. 1: IR & DR M=	0.31

Table 2.1

Continued

Article	Participant characteristics				Item characteristics
	Population	***N* of participants**	**Age *M* (*SD*) [Range]**	**Musical expertise**	**Materials for memorization**
Rainey & Larsen, 2002	Exp. 1: YA	79	19.7	N.R.	Names sport players
	Exp. 2: YA	102	19.5		Fictional names
Ratovohery et al., 2018	YA	24	22.8 (2.0)	ME NGD	Text
	OA	30	75.5 (6.9)		
Ratovohery et al., 2019	AD	13	77.9 (8.1)	LME	Text everyday life
	OA	26	77.1 (8.2)		
Rukholm et al., 2018	YA	66	[17-30+]	N.R.	Lyrics
Schön et al., 2008	Exp. 1: YA	26	23	NMu	Nonsense words
	Exp. 2: YA	26	23		
	Exp. 3: YA	26	23.5		
Silverman, 2007	YA	120	N.R.	ME/NME (72/48)	Digit span
Silverman, 2010	YA	60	N.R.	ME/NME (30/30)	Digit span
Silverman, 2012	YA	60	N.R.	ME/NME (30/30)	Digit span
Silverman & Schwartzberg, 2014	YA	60	22.9 (5.8)	ME (30)	Digit span
			21.1 (3.0)	NME (30)	
Silverman & Schwartzberg, 2019	YA	60	N.R.	ME/NME (30/30)	Digit span
Simmons-Stern et al., 2010	AD	13	77.3 (7.6)	NMu + ME (y/n)	Lyrics excerpts
	OA	14	73.7 (5.5)		

Item characteristics			Memory domain	Summary music effect	Effect sizes (Cohen's *d*)
Musical stimulus embedding					
Paradigm	**Learning phase**	**Testing phase**			
	Familiarity	**Modality**			
Sung +/- PA vs. spoken	F	Spoken	EM	Exp. 1: M= IL	0.06
				Exp. 1: M+ RL	0.47
Sung vs. spoken/ visual presented				Exp. 2: M= IL (vs. spoken)	0.44
				Exp. 2: M+ RL	1.43
Sung on melody of instrumental music (PV/NV) vs. spoken	F	Spoken	EM	M+ PV OA (IR & DR (10m & 24h)	0.56
Sung on melody of instrumental music (PV/NV) vs. spoken	F	Spoken	EM	M+ AD (Encoding & IR & DR (10m &24h)	1.14
Sung vs. spoken (poem) & amount of elaboration (LE/HE)	F	Written	EM	M+ HE receptive learning	I.D.
				M+ HE productive learning	I.D.
Exp. 1: Spoken	UF	Passive Re	EM	M+ Exp. 2 vs. Exp. 1	1.45
Exp. 2: Sung (constant syllable-pitch matching)				M+ Exp. 3 vs. Exp. 1	0.72
Exp. 3: Sung (variable syllable-pitch mapping)					
Sung vs. spoken (Pitch/Rhy/Pitch & Rhy)	UF	Written	WM	M+	0.71
Sung (Pitch/Rhy/Pitch & Rhy)	UF/F	Written	WM	M+ Rhy > Pitch, Pitch & Rhy	0.67†
Sung (Melodic complexity/ Rhy/NRhy)	UF	Written	WM	M+ Rhy > NRhy	1.57†
Sung (Fe/M voice) & NA/ Acc (piano, guitar)	UF	Written	WM	M+ M > Fe voice,	0.58†
				M+ piano, N Acc > guitar	1.01†
Sung (V + Au/Au) vs. Spoken (V + Au/Au) vs. Melody (V + Au/Au)	UF	Written	WM	V+ Au: M+ Sung	0.55
				V+ Au: M+ Melody	0.47
Sung vs. spoken	UF	Passive Re	EM	M+ AD	1.07
				M= OA	0.35

Table 2.1

Continued

Article	**Participant characteristics**				**Item characteristics**
	Population	***N* of participants**	**Age *M* (*SD*) [Range]**	**Musical expertise**	**Materials for memorization**
Simmons-Stern et al., 2012	AD	12	81.2 (4.0)	ME NGD	Novel lyrics
	OA	12	78.6 (8.7)		
Tamminen et al., 2017	Students/ staff	Exp. 1: 39	21	NMu	Novel words
		Exp. 2: 39	21		
		Exp. 3: 39	20		
Wallace, 1994	Exp. 1: YA	64	N.R.	Some ME	Text
	Exp. 2: YA	21	N.R.		
	Exp. 3: YA	39	N.R.		
	Exp. 4: YA	48	N.R.		
Wolfe & Hom, 1993	Ch	10	5	N.R.	Telephone numbers
Yalch, 1991	Exp. 2: YA	124	N.R.	N.R.	Exp. 2: Soundtrack television commercials

Notes. Articles listed in alphabetical order. If the effect concerned both groups this is not specified, if an effect concerned one of the groups this is separately mentioned in the 'summary of music effect' column. Positive effect sizes indicate an advantage of the condition of interest versus spoken (unless otherwise specified†). Abbreviations in alphabetical order: Acc = accompaniment; AD = Alzheimer's dementia; ADS = adult directed speech; AR = aided recall; Au = auditory; C = comprehension; Ch = children; CR = cued recall; DM = different melodies; DR = delayed recall; DS = digit span; DT = delayed translation; EM = episodic memory; ER = extended rehearsal; Exp. = experiment; F = familiar; Fe = female; FR = free recall; GC = general content; HE = high elaboration; IA = instrumental accompaniment; I.D. = insufficient data reported to compute the (parametric) effect size; IDS = infant directed speech; IL = initial learning; IML = integration mental lexicon; IP = immediate production; IR = immediate recall; IT = initial translation; L = learning; LE = low elaboration; LME = low musical expertise; M = male;

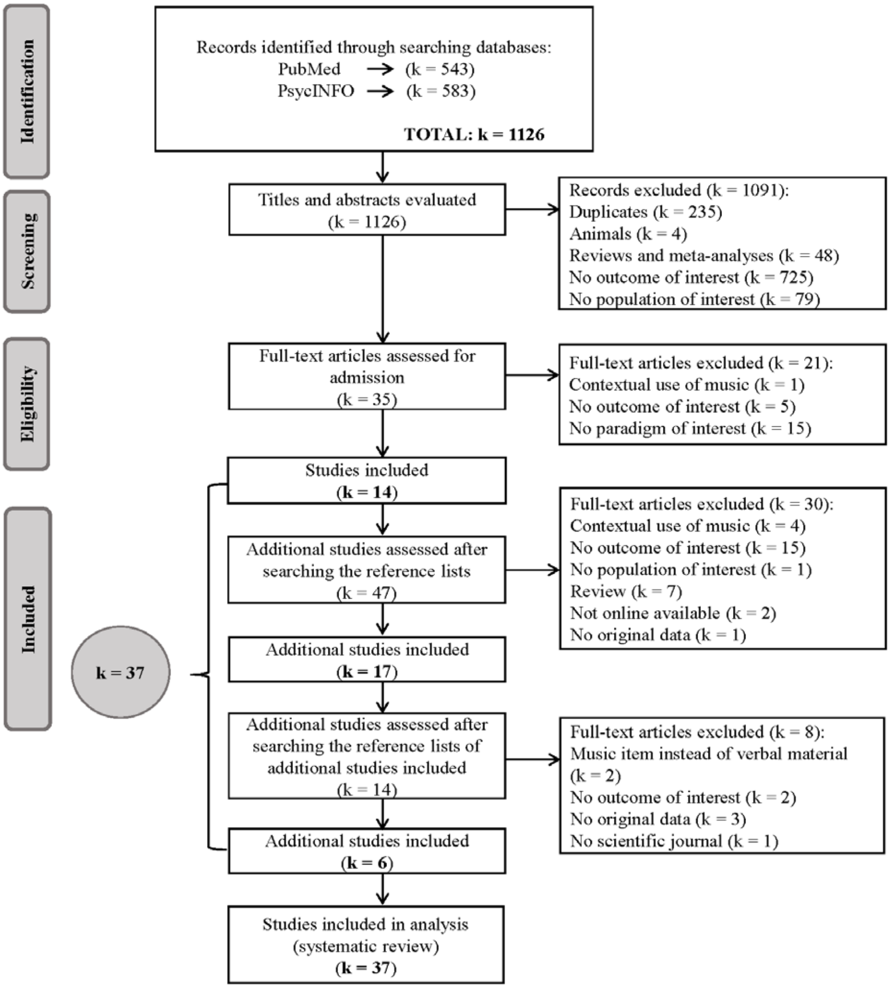
Item characteristics			Memory domain	Summary music effect	Effect sizes (Cohen's *d*)
Musical stimulus embedding					
Paradigm	**Learning phase**	**Testing phase**			
	Familiarity	**Modality**			
Sung vs. spoken	UF	Passive Re	EM	M+ GC	0.80
				M= SC	0.00
Exp. 1: Spoken	UF/F	Spoken & passive measures	EM	M= R Exp. 2 & 3 vs. Exp. 1	I.D.
Exp. 2: Sung UF				M= Re Exp. 2 & 3 vs. Exp. 1	I.D.
Exp. 3: Sung F				M+ IML F Exp. 3 vs. Exp. 1	0.70
Exp. 1: 3 vs Sung (OM) vs. spoken	UF	Written	EM	Exp. 1: M+	1.11
Exp. 2: 3 vs Sung (OM) vs. rhythmic spoken				Exp. 2: M+	0.54
Exp. 3: 1 vs Sung vs. spoken				Exp. 3: M-	-0.60
Exp. 4: 3 vs Sung (OM) vs. 3 vs Sung (DM) vs. spoken				Exp. 4: M+	0.83
Sung vs. spoken with(out) contingent music)	UF/F	Spoken	WM & EM	M+ L	1.00
				M= IR	I.D.
				M= Ret	I.D.
Exp. 2: Jingle vs. no jingle Number of exposures	N.R.	AR & Passive Re	EM	Exp. 2: M+ AR & Re	1.21

ME = musical expertise; ME+ = musical experts perform better on a sung presentation than persons with less musical expertise; Mu = musicians; M= = no difference between a sung or spoken presentation; M- = sung < spoken; M+ = sung > spoken; *N* = number of participants; NA = no accompaniment; NGD = no group differences; NME = no musical expertise; NMu = non-musicians; NV = negative valence; N.R. = not reported; NRhy = no rhythm; OA = (cognitively unimpaired) older adults; OM = one melody; PA = piano accompaniment; PAP = paired associate phrases; PV = positive valence; R = recall; Re = recognition; RE = repeated exposure; Ret = retention; RL = relearning; Rhy = rhythm; SC = specific content; SE = single exposure; SME = silent movie excerpts; SR = single rehearsal; UF = unfamiliar; V = visual; vs = verses; vs. = versus; WL = word learning; WM = working memory; WS = word span; YA = (cognitively unimpaired) young adults; # = Hedges'*g;* * = for this study the content of the verbal information differed across conditions.

Figure 2.1 depicts the flowchart of this search. Regarding the *results of the individual studies*, Table 2.1 shows the characteristics of the included papers (see also Supplementary Table 2.1 [Appendix A], which provides more detailed information about the differences in learning phase, as well as a more elaborate description of the included studies).

Figure 2.1

Flowchart of literature search



Note. This flowchart represents the search completed on May 9, 2022. k = number of studies.

Participant characteristics

Twenty studies regarding the use of music as a mnemonic aid were performed in young adults (see Table 2.1 for the demographic variables, including age) (Calvert & Tart, 1993; Jellison, 1976; Jellison & Miller, 1982; Kilgour et al., 2000; Lehmann & Seufert, 2018; Ludke et al., 2014; Ma et al., 2020; McElhinney & Annett, 1996; Purnell-Webb & Speelman, 2008; Racette & Peretz, 2007; Rainey & Larsen, 2002; Rukholm et al., 2018; Schön et al., 2008; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019; Wallace, 1994; Yalch, 1991), one study used students and university staff (Tamminen et al., 2017), and five studies were conducted in children (aged 4–13) (Calvert & Billingsley, 1998; Chazin & Neuschatz, 1990; Gfeller, 1983; Good et al., 2015; Wolfe & Hom, 1993). One of these compared learning-impaired elementary school children (with reading, math or written language difficulties) and typically developing children (Gfeller, 1983) and one included elementary school children and young adults (Chazin & Neuschatz, 1990).

In total, eight studies included cognitively unimpaired older adults (all aged above 65). Two of these studies focused only on cognitively unimpaired older adults (Deason et al., 2012; Ratovohery et al., 2018), and six studies on AD had a control group consisting of cognitively unimpaired older adults (Baird et al., 2017; Moussard et al., 2014; Palisson et al., 2015; Ratovohery et al., 2019; Simmons-Stern et al., 2010, 2012).

Nine studies regarding the use of music as a mnemonic aid have been conducted in persons diagnosed with AD (Baird et al., 2017; Moussard et al., 2012, 2014; Oostendorp & Montel, 2014; Palisson et al., 2015; Prickett & Moore, 1991; Ratovohery et al., 2019; Simmons-Stern et al., 2010, 2012). No studies on musical mnemonics in persons with MCI were found.

Materials for memorization

In all of the studies, participants were asked to remember verbal information. When working memory was assessed, researchers used digit span paradigms (Jellison, 1976; Jellison & Miller, 1982; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019), word span tasks (Jellison & Miller, 1982), multiplication tables (Gfeller, 1983), mineral names (Chazin & Neuschatz, 1990), and a telephone number (Calvert & Billingsley, 1998; Wolfe & Hom, 1993).

When episodic memory was assessed, studies used novel types of information such as fictional names (Rainey & Larsen, 2002), nonsense words (Schön et al., 2008; Tamminen et al., 2017), word lists (Oostendorp & Montel, 2014), ballad verses (Wallace, 1994), text (Palisson et al., 2015), poetry verses (Purnell-Webb & Speelman, 2008), excerpts of unfamiliar folk songs (Racette & Peretz, 2007), lyrics (Deason et al., 2012; Kilgour et al., 2000; McElhinney & Annett, 1996; Moussard et al., 2012, 2014), lyrics excerpts (Simmons-Stern et al., 2010), novel lyrics about activities of daily living (Simmons-Stern et al., 2012), sentences relevant to daily life of older adults (Baird et al., 2017), text about everyday themes (Ratovohery et al., 2018, 2019), a foreign language (Good et al., 2015; Ludke et al., 2014; Ma et al., 2020; Rukholm et al., 2018), lifelong familiar material in comparison to firstly presented material (Prickett & Moore, 1991), advertisement slogans (Yalch, 1991), and prose (Calvert & Tart, 1993).

Musical stimulus embedding

Almost all studies compared a sung versus spoken (or combined) presentation of stimuli, but considerable differences exist between the different paradigms. In the majority of research, the participants took part on an individual basis (except in the studies of Calvert & Tart, 1993; Calvert & Billingsley, 1998; Good et al., 2015; Lehmann & Seufert, 2018; McElhinney & Annett, 1996; Rukholm et al., 2018, and Yalch, 1991, who used (small) groups). Most research (except the studies by Good et al., 2015; Oostendorp & Montel, 2014; Prickett & Moore, 1991, and Wolfe & Hom, 1993) used prerecorded sound files of male or female singers, with sufficient experience in singing or professional singers. In most of the paradigms, at encoding, participants only listened to a musical presentation of information, but in some studies they actively participated by singing the to-be-learned information themselves (e.g., Chazin & Neuschatz, 1990; Good et al., 2015; Oostendorp & Montel, 2014; Prickett & Moore, 1991). Some researchers compared a rhythmical, melodic or combined presentation to a spoken presentation (e.g., Ludke et al., 2014; Purnell-Webb & Speelman, 2008; Silverman, 2007, 2010; Wallace, 1994). Six studies considered or matched the presentation rate of sung or spoken material (Baird et al., 2017; Good et al., 2015; Kilgour et al., 2000; Lehmann & Seufert, 2018; Ludke et al., 2014; Ma et al., 2020). In several studies the verbal material was presented bimodally at encoding (i.e., visually and auditory), for example in the study of Rainey and Larsen (2002). Others used also visually presented text accompanied by a sung or spoken presentation (Calvert & Billingsley, 1998; Calvert & Tart, 1993; Deason et al., 2012; Good et al., 2015; Ma et al., 2020; Ratovohery et al., 2018, 2019; Rukholm et al., 2018; Simmons-Stern et al., 2010, 2012). Silverman and Schwartzberg (2019) compared a visual and auditory versus only auditory presentation. Lehmann and Seufert (2018) compared learning of a text in three modalities (i.e., visual, sung or spoken).

Other aspects of the musical stimulus embedding that have been considered are melodic complexity, variable vs. constant syllable mapping, vocalization type, voice timbre (male/female) and type of instrumental accompaniment, musical valence, i.e., the emotional value of music (positive or negative affect), and the familiarity of the melodies (Ludke et al., 2014; Ma et al., 2020; Ratovohery et al., 2018, 2019; Schön et al., 2008; Silverman, 2012; Silverman & Schwartzberg, 2014).

Some authors systematically investigated the effect of familiarity of the melody (Ma et al., 2020; Moussard et al., 2012, 2014; Prickett & Moore, 1991; Purnell-Webb & Speelman, 2008; Silverman, 2010; Tamminen et al., 2017; Wolfe & Hom, 1993). Other researchers only used unfamiliar melodies (Deason et al., 2012; Gfeller, 1983; Jellison, 1976; Jellison & Miller, 1982; Kilgour et al., 2000; Lehmann & Seufert, 2018; Ludke et al., 2014; McElhinney & Annett, 1996; Racette & Peretz, 2007; Schön et al., 2008; Silverman, 2007; Silverman & Schwartzberg, 2014; Simmons-Stern et al., 2010, 2012; Wallace, 1994). Finally, some studies only used familiar music (Baird et al., 2017; Calvert & Tart, 1993; Chazin & Neuschatz, 1990; Good et al., 2015; Palisson et al., 2015; Rainey & Larsen, 2002; Ratovohery et al., 2018, 2019; Rukholm et al., 2018) or used a previously learned melody (Oostendorp & Montel, 2014).

In the vast majority of studies participants were tested through spoken or written recall. Jellison and Miller (1982) and Good et al. (2015) gave their participants the choice if they wanted to sing or speak at recall. Some researchers instructed their participants to recall the material preferably in the same modality (i.e., sung or spoken) as they learned the material (Moussard et al., 2012, 2014) following the encoding-specificity principle (i.e., how information can be retrieved depends on how it was stored) (Tulving & Thomson,1973). Some authors investigated different combinations of modalities of learning (sung versus spoken) and recall (sung versus spoken) (Ludke et al., 2014; Racette & Peretz, 2007). Finally, Lehmann and Seufert (2018) also studied the effect of listening to the previously learned melody while recalling the to-be-learned text.

Memory domain

Nine studies focused on working memory (Calvert & Billingsley, 1998; Gfeller, 1983; Jellison, 1976; Jellison & Miller, 1982; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019). Of these, Calvert and Billingsley (1998) focused on working memory in pre-school children and Gfeller (1983) focused on elementary school children, while all others focused on young adults. No studies on the effects of a musical presentation on working memory conducted in cognitively unimpaired older adults or persons with MCI or AD were found.

Three studies focused on working memory as well as on episodic memory (Calvert & Tart, 1993; Chazin & Neuschatz, 1990; Wolfe & Hom, 1993). Sixteen of the 25 studies on episodic memory focused on cognitively unimpaired participants (Deason et al., 2012; Lehmann & Seufert, 2018; Good et al., 2015; Kilgour et al., 2000; Ludke et al., 2014; Ma et al., 2020; McElhinney & Annett, 1996; Purnell-Webb & Speelman, 2008; Racette & Peretz, 2007; Rainey & Larsen, 2002; Ratovohery et al., 2018; Rukholm et al., 2018; Schön et al., 2008; Tamminen et al., 2017; Wallace, 1994; Yalch, 1991), of which two focused specifically on episodic memory in older adults without cognitive impairment (Deason et al., 2012; Ratovohery et al., 2018). The other nine included persons diagnosed with AD (Baird et al., 2017; Moussard et al., 2012, 2014; Oostendorp & Montel, 2014; Palisson et al., 2015; Prickett & Moore, 1991; Ratovohery et al., 2019; Simmons-Stern et al., 2010, 2012). Most studies used immediate and recall measures, a few researchers used recognition measures (Deason et al., 2012; Ma et al., 2020; Schön et al., 2008; Simmons-Stern et al., 2010, 2012), and some both (Baird et al., 2017; Tamminen et al., 2017; Yalch, 1991). Some authors used both free and cued recall measures (Oostendorp & Montel, 2014). Finally, some authors also included comprehension measures (Lehmann & Seufert, 2018).

Synthesis of findings

Overall, 28 out of 37 studies found that a musical (i.e., sung) presentation had a beneficial effect on some aspect of memory performance (seven out of nine studies concerning working memory: Gfeller, 1983; Jellison, 1976; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019, and twenty-one out of 28 studies concerning episodic (or working and episodic) memory: Calvert & Tart, 1993; Chazin & Neuschatz, 1990; Good et al., 2015; Ludke et al., 2014; Ma et al., 2020; McElhinney & Annett, 1996; Moussard et al., 2012, 2014; Oostendorp & Montel, 2014; Palisson et al., 2015; Prickett & Moore, 1991; Purnell-Webb & Speelman, 2008; Rainey & Larsen, 2002, Ratovohery et al., 2018, 2019; Rukholm et al., 2018; Schön et al., 2008; Simmons-Stern et al., 2010, 2012; Wallace, 1994; Yalch, 1991).

However, some of these authors did not find an effect on other aspects of the included measures (Calvert & Tart, 1993; Chazin & Neuschatz, 1990; Good et al., 2015; McElhinney & Annett, 1996; Moussard et al., 2014; Rainey & Larsen, 2002; Simmons-Stern et al., 2012; Yalch, 1991), participant groups (Simmons-Stern et al., 2010), or even a partly detrimental effect (Gfeller, 1983; Moussard et al., 2012; Wallace, 1994).

Nine studies did not find overall effects of a musical presentation on memory performance (working memory: Calvert & Billingsley, 1998; Jellison & Miller, 1982, episodic memory: Baird et al., 2017; Deason et al., 2012; Lehmann & Seufert, 2018; Kilgour et al., 2000; Racette & Peretz, 2007; Tamminen et al., 2017; Wolfe & Hom, 1993). As before, some of these authors did however find positive effects in a part of their experiments (Calvert & Billingsley, 1998; Kilgour et al., 2000) or in other cognitive measures (Lehmann & Seufert, 2018; Tamminen et al., 2017; Wolfe & Hom, 1993) and in comparison to another control condition than spoken presentation (Lehmann & Seufert, 2018). Finally here too, some authors found a detrimental effect in a part of their experiments (Calvert & Billingsley, 1998; Jellison & Miller, 1982; Kilgour et al., 2000) or in a part of the participant groups (Baird et al., 2017). Thus, in general beneficial effects of musical mnemonics on some aspect of memory performance were reported in children, young and older adults with and without memory impairment, however a minority of studies found no overall effect. In the following sections, these results are discussed in more detail, starting with the results summarized by participant population (children, cognitively unimpaired young adults, older adults, AD, musical expertise of the participants) followed by discussion of the results summarized by aspects of the musical stimulus embedding (i.e., melody, rhythm, participation at encoding, familiarity, and other variables) (see also Table 2.1 and Supplementary Table 2.1 [Appendix A] for more details about specific effects of the included studies).

Children and cognitively unimpaired young adults

Twenty-eight studies focused on cognitively unimpaired participants. Five studies conducted in children showed mixed results concerning different stages of memory; Gfeller (1983) found that musical rehearsal together with modelling and cueing significantly aided retention of sung information in both typically developing and learning-impaired students. Chazin and Neuschatz (1990) found only a benefit at immediate recall of musically presented mineral names; Wolfe and Hom (1993) found that a sung presentation of a telephone number at initial learning resulted in fewer learning trials in young children, however, Calvert and Billingsley (1998) found in one of two experiments that young children remembered their telephone numbers best when presented in prose relative to a song. Good et al. (2015) found that Spanish-speaking children (aged 9–13) who learned a novel sung English passage for two weeks, outperformed children who learned the passage presented as an oral poem (i.e., on verbatim recall, pronunciation, translation). Furthermore, the recall advantage of the sung presentation still existed at very long-term recall (six months). Most of the studies performed in young adults found a significant effect of a musical presentation of information to enhance aspects of memory performance (Calvert & Tart, 1993; Jellison, 1976; Ludke et al., 2014; Ma et al., 2020; McElhinney & Annett, 1996; Purnell-Webb & Speelman, 2008; Rukholm et al., 2018; Schön et al, 2008; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019; Wallace, 1994; Yalch, 1991). Rainey and Larsen (2002) found no significant effect at initial learning; however, they did find that relearning the word list a week later required fewer trials in the sung version.

Others found no significant effect (Jellison & Miller, 1982; Racette & Peretz, 2007; Tamminen et al., 2017), or a partly detrimental effect (Jellison & Miller, 1982, only for digit span). Kilgour et al. (2000) initially found an effect of a sung presentation which reversed after controlling for presentation rate. Tamminen et al. (2017) on the other hand, failed to find effects on memory but did find effects of a sung presentation on learning. In line with this, Lehmann and Seufert (2018) also did not find any effects of sung versus spoken presentation on text recall, but only demonstrated an effect on comprehension (sung vs. visual presentation).

To conclude, only a few researchers have investigated the use of musical mnemonics in children, showing mixed results, while the majority of research in cognitively unimpaired participants that focused on young adults generally showed beneficial results.

Cognitively unimpaired older adults

Of the 28 studies using cognitively unimpaired participants, two focused specifically on cognitively unimpaired older adults (Deason et al., 2012; Ratovohery et al., 2018). Deason et al. (2012) did not find a significant benefit in recall of sung lyrics (even) after a one-week delay (to avoid a ceiling effect), in contrast with persons with AD (from the study of Simmons-Stern et al., 2010), whose memory performance was enhanced by musical encoding. Deason et al. (2012) concluded that maybe there is a fundamental difference in musical encoding between older adults without cognitive impairments and those with AD. Ratovohery et al. (2018) on the other hand, found a significant better recall of sung lyrics in cognitively unimpaired older adults. This result however was only found when the music was positively valenced in terms of emotional content, regardless of the retention delay.

Interestingly, six of the studies on AD included a control group consisting of matched cognitively unimpaired older adults. Simmons-Stern et al. (2010) did not find a benefit of a sung presentation of lyrics, and Baird et al. (2017) also failed to find a significant effect of a sung versus spoken presentation in cognitively unimpaired musicians and non-musicians, but here before the last learning trials all cognitively unimpaired older adults reached errorless performance, indicating a ceiling effect. Additionally, there were no significant differences found between musicians or non-musicians for any of the experimental task variables.

The other four studies demonstrated a significant effect of a sung presentation in cognitively unimpaired older adults. Simmons-Stern et al. (2012) found a benefit of recall of sung lyrics concerning general content. Moussard et al. (2014) only showed a significantly improved delayed (but not immediate) recall, while Palisson et al. (2015) reported a significantly improved immediate and delayed recall, and Ratovohery et al. (2019) found a better recall only for positively valenced music.

In conclusion, research on the effects of musical mnemonics in cognitively unimpaired older adults is scarce. Only recently have some researchers focused on effects of musical mnemonics in older adults, mostly using them as a control group for persons with AD, again showing mixed results.

Alzheimer's disease

Nine studies focused on the effects of music as a mnemonic device on episodic memory in AD (Baird et al., 2017; Moussard et al., 2012, 2014; Oostendorp & Montel, 2014; Palisson et al., 2015; Prickett & Moore, 1991; Ratovohery et al., 2019; Simmons-Stern et al., 2010, 2012). All studies except one (Baird et al., 2017) reported a beneficial effect of a sung versus spoken presentation on episodic memory functioning in AD.

The first study on musical mnemonics in AD was carried out by Prickett and Moore (1991), who showed that persons with AD recalled long-familiar songs most accurately (compared to new songs, rhymed speech and spoken words). In line with this, Simmons-Stern et al. (2010) found a significant better recognition of sung lyrics in persons with AD, and in follow-up research (Simmons-Stern et al., 2012) improved memory was reported for only general (rather than specific) content in a sung compared to a spoken presentation of novel song lyrics related to instrumental activities of daily living. This study was followed-up by a case study by Moussard et al. (2012) in a person with AD, showing that singing new lyrics significantly improved the free delayed (10 min) and long-term delayed (four weeks) recall of words, albeit after repeated learning trials. Moussard et al. (2014) confirmed their previous findings in a follow-up patient control study; sung presentation of lyrics only significantly improved delayed (not immediate) recall.

In contrast to Moussard et al., (2012, 2014), Palisson et al. (2015) found that a sung presentation (familiar melody) of texts compared to a non-musical association or spoken presentation not only led to significantly increased delayed, but also immediate recall, relative to a spoken presentation. Finally, Oostendorp and Montel (2014) reported that free and cued recall of word lists significantly improved after sung presentation in persons with moderate to severe AD.

Although research aimed at musical mnemonics in AD showed positive results in general, the research paradigms that have been used vary greatly with respect to musical stimulus embedding, verbal stimulus, test type (recall versus recognition) or delay (immediate versus delayed), as did the participant characteristics. This may explain the heterogeneity of the findings.

Musical expertise

Although musical background and training were operationalized in different ways, we consider them together under the umbrella term expertise. Ten studies included musical expertise as a covariate (Baird et al., 2017; Jellison, 1976; Jellison & Miller, 1982; Kilgour et al., 2000; Racette & Peretz, 2007; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019). Performance differences related to musical expertise were found in nine studies, focusing either on generally higher memory performance in musically trained or expert participants (Jellison & Miller, 1982; Kilgour et al., 2000; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019), or interactions indicating a larger benefit of musical presentation on memory performance in participants with more musical expertise (Baird et al., 2017; Jellison, 1976).

For student participants, Jellison (1976) found that while song facilitated digit recall in both musically trained and untrained participants, sung presentation led to a consistently better performance for the musically trained group. Other studies on the other hand, did not find a difference between levels of musical expertise of students in terms of the benefits of sung versus spoken presentation (e.g., Jellison & Miller, 1982; Kilgour et al., 2000; Racette & Peretz, 2007). However with regard to verbal recall, Jellison and Miller (1982) found that musically trained participants recalled more words and digits than untrained participants, and Kilgour et al. (2000) also reported that the musically trained participants outperformed those without training. Silverman (2007, 2010, 2012) and Silverman and Schwartzberg (2014, 2019) also repeatedly reported in young adults that musicians tended to outperform non-musicians in overall on working memory tasks.

In previous AD research, some researchers either did not systematically compare participants with different levels of musical expertise (Oostendorp & Montel, 2014; Prickett & Moore, 1991; Simmons-Stern et al., 2010, 2012) or explicitly focused on non-musicians only (Moussard et al., 2012, 2014). However, Baird et al. (2017) specifically directed their research to possible differences in the benefits of a musical mnemonic between musicians and non-musicians (persons with AD and cognitively unimpaired older adults). Baird et al. (2017) reported that AD musicians did not show a difference in memory performance between a sung and spoken presentation (in contrast to AD non-musicians who actually experienced a negative effect). However, compared to nonmusicians with AD, musicians with AD performed better in the sung modality. In contrast, Ratovohery et al. (2019) focused specifically on persons with AD and a low musical expertise, and found improvement of text recall of daily-life themes with a sung (regardless of musical valence) presentation. They showed that even after a 24-h delay and the presence of severe memory impairments in persons with AD with low musical expertise, the musical mnemonic was effective.

To summarize, most studies in cognitively unimpaired participants found no evidence for musical expertise modulating the effect of a sung presentation of information, except one (Jellison, 1976). In AD some authors did not systematically compare musical expertise, others included only musically untrained participants, however, one study that included musical expertise as a covariate showed better learning of sung information in AD musicians (Baird et al., 2017).

Musical stimulus embedding

As mentioned above, almost all included studies compared a sung versus spoken presentation of stimuli (except the studies of Silverman, 2010, 2012, and Silverman & Schwartzberg, 2014).

Melody

Some investigators report that melody contributes to the beneficial results: Wallace (1994) found better verbatim immediate and delayed word recall in a sung condition compared to other presentations (among which a rhythmically spoken presentation) thus supporting melody as a memory enhancer for text if the same, simple melody was repeatedly heard. Ludke et al. (2014) also reported benefits of singing (using an unfamiliar melody) immediately and after 20 min delay compared to (rhythmically) speaking on verbatim recall of short-term paired-associated phrase learning in a foreign language (Hungarian) and native language (not explained by presentation rate as this possible confounder was carefully controlled). Similar effects were described by Rukholm et al. (2018) in adults and in children (Good et al., 2015). Schön et al. (2008) found that by constant mapping of melodic information (pitch) to the syllables of to-be-learned new (nonsense) words arousal and boundary enhancement was reached, presumably contributing to speech segmentation in learning a foreign language and concluded that especially in the first learning phase (i.e., where it is needed to segment new words), one may largely benefit from the structural and motivational benefits of melodic information in song.

Rhythm

Others have found that specifically rhythm yielded significant positive results compared to a spoken presentation. Purnell-Webb and Speelman (2008) reported that rhythm, as compared to an unfamiliar melody and spoken condition, facilitates verbatim recall of verbal information. Silverman (2007, 2010, 2012) also described a significant effect of rhythmic presentation on working memory functioning as measured by experimental digit span task performance.

Participation at encoding

All studies that included active rehearsal conditions (participants had to sing the to-be-learned information) (Chazin & Neuschatz, 1990; Gfeller, 1983; Good et al., 2015; Ludke et al., 2014; Moussard et al., 2012, 2014; Oostendorp & Montel, 2014; Palisson et al., 2015; Prickett & Moore, 1991; Ratovohery et al., 2018, 2019) showed positive results on some aspect of memory performance (except the study of Racette & Peretz, 2007). In contrast, of the studies where encoding consisted of listening to a sung presentation, 17 out of 25 showed an effect of a sung presentation on some aspect of memory performance (Calvert & Tart, 1993; Jellison, 1976; Ma et al., 2020; McElhinney & Annett, 1996; Purnell-Webb & Speelman, 2008; Rainey & Larsen, 2002; Rukholm et al., 2018;

Schön et al., 2008; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019; Simmons-Stern et al., 2010, 2012; Wallace, 1994; Yalch, 1991).

Familiarity

Previous research considering the familiarity of the melody can be divided into research that systematically investigated the effect of familiarity and research that only used either unfamiliar or familiar melodies. Familiarity contributed positively to this beneficial effect of sung presentation in cognitively unimpaired adults, requiring more extensive investigation in AD. In sum, four of the eight studies that systematically assessed the effect of the familiarity of the melody or rhythm, found a positive effect (Prickett & Moore, 1991; Purnell-Webb & Speelman, 2008; Tamminen et al., 2017; Wolfe & Hom, 1993), four failed to find an effect of familiarity (Ma et al., 2020; Moussard et al., 2012, 2014; Silverman, 2010). In the following we will discuss the findings in the cognitively unimpaired participants first, followed by findings in AD.

In cognitively unimpaired participants, research that systematically evaluated the effects of familiarity of the melody found that a familiar melody or rhythm (i.e., presenting in a temporal pattern including strong and weak beats that complements the natural meter of spoken text, derived from a well-known melody; Purnell-Webb & Speelman, 2008) facilitated learning (Tamminen et al., 2017) or recall (Purnell-Webb & Speelman, 2008; Wolfe & Hom, 1993). However, Silverman (2010), did not find any difference in reduction of the working memory overload when a familiar melody was used, as compared to an unfamiliar melody. Ma et al. (2020) found also no difference in immediate and long term memory performance between a familiar and unfamiliar melody. Several studies in cognitively unimpaired participants used unfamiliar melodies; nine of these sixteen studies found a positive (or partly positive) result (Gfeller, 1983; Jellison, 1976; Ludke et al., 2014; McElhinney & Annett, 1996; Schön et al., 2008; Silverman, 2007; Silverman & Schwartzberg, 2014, 2019; Wallace, 1994). Seven studies used a familiar melody, of which five studies found a positive (or partly positive) result (Calvert & Tart, 1993; Chazin & Neuschatz, 1990; Good et al., 2015; Ratovohery et al., 2018; Rukholm et al., 2018).

In research on AD, only one of the three studies that systematically compared the familiarity of the melody (Moussard et al., 2012, 2014; Prickett & Moore, 1991) reported that a familiar melody facilitated the recall (Prickett & Moore, 1991). Moussard et al. (2012) found a detrimental effect of an unfamiliar melody at initial learning. Two studies used an unfamiliar melody and found some positive results (Simmons-Stern et al., 2010, 2012), the four remaining studies used a familiar or familiarized (Oostendorp & Montel, 2014) melody, of which three studies found a positive result (Oostendorp & Montel, 2014; Palisson et al., 2015; Ratovohery et al., 2019). Baird et al. (2017) observed no overall effect of a sung presentation using a familiar melody (although AD musicians did benefit compared to AD non-musicians).

To summarize, studies that systematically compared familiarity in cognitively unimpaired participants showed an advantage of a familiar melody (or rhythm). However, many studies used only a familiar or an unfamiliar melody, showing mixed results. In AD some researchers systematically compared familiarity of the melody, others applied either familiar or unfamiliar melodies only, showing mixed results.

Other variables

Other aspects that have been investigated are the singer's sex, the kind of accompaniment, live or recorded presentation, sensory modality (purely audio or combining or compared with visual embedding), serial position, degree of elaboration of the verbal information, speech register with some melodic features (infant-directed speech), presentation speed, melodic complexity as well as the emotional valence of the music. Silverman and Schwartzberg (2014) compared recorded melodies using female and male voices and three kinds of accompaniment (guitar, piano and no accompaniment) and found that the use of a male voice and piano (or no) accompaniment enhanced recall. Silverman and Schwartzberg (2019) revealed that additional visual input overloaded working memory, thereby worsening the recall.

Finally, their overall results indicated that information in primacy and recency positions was best recalled. As mentioned, Ratovohery et al. (2018) investigated the impact of the emotional valence of music in cognitively unimpaired older adults and found that musical encoding enhanced their recall only when positively valenced music was used.

Overall, researchers have come to different conclusions about the contributing factors of music as a mnemonic aid (e.g., rhythm, melody, position of the information, degree of elaboration, speech register with some melodic features, male or female voice, musical accompaniment, live or recorded presentation, sensory modality, emotional valence, active or passive rehearsal), leaving no clear answer other than that it seems that each of these aspects can potentially have an effect, and it is likely that their combination, leading to specific accent structures in the musical stimulus that can direct attention, are important.

Discussion

This systematic review provides an analysis of the effect of musical mnemonics on memory functioning in children, cognitively unimpaired young and older adults, and persons with AD. Additionally, we aimed to clarify which aspects of music can facilitate memory (e.g., melody, rhythm, familiarity), and consider the possible influence of musical expertise on the degree of benefit of music as a mnemonic aid.

In most studies, a beneficial effect of musical presentation was reported although some studies observed no beneficial effect. The findings in younger participants included a few studies in children showing mixed results, but the majority of research that focused on young adults generally showed beneficial results. Studies focusing on cognitively unimpaired older adults were limited; this group serving primarily as a control for persons with AD. Despite a sparsity of studies, predominantly positive results of a musical presentation on episodic memory functioning have been reported in AD. Researchers used varying paradigms (musical stimulus embedding, verbal material, testing method (e.g., immediate or delayed (cued or free) recall or recognition), and participant characteristics, see Table 2.1) possibly explaining the heterogeneity of the findings. However, our findings support the notion that in AD, the use of a sung presentation improves episodic memory performance, with only one study reporting no beneficial effect in AD musicians and a detrimental effect in AD non-musicians. Possibly in line with the great variety in research paradigms of the studies included in this systematic review, the effect sizes ranged from medium to large. However, several studies failed to find effects of musical mnemonics, with small effect sizes.

Regarding the relevance of specific musical aspects, it is important to mention that very few studies systematically assessed musical components' potential to facilitate memory. In previous studies, various musical aspects forming the musical stimulus embedding have been considered. Taken together, researchers have come to different conclusions about the contributing factors of musical mnemonics (e.g., rhythm, melody, primacy or recency positions, visual, auditory or combined presentation, male or female voice, musical accompaniment, emotional valence, active or passive rehearsal, individual or group participation), leaving no clear answer other than that it seems that each of these aspects can potentially have an effect. It is likely that combined accent structures (resulting from a combination of the emphasis in the verbal material and the accents in the music) are important. With regard to visual, auditory or combined presentation, Silverman and Schwartzberg (2019) found that addition of visual input to auditory presentation hampered digit recall performance through possible overload of working memory. With regards to the contribution of the degree of familiarity of the melody, most research in cognitively unimpaired participants did not systematically compare familiar and unfamiliar melodies. A small majority of the studies that systematically compared familiarity reported an advantage of a familiar melody (or rhythm). In AD, again only few researchers systematically compared the familiarity aspect, showing mixed results. Moussard et al. (2012, 2014) demonstrated a beneficial effect (only) on delayed recall of a sung presentation even when an unfamiliar melody was used, concluding that a sung presentation facilitates verbal memory regardless of the familiarity aspect. One study found evidence for improved recall after relearning the lyrics belonging to long-familiar songs as compared to lyrics belonging to a new song (Prickett & Moore, 1991). However, this could be due to reactivation of existing memory traces of previously learned lyrics, which is fundamentally different from learning new lyrics with a familiar melody.

To answer the question whether musical expertise leads to additional benefits of musical encoding, the findings indicate that musical expertise did not enhance beneficial effects of a sung presentation of information in most studies with cognitively unimpaired participants, except in one (Jellison, 1976). In AD studies, some researchers only included musically untrained participants while others did not systematically compare levels of musical expertise. However, Baird et al. (2017) included musical expertise as a covariate and demonstrated better learning of sung information in AD musicians compared to AD non-musicians.

Underlying mechanisms proposed from previous studies

Several explanations have been provided for the positive results of music enhancing memory performance in cognitively unimpaired individuals and individuals with AD, related to automatic internal rehearsal (e.g., Calvert & Tart, 1993), enhanced structuring and chunking (e.g., Purnell-Webb &

Speelman, 2008; Silverman, 2010, 2012), residual memory traces of familiar melodies (Baird & Samson, 2009), and emotional valence of the music (Ratovohery et al., 2018, 2019). These partly overlap with Ferreri and Verga's (2016) model, in which a two-fold explanation focuses on the embedding of verbal material in musical structures on the one hand, and music-related effects of mood, arousal and reward on the other. In the following we will consider these ideas in the light of the reported findings.

Automatic internal rehearsal

Several authors put forward the notion that facilitation of delayed memory performance after musical embedding occurs because of automatic rehearsal of the music in the intermediate period (relative to a spoken presentation) (Calvert & Tart, 1993; Gfeller, 1983; Rainey & Larsen, 2002). Calvert and Tart (1993) refer to the experience of having a song stuck in your head, and the fact that one is thus automatically rehearsing the lyrics effortlessly. Reports from their participants revealed that they sang the words to themselves during a retrieval task. Calvert and Tart (1993) stated that repetition facilitates chunking the tune and words together (i.e., combining the accent structures of verbal and musical materials). Through this dual encoding, later retrieval efforts can be assisted by chunks of words that are stored with aid of the structural, repeating pattern of music. Researchers therefore concluded that songs are a helpful encoding, retrieval and recall strategy for long-term memory (e.g., Calvert & Tart, 1993; McElhinney & Annett, 1996).

Enhanced structuring

Another explanation is that rather than repetition, the time structure or rhythm facilitates the ability to chunk (Purnell-Webb & Speelman, 2008; Silverman, 2010, 2012). Silverman (2007) concluded that rhythmic grouping resulted in pre-formed chunks that facilitated sequential recall and referred to past research on chunking into memory as a result of the use of rhythm (e.g., Schellenberg & Moore, 1985; Stoffer, 1985). However, in contrast to previous studies (e.g., Ee et al., 2015), Silverman et al. (2021) did not report significant differences between rhythm and no rhythm conditions. Purnell-Webb and Speelman (2008) concluded that a familiar rhythm, complementing the rhythm of the text, (with or without musical accompaniment) may provide the attachment of text to a schematic frame, thus possibly facilitating recall. Their findings were in line with the integration hypothesis as suggested by Serafine et al., (1984, 1986) who asserted that integrated in a melody, verbal material is changed and thus remembered differently. Both these ideas rest on the notion of a ‘joint accent structure’ created from the verbal material and the music, itself an integrated combination of the pattern of perceptual accents in pitch, rhythm and other kinds of musical structures (Jones, 1987), providing cues for memory by inducing enhanced attention to specific time points in the music. This mechanism is similar to what has been described in Dynamic Attending Theory (Jones, 1976; Jones & Boltz, 1989), which focuses on how attention is directed to specific points in temporally complex structures. Considering Purnell-Webb and Speelman’s (2008) findings, who referred to this joint structure as ‘prosodic match’, the dynamic attending mechanisms would direct attention to the structure resulting from integrating verbal material with a melody or rhythm. Thus, this may facilitate memory, especially if the accent structure of the melody and verbal material are well-matched. Ferreri and Verga (2016) also build their framework on the idea that melodic and rhythmic aspects of music provide a template contributing to the formation of internal rhythm in cortical networks involved in learning and memory. Notably, as the verbal material often also has a temporal structure of accents, this is merged with the accent structure in the music when verbal material is embedded, with varying levels of fit between the words and the music they are set to. It is likely that well-fitting accent structures lead to less complex stimuli, perhaps facilitating encoding.

In AD it has been proposed that structuring mechanisms might also play a role (Moussard et al., 2012). Moussard et al. (2014) also referred to previous research supposing that the melody might provide cues to the structure of the lyrics (e.g., number of syllables per line) and limit the possibility of words to be set to the melody (i.e., Wallace, 1994).

Familiarity and existing memory traces

The degree of familiarity of the melody (or rhythm) has also been proposed as a relevant aspect of music enhancing verbal memory and which is hypothesized to build on existing memory traces. Korenman and Peynircioglu (2004) used music snippets of varying instrumental and melodic familiarity and found enhanced recall in students when melodic familiarity increased. However, the downside of using a well-known melody may be that there is interference between the new verbal material to be learned and the previously overlearned lyrics belonging to a familiar tune. To avoid this potential problem, some authors specifically chose to use an unknown song (e.g., McElhinney & Annett, 1996) or to achieve familiarity with an unfamiliar melody prior to the actual experiment (e.g., Good et al., 2015; Oostendorp & Montel, 2014; Tamminen et al., 2017). Van den Bosch et al. (2013) showed that the level of expectation and predictability which is mediated by exposure to music, plays an important role in the arousal caused by the music. So, it could well be that using music that is to some degree familiar improves verbal memory through arousal.

In cognitively unimpaired older adults, some researchers have shown a beneficial effect of musical mnemonics (Moussard et al., 2014; Palisson et al., 2015; Ratovohery et al., 2018, 2019; Simmons-Stern et al., 2012); all of them used a familiar melody, except Simmons-Stern et al. (2012). Moussard et al. (2014) varied the degree of familiarity and found positive results of the highly familiar condition only in older adults. Ratovohery et al. (2019) supposed that in AD, a richer multimodal encoding may be the underlying mechanism of a familiar melody improving verbal memory. The previous results showed that ageing individuals and individuals with (even severe) memory impairment can also benefit from musical mnemonics. Given the mixed results on familiarity it can be hypothesized that familiarity might be linked with arousal mechanisms, possibly improving verbal memory in cognitively unimpaired participants, whereas music in general—regardless of the familiarity aspect—may cause arousal and reward mechanisms more easily in AD, where cognitive resources may be less available.

Emotional valence

Several authors note that music seems easier to retain than verbal material, sometimes interpreted to be due to the strong emotional power of music enhancing consolidation of memory traces (Ferreri & Verga, 2016; Samson et al., 2009).

Others revealed that specifically positively valenced music improved encoding in cognitively unimpaired older adults (Ratovohery et al., 2018), consistent with the positivity effect which has been frequently reported (e.g., Kalenzaga et al., 2016) in normal ageing. Furthermore, it was found in AD that positively valenced music seemed to improve only immediate performance (Ratovohery et al., 2019).

However, it has also been reported that both positive and negatively valenced music improved delayed (10 min) verbal memory performance (Ratovohery et al., 2019). In line with this results, it is suggested that it is the musical experiences themselves, regardless of valence, that is generally more associated with positive emotions and memories in AD, leading to reward feelings, enhancing recollection.

Explanations and interpretation of conflicting results

On one side, studies in cognitively unimpaired young adults generally showed a positive effect of musical mnemonics, on the other side studies suggested that music decreases the memory performance through distraction and divided attention (Ferreri & Verga, 2016). In cognitively unimpaired older adults results were also mixed, and in AD we found a heterogeneity within the positive results. We will here briefly discuss the conflicting results and interpretations of these outcomes.

Various explanations for non-significant results in cognitively unimpaired participants have been given, relating to varying aspects, such as complexity of the verbal stimuli (e.g., unusual words, unconnected versus connected text), musical stimuli (e.g., (un)familiarity), personal aspects (e.g., musical expertise), task or practice specifics (e.g., presentation rate, rehearsal time, modality shift, memory paradigm), and stimulus complexity in relation to subsequent cognitive load and selective attention.

With respect to the complexity of the verbal stimulus, researchers, for example, reported the use of unusual words (Chazin & Neuschatz, 1990) or unconnected text instead of meaningful connected information (Rainey & Larsen, 2002). Moore et al. (2008) concluded in their study on persons with MS with regards to the musical stimulus, that the degree of familiarity with the used song was sometimes insufficient. Silverman (2007) concluded that the use of unfamiliar melodies may have resulted in working memory overload. Lehmann and Seufert (2018) suggested that the fact that the melody they used did not differ between every verse line, potentially could have led to simultaneous activation of multiple verse lines, consequently not being specific enough to function as an anchor. With regard to personal aspects, Rainey and Larsen (2002) hypothesized that differences in musical expertise (leading to differences in the degree of sensitivity to and effective use of musical elements, e.g., melody and rhythm) could play a role in the benefit of music as a prompt at initial learning. Regarding task specifics, Kilgour et al. (2000) thought that the success of a sung presentation might rely only on an artefact of presentation rate, which was also controlled for in other studies (e.g., Good et al., 2015; Ludke et al., 2014). Non-significant results can also be explained by insufficient rehearsal time, the memory paradigm used, or a modality shift between the training and testing phase (Moore et al., 2008). Interestingly, Good et al. (2015) indeed found that when participants were allowed to choose in the testing phase whether they wanted to speak or sing, the children who learned the information sung almost all chose to sing it back. Concerning stimulus complexity, Racette and Peretz (2007) supposed that singing is at least in the first steps of learning to perform a dual task, because of possible separate memory representations of text and melody.

In cognitively unimpaired older adults, several explanations have been provided for the mixed results of musical mnemonics. Most of the previous studies included them as controls to AD, which might have led to a ceiling effect (Ratovohery et al., 2018). Ratovohery et al. (2018) mentioned that the use of a recognition paradigm could have been too easy (e.g., Deason et al., 2012; Simmons-Stern et al., 2010, 2012).

Turning to the heterogeneity of the predominantly positive results in the AD population, Ratovohery et al. (2019) stated for example that the retention delay that was too long in relation to the disease severity could explain the absence of positive results in research of their colleagues (e.g., Baird et al., 2017). Moussard et al. (2012) concluded in their case study that singing at initial learning might not help memorization (or only when using a familiar melody). They referred to the theory of dual representation of song lyrics and the melody (cf. Hébert & Peretz, 2001; Peretz, 1996; Peretz et al., 2004), and hypothesized that this causes a slow and demanding initial memorization in AD but provides a robust trace, facilitating the retrieval from long-term memory (cf. Calvert & Tart, 1993; McElhinney & Annett, 1996; Rainey & Larsen, 2002; Wilson et al., 2006).

Model of musical mnemonics in ageing and AD

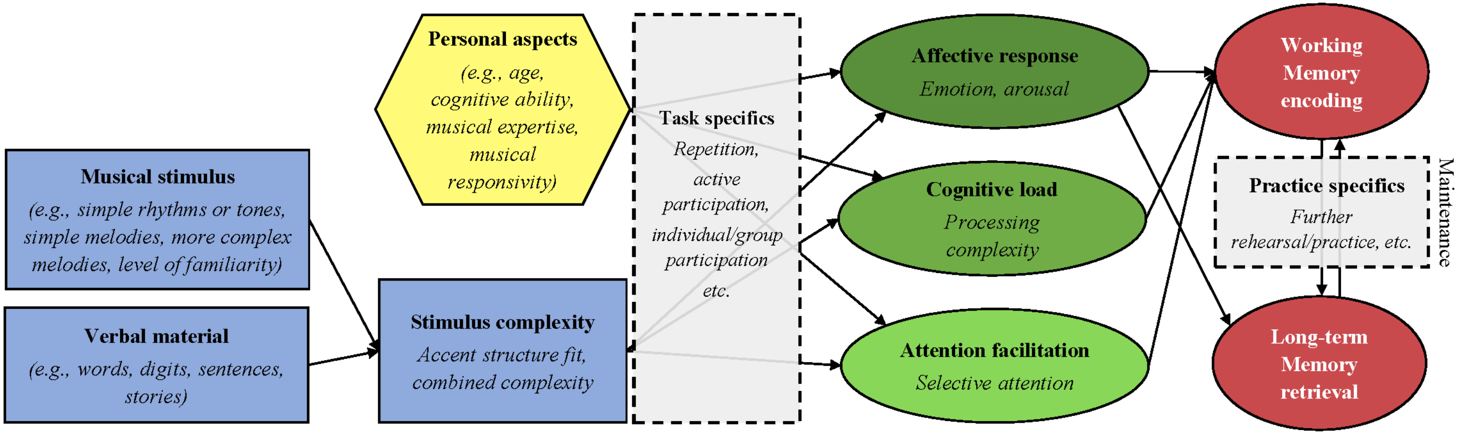
The aforementioned explanations for the beneficial effects of music as a mnemonic aid indicate that several factors must be taken into account: the complexity of the verbal stimulus (e.g., words, digits, sentences, stories), various aspects of the musical stimulus (e.g., simple or more complex rhythms of melodies, familiarity, emotional valence), together resulting in an overall stimulus complexity, and personal aspects (e.g., age, cognitive ability (cognitively unimpaired participants, cognitively unimpaired older adults, persons with MCI or AD), musical expertise, musical responsivity), in combination with task and practice specifics (e.g., presentation rate, repetition, level of participation, rehearsal time, modality congruence between training and testing, memory paradigm). The embedding of the verbal material in the musical stimulus possibly activates diverse mechanisms such as automatic internal rehearsal, enhanced structuring and chunking, richer multimodal encoding and the eliciting of emotion, arousal and reward mechanisms. We assume based on the diverging results of previous research, that in each individual a specific combination of these factors influences the degree of cognitive load, selective attention, and the affective response, resulting in an enhanced, unaffected, or even degraded performance in working memory encoding and long-term memory retrieval.

The above considerations can be summarized in a theoretical framework (see Fig. 2.2), thereby building on the sung vs. spoken part of the model by Ferreri and Verga (2016) as we hypothesize it applies to cognitively unimpaired older adults, and persons with MCI or AD. Specifically, we further elaborate on the nature of full stimulus complexity by including the result of the complexity of the verbal and musical stimulus separately and their accent structure fit, as well as personal and task characteristics, in the context of cognitive load (which may be especially relevant for ageing or cognitively impaired populations).

The model indicates several ways in which musical embedding of verbal material may support memory functioning, and includes the aforementioned aspects that might play a role in making music a successful mnemonic aid in various points of the process of memorization, such as aspects of the verbal material, the musical stimulus embedding, task and practice specifics, and personal aspects (e.g., age, cognitive ability). The musical stimulus and verbal material together might create a match (or mismatch) resulting in the overall stimulus complexity for that specific pairing (based on complexity of each separate element, and accent structure fit). The combined accent structure thus represents the combination of the emphasis in the verbal material and the accents in the music and how well they match. The overall complexity is the outcome of this combination of accent structures; a good fit provides a more coherent and integrated accent structure and thus less complexity than when music and text do not fit very well. This complexity level influences the affective response (cf. North & Hargreaves, 1995), cognitive load, and attention facilitation, resulting in a more or less effective working memory encoding. The affective response, cognitive load and attention facilitation are also influenced by personal factors. Furthermore, task specifics not only potentially influence this affective response, cognitive load and attention facilitation, but possibly also affect working memory encoding, maintenance (e.g., further rehearsal, practice) and long-term memory retrieval (e.g., by eliciting an affective response; Ferreri & Verga, 2016).

Figure 2.2

Proposed model of the effects of musical mnemonics on memory function



Note. The model includes aspects of the verbal material (e.g., words, digits, sentences, stories), the music used for stimulus embedding (e.g., simple rhythms or tones, simple melodies, more complex melodies, level of familiarity), task specifics (e.g., repetition, level of participation), and personal aspects (e.g., age, cognitive ability, musical expertise, musical responsivity). Person-specific aspects are shown in a hexagon, cognitive processes are shown in ovals, external stimulus, task-, and practice specifics with boxes. The (mis-)match between accent structures of the musical stimulus and verbal material together contributes to the stimulus complexity (i.e., accent structure fit, or combined complexity). The latter influences the affective response, cognitive load, and attention facilitation, resulting in more or less effective working memory encoding. The affective response, cognitive load and attention facilitation are also dependent on personal factors such as age, age-related differences in emotion recognition, cognitive ability (i.e., cognitively unimpaired participants, cognitively unimpaired older adults, persons with MCI or AD) and musical expertise and responsivity. The two grey coloured boxes with dotted lines represent task specifics (i.e., amount of repetition, modality congruence, memory paradigm, active participation) and practice specifics (i.e., rehearsal, more practice) that possibly play a role in working memory encoding, maintenance (e.g., further rehearsal, practice) and long-term memory retrieval.

Different elements in the model may be crucial to different populations, with the importance of each model element based on the characteristics of the population at hand. Specific mechanisms might be activated, for example, through positively valenced music in cognitively unimpaired older adults or through musical embedding in general in AD, causing activation of arousal, emotional and reward systems, possibly leading to enhanced memory performance. Although no studies on MCI were found in the current systematic review, this model may cover specific mechanisms for this population as well.

It is also important to note that our model extends, yet also differs from the one proposed by Ferreri and Verga (2016). While there are several similarities with the 'sung versus spoken'- part of the framework put forward by Ferreri and Verga (2016), we here further elaborate the nature of overall stimulus complexity, which not only includes (1) the complexity of verbal or musical stimulus but notably also (2) the accent structure fit between verbal and musical stimulus and argue that there is a need for future studies to further clarify and test relationships between overall stimulus complexity and memory outcome. As the stimulus complexity might affect cognitive load and attention facilitation, this may be especially relevant for ageing or cognitively impaired populations.

Limitations

The results of our systematic review should be interpreted with caution due to the mixed outcomes of the studies identified. Few studies systematically assessed the potential of specific musical components or the role of musical expertise to facilitate memory. The inconsistencies in the methodological approaches cannot be easily interpreted; studies differed in the complexity of verbal information to be learned and remembered and musical stimulus embedding, the memory domain (i.e., working or episodic memory), and the memory process of interest (encoding, maintenance, retrieval). Previous research has mostly focused on cognitively unimpaired young adults and those findings cannot be generalized to patient groups. The few patient studies often have small sample sizes, often without appropriate controls, and the severity of cognitive impairments is not always well-defined. However, AD patient studies reflect evidence-based steps in this direction. Finally, there is a risk of publication bias in this field of research, compounded with methodological issues that can lead to false positive results (cf. Sala & Gobet, 2020).

Recommendations for future research

The model formulated above may be of help to further systematize methodologies, drive research questions, and stimulate precise reporting of the verbal stimulus, musical stimulus embedding, personal aspects, and task and practice elements used. Based on the existing literature, we created reporting guidelines for research on musical mnemonics (See Box 2.2). The degree of participation at initial learning, the comparison between a self-created or imposed mnemonic (Moore et al., 2008), and the familiarity of the music (Rainey & Larsen, 2002) need to be investigated more thoroughly. Additionally, with neuro-imaging techniques and monitoring of psychophysiological arousal (Tamminen et al., 2017), we may deepen our knowledge of the mechanisms through which a musical presentation influences cognitive and brain functions and behaviour (cf. Ferreri & Verga, 2016).

To our knowledge, the existing research on AD has focused on episodic memory functioning. Furthermore, there was a lack of studies in MCI. However, Rainey and Larsen (2002) suggested to examine also the role of working memory, hypothesizing that music can be best used to provide an additional structure for people with a limited working memory capacity (as can be the case in MCI and AD) to improve the ability to transfer information to episodic memory. Therefore, there is a need for future studies on effects of musical mnemonics on working (and episodic) memory functioning in persons with MCI and AD.

Finally, good measurement instruments need to be developed to allow for more systematic comparison of the degree of musical expertise since this is a probable moderating factor in the degree of benefit of a musical mnemonic. Several validated questionnaires are available that not only look at formal training, but also take musical engagement, exposure, or responsiveness into account (e.g., Chin & Rickard, 2012; Mas-Herrero et al., 2013; Müllensiefen et al., 2014).

Box 2.2

Suggested reporting guidelines for research on musical mnemonics

To better specify underlying mechanisms of musical mnemonics, future researchers are recommended to report precisely on the musical stimulus embedding and testing procedure, participant characteristics and musical and verbal stimuli used, specifically:

Musical stimulus embedding and testing procedure

- Presentation paradigm (i.e., sung vs. spoken/rhythmically spoken, or other)
- Learning phase (encoding): social setting (individual vs. group), active (i.e., singing) or passive (i.e., listening) rehearsal conditions, live or recorded presentation, specific modality (auditory, visually, combined or other), imposed or self-created mnemonic
- Tasks specifics: e.g., number of repetitions, amount of rehearsal time, potential control for confounders (e.g., equation of duration of sung and spoken stimuli)
- Testing phase (maintenance and retrieval): if possible use standardized outcome measures (to promote the inclusion of the study results in future meta-analysis), specify memory measure (active immediate or (long-term) delayed recall, passive recognition, or both), duration of retention delay, modality (spoken, sung, written, multiple choice) and modality congruence between learning and testing (same or different from learning phase, choice/no choice), and practice specifics (e.g., amount of rehearsal, cues)

Participant characteristics

- Demographic variables (e.g., age, cognitive ability, other clinical characteristics)
- Musical background (ideally using validated questionnaires)

Musical and verbal stimulus material

- Music/Verbal: Materials used for memorization (i.e., level of complexity, tones vs. chords, words vs. text, etc.). If self-composed or created for the study: provide musical scores or text as supplementary materials
- Music/Verbal: Degree of familiarity (unfamiliar, familiar/familiarized)
- Music/Verbal: Potential pairing of semantics to acoustical characteristics of a tune
- Music: Whether valence, emotional pleasantness, or genre was accounted for
- Verbal: Potential relevance of verbal stimulus for daily living (for memory-impaired persons)
- Verbal: If relevant, serial position of important information

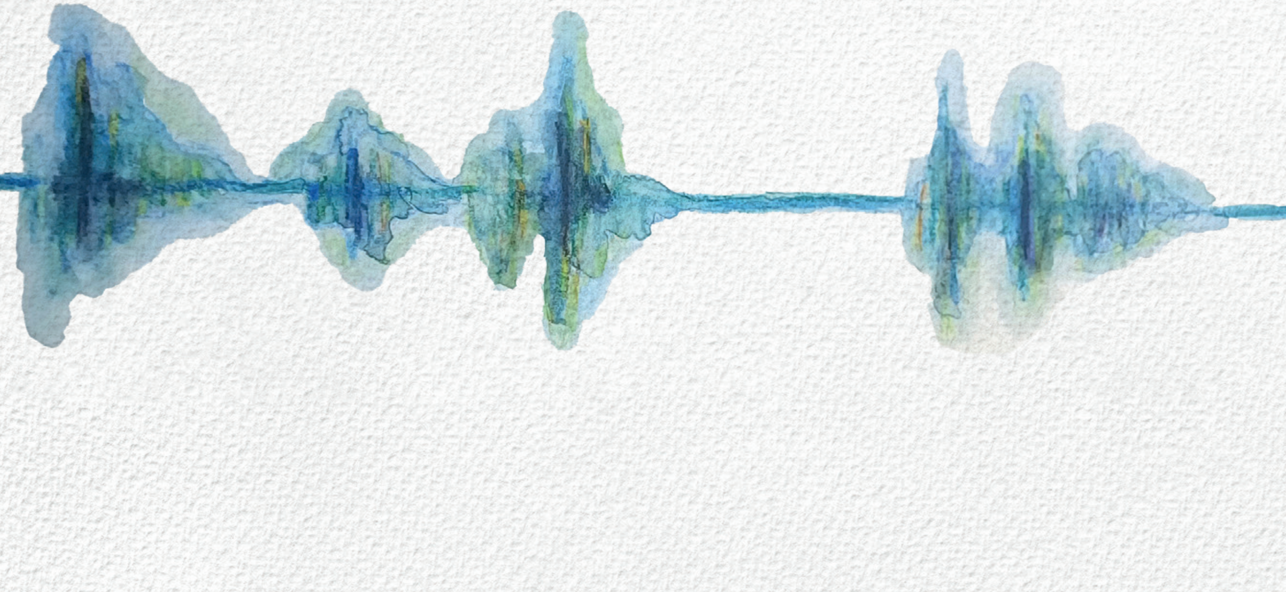
Clinical implications

Based on the above, we can conclude that musical mnemonics may be beneficial in AD and represent a low-cost strategy for improving recall of a limited amount of information in persons with mild to moderate (and even severe) AD (Oostendorp & Montel, 2014; Ratovohery et al., 2019). Future interventions should be designed personalizing the musical stimulus (e.g., genre, emotional valence, pleasantness, familiarity) to individual aspects (e.g., age, cognitive capacity, musical expertise, responsivity, and preferences), in order to maximize the potential of compensating for memory problems in everyday life of persons with MCI or AD.

Factors such as the relevance of the lyrics for daily living (Moussard et al., 2014), pairing the semantics to the acoustical characteristics of a tune (Moussard et al., 2014), enough rehearsal time to initially learn new information (Moore et al., 2008), the number of repetitions, the place of the important information at the beginning or end (Silverman & Schwartzberg, 2019), the degree of participation at encoding, familiarity of the music, and self-creating of a mnemonic (Moore et al., 2008) are all important to keep in mind when designing a musical mnemonic together with the patient. Interestingly, evidence from a word learning paradigm with background music rather than a sung presentation suggests that social aspects of the learning setting have an independent contribution to learning outcomes from musical aspects, suggesting that both are relevant to consider in clinical settings (Verga et al., 2015).

Conclusion

We report an overall beneficial effect of musical mnemonics (i.e., sung presentation of verbal information at encoding), although results of individual studies are mixed. Building on existing theoretical work, we formulated a model of the cognitive processes activated by musical mnemonics depending on stimulus complexity and personal aspects of persons with and without cognitive impairment. Aspects that appear promising include familiarity with the musical material and musical expertise in the participants, which require more extensive investigation. Consequently, more systematic research is needed to identify which musical aspects, possible mechanisms, and mediating or moderating factors play a contributing role in the application of musical mnemonics in MCI and AD.



Chapter 3

Effects of musical mnemonics in ageing

Published as:
Derks-Dijkman, M. W., Schaefer, R. S., Stegeman, M. L., van Tilborg, I. A. D. A., & Kessels, R. P. C. (2023). Effects of musical mnemonics on working memory performance in cognitively unimpaired young and older adults. *Experimental Aging Research*, *49*(4), 307–320.
https://doi.org/10.1080/0361073X.2022.2104061

Abstract

Objective: To overcome memory decrements in healthy ageing, compensation strategies and mnemonics have been found to be promising. The effects of musical mnemonics in ageing have been scarcely studied.

Methods: The present study examined the effects of musical presentation of digits (pitch sequences, rhythms, and their combinations) on working memory performance in young and older adults, as compared to spoken presentation.

Results: A facilitating effect of rhythm was found in both groups, whereas pitch and melodic cues affected performance negatively in older adults only. Musical training did not moderate the effect of musical mnemonics.

Discussion: To investigate whether persons with working memory impairment also benefit from musical mnemonics, follow-up research in older persons with, for instance, mild cognitive impairment or Alzheimer's dementia is recommended.

Introduction

Cognitive ageing refers to cognitive change due to nonpathological ageing, which does not affect every cognitive domain to the same extent. For instance, semantic memory (for example measured using vocabulary) is relatively resilient to brain ageing, whereas for example conceptual reasoning and processing speed show a gradual decline over time (see for an overview Eikelboom et al., 2020). Furthermore, there is considerable heterogeneity among older adults in the rate of decline (Harada et al., 2013). Overall, ageing-related decline in memory function is consistently reported (Nyberg et al., 2012). Notably, the ability to maintain and manipulate information for a brief period of time (i.e., working memory [WM] capacity) declines with age (Nyberg et al., 2012) as does everyday memory function (episodic memory [EM]; Nyberg et al., 2012; Rönnlund et al., 2005).

The use of memory strategies – mnemonics – may ameliorate ageing-associated memory decline that negatively influences wellbeing, quality of life and social participation (Fu et al., 2020). In the Method of Loci for example, a complex memory strategy requiring training, information is recalled by following a previous learned route and retrieving information that was previously mentally placed at salient landmarks along the route (Wagner et al., 2021). Older adults (OA) have been found to apply such mnemonics to compensate for the decline (De Frias et al., 2003). Memory strategy use in OA has been shown to depend on executive functioning and on the degree of their cognitive reserve, a concept related to educational attainment, premorbid intelligence, as well as social and leisure activities. Individuals with higher cognitive reserve have been found to use more effective strategies (Frankenmolen et al., 2018a).

With increasing age, a decreased repertoire of strategies is frequently reported (cf. Lemaire, 2016). However, Chevalère et al. (2020) found that OA used more verbal WM maintenance strategies (i.e., semantic, phonological, or 'phono- semantic') and used 'other' strategies (e.g., self-reference, imagery, idiosyncratic, or letter grouping) more frequently as compared to young adults (YA). Interestingly, one of the 'other' strategies spontaneously used by OA as reported by Chevalère et al. (2020) was making a melody with the words, relying on rhythm or associating the words to music keys.

Indeed, the use of music is also an example of a mnemonic, that is, setting the to-be-learned information to music (e.g., Ferreri & Verga, 2016). "Music as a structural prompt" (Madsen et al., 1975) has often been applied for teaching social and academic skills (e.g., Jellison, 1976; Jellison & Miller, 1982; Ludke et al., 2014; Wolfe & Hom, 1993). In the ABC song for example, the alphabet is sung to the familiar melody "Twinkle, twinkle, little star," to support learning the alphabet in school-age children (Wolfe & Hom, 1993). However, empirical evidence on the beneficial effects of using music as a structural prompt is limited (Rainey & Larsen, 2002), and to date mainly focused on YA (for an overview, see chapter 2).

Silverman (2007, 2010, 2012) consistently reported a significant beneficial effect of rhythmic presentation on working memory performance in students. Possibly, time structure or rhythm added to the presentation of the material facilitates the ability to chunk, thus optimizing performance using the limited WM capacity (Purnell-Webb & Speelman, 2008; Silverman, 2012). In contrast, adding melody (including both rhythmic and pitch patterns) has been found to negatively affect WM performance, possibly as it may act as a distractor. The combination of pitch and rhythm in unfamiliar melodies may have caused WM overload (Silverman, 2007). Thus, musical presentation may have a beneficial effect, but specific musical components (e.g., rhythm, pitch, melody, familiarity) and their combinations may differentially affect WM functioning. Except for the studies by Silverman and colleagues, very few previous studies have systematically assessed musical components' possibly facilitating potential for memory. Studies that have been performed differed largely with respect to research methods (i.e., verbal materials for memorization and musical stimulus embedding) and showed mixed results regarding the contribution of musical components to being a mnemonic device (for a systematic review see chapter 2).

Overall, research on effects of musical mnemonics on WM has mainly focused on YA, notably undergraduate students who are not representative for the general population. Only recently have the effects of musical mnemonics been investigated in OA, mainly focusing on EM, showing mixed results (for a review see chapter 2). Finally, in previous research, the degree of musical expertise (i.e., an umbrella term referring to musical background and training of the participants) has often not been systematically examined and has been operationalized in different ways in previous studies (see chapter 2), although this may be a relevant variable to take into account as it could possibly moderate effects of musical mnemonics on memory functioning (cf. Baird et al., 2017).

Therefore, the purpose of the present study is to determine the effects of musical presentation of digit span on WM performance in cognitively unimpaired YA versus OA (matched on educational attainment). Our main research question is whether musical mnemonics affect WM performance (differently) in cognitively unimpaired YA and OA, since WM function both relies on executive function and is crucial for long-term episodic memory encoding and retrieval (see, e.g., Baddeley, 2012). Next, we are interested in whether or not specific aspects of music used as a prompt are crucial (i.e., rhythm, pitch or a combination of rhythm and pitch [‘melody’]). Finally, we study whether musical expertise affects the beneficial effects of a musical mnemonic.

We designed a forward digit span task based on the method described by Silverman (2007) with four different conditions: 1) spoken, 2) sung to an unfamiliar isochronous five-tone pitch sequence (“pitch”), 3) spoken to an unfamiliar rhythmic pattern with varying durations (“rhythm”), 4) sung to an unfamiliar isochronous five-tone pitch sequence with an added rhythmic pattern with varying durations (“melody”). Furthermore, we administered two subtasks and the Self-Report Inventory of the Goldsmith Musical Sophistication Index (Gold-MSI, Müllensiefen et al., 2014) to systematically assess the degree of musical expertise of our participants.

In line with the findings of Ratovohery et al. (2018) regarding effects of musical mnemonics (i.e., sung text) on episodic memory performance in cognitively unimpaired YA and OA, we hypothesized that YA will outperform OA in the baseline (spoken) condition and in general on the experimental digit span. Although both YA and OA are expected to perform best in the “rhythm” condition (Silverman, 2007, 2010, 2012), and worst in our “pitch” condition (Silverman, 2007) and “melody” condition (Silverman, 2010), OA might benefit more from the expected beneficial effects of rhythm than YA, as WM declines with ageing and rhythmic presentation may reduce the need to rely on limited executive resources (e.g., Hester et al., 2004; Purnell-Webb & Speelman, 2008; Schellenberg & Moore, 1985). In turn, OA may also display a faster WM overload when there is only varying pitch, or a pitch component is added to a rhythmic pattern (i.e., in our “melody” condition) (Silverman, 2007, 2010). Finally, musically experienced YA are not expected to benefit more from musical presentation than less experienced YA, as their WM performance may already be optimal (e.g., Jellison & Miller, 1982; Kilgour et al., 2000; Racette & Peretz, 2007; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019). However, we hypothesized that musically experienced OA show a better performance for rhythmically presented material and a less degraded performance on melodically presented material, as compared to less experienced OA.

Materials and Methods

Participants

Twenty cognitively unimpaired young adults (YA; 5 men, 15 women; age: *M* = 20.3, *SD* = 1.9, range = 18–23) and 27 cognitively unimpaired older adults (OA; 8 men, 19 women; age: *M* = 72.6, *SD* = 7.0, range = 65–91) were included. All participants voluntarily participated in this study and gave their written informed consent. OA were included when they were 65 years or older, able to read, understand, and communicate in Dutch, and had sufficient hearing and vision for performing the neuropsychological tests. Exclusion criteria were a score below the cut-off score of 24 on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), a diagnosis of a stroke, mild cognitive impairment (MCI), dementia, a psychiatric disease, or excessive alcohol or drug use.

The OA were matched with YA on sex, and education level. We used the Dutch educational system based on education levels rather than years of education, similar to the UNESCO (2011) classification of education levels, using a 7-point scale (1 = less than primary school; 2 = primary school; 3 = secondary education with no diploma; 4 = lower secondary vocational education; 5 = intermediate vocational education; 6 = higher vocational/professional education; 7 = academic degree; Duits & Kessels, 2014). In addition to the levels of education, we have also listed estimated years of education for comparison with the Anglo-Saxon educational system for descriptive purposes (Hochstenbach et al., 1998). Descriptive statistics of the YA and OA groups are described in Table 3.1. The data collection for this study has been approved by the local ethical committee of ZGT (September 12, 2016, ZGT16-22) and Radboud University (ECG2012-1304-025).

Materials

In OA, general cognitive functioning was assessed with the MoCA (Nasreddine et al., 2005). To estimate the premorbid verbal intelligence level in all participants, the Dutch version of the National Adult Reading Test (NART) was administered (Schmand et al., 1991). As descriptive measure of WM functioning, the Digit Span subtest of the WAIS-IV (Wechsler, 2008) was administered. Musical sophistication was assessed with two perceptual tests (Beat Perception and Melody Memory) and the Self-Report Inventory of the Goldsmiths Musical Sophistication Index v1.0 (Gold-MSI, Müllensiefen et al., 2014). The questionnaire comprised 31 statements on musical engagement and behaviour and some additional questions (e.g., number of musical instruments played, formal music training, number of hours listening to music per day) and consisted of the subscales Active Involvement, Perceptual Skills, Musical Training, Emotions, and Singing Skills and a general index; General Sophistication. The English version of the questionnaire has good psychometric properties.

Table 3.1

Descriptive statistics of the participants

	Young adults (*N* = 20) ***M(SD)***	**Older adults (*N* = 27)** ***M(SD)***	***p*-value**
Age	20.25 (1.86; 18–23)	72.63 (6.98; 65–91)	<.001
Sex (men:women)	5:15	8:19	.726
Education level	5# (.68)	5# (.95)	.015
Years of education	12.15 (2.71)	10.78 (2.45)	.076
NART-IQ	87.00 (6.91; 80–100)	106.15 (15.46; 73–140)	<.001
MoCA	-	27.07 (1.82)	
WAIS-IV Digit Span			
Forward	8.80 (1.32)	8.26 (2.03)	.305
Backward	8.65 (2.37)	7.85 (2.18)	.238
Sorting	9.80 (1.94)	7.63 (1.86)	<.001
Gold-MSI			
Beat Perception	13.10 (2.47)	10.96 (2.77)	.009
Melody Memory	7.55 (2.06)	7.00 (2.39)	.413
Self-Report Inventory			
General Sophistication	67.50 (15.41)	51.74 (16.65)	.002
Active Engagement	35.85 (7.95)	23.26 (7.85)	<.001
Perceptual Abilities	42.25 (7.71)	34.96 (9.49)	.007
Musical Training	19.05 (8.31)	15.56 (8.42)	.164
Emotions	27.10 (5.32)	22.93 (6.03)	.018
Singing Abilities	29.25 (8.03)	22.85 (7.12)	.006

Note. Mean scores and differences between young and older adults. Standard deviations are shown between parentheses. Between group differences were tested with independent-samples *t*-tests. Differences in sex distribution were tested using a Chi-square test. Differences in distribution of education level were tested using a Mann-Whitney *U* test. Note that the significant NART-IQ difference between both groups was driven by one outlier in the older adults, who had an estimated IQ of 140. MoCA = Montreal Cognitive Assessment. NART-IQ = NART IQ-estimation. WAIS-IV = Wechsler Adult Intelligence Scale-IV. # = Median/Mode.

Figure 3.1

Musical notation of the musical digit span task

Note. Typical examples of the four task conditions (8- digit sequences), showing two digit sequences per condition. a) spoken condition, b) pitch condition, c) rhythm condition, d) melody condition.

The experimental digit span task used in this study was partly based on the method used by Silverman (2007), though combined with the standard procedure that is also applied in the WAIS-IV Digit Span subtests in which digit sequences of increasing lengths are presented with two different sequences per length (Wechsler, 2008). We used 32 digits sequences of mono-syllabic digits (1, 2, 3, 4, 5, 6, 8, 10) of increasing lengths (5, 6, 7, 8 digits), exempting the numbers 7 and 9 (because these are multi-syllabic digits in Dutch with melodic consequences in the sense that two tones would be needed for one number). The digits were pseudo-randomly assigned to the melodies. Each digit occurred only once in each sequence. The task started with two 5-digit sequences, followed by two 6-, 7- and 8-digit sequences. There were four task conditions: spoken, sung to an unfamiliar simple isochronous five-tone pitch sequence ("pitch"), spoken to an unfamiliar rhythmic pattern with varying durations ("rhythm"), and sung to an unfamiliar isochronous five-tone pitch sequence with an added rhythmic pattern with varying durations ("melody").

The pitch sequence was based on the pitches C, D, E, G and A (in the key of C major, starting on a C, moving upward and eventually returning back to a C), while pitch intervals were restricted to a major third or less. Quarter notes (quavers), eighth and half notes were used in the rhythm and melody conditions, only quarter notes were used for the spoken and pitch conditions (See Figure 3.1 for an example of the musical notation in the different conditions).

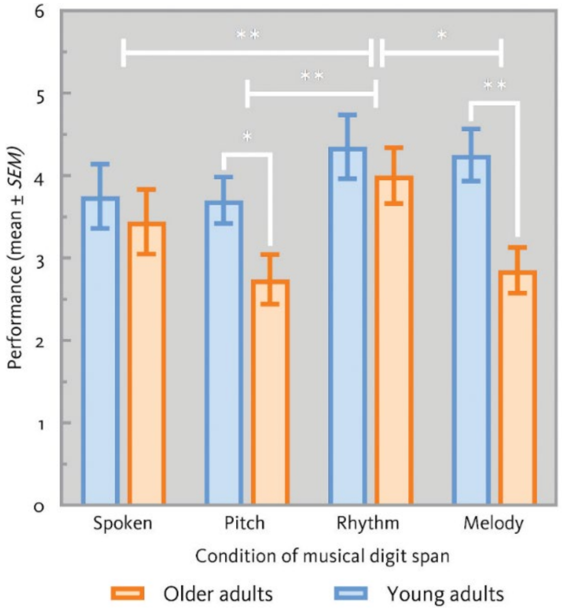
Procedure

All tests were administered in the same order: MoCA (only for the OA), WAIS-IV Digit Span, NART, Gold-MSI Beat Perception, musical digit span, Gold-MSI Melody Memory, and finally the Gold-MSI Self-Report Inventory. The study took place in a quiet room though in different settings (i.e., home, university room), making sure there were no other people, or other possible distractions present. All data of the participants were stored and analysed in an anonymized way.

The four conditions of the experimental digit span task were administered in a counterbalanced way (to control for learning or fatigue effects); that is, one participant might have the order spoken, pitch, melody, rhythm, while another participant might have the order pitch, rhythm, spoken, melody (a total of 24 possible orders of administration, see Supplementary Table 3.1 [Appendix B] for details). To control for carry-over (e.g., fatigue or practice) effects and order effects participants were randomly assigned to one of the 24 possible orders. As we intended to include 30 participants in each group, then each possible order would have occurred at least once in both a YA and OA participant. The stimuli were prerecorded mp4 sound files using a female soprano voice and played on a laptop, initially using headphones in the OA group but for practical reasons we switched to the use of speakers (Philips SPA 2200/00). The volume was adjusted for each participant and it was checked beforehand whether the participant could hear it well enough. Participants were instructed as follows: “You will now hear a number of digits. Listen carefully, because you will only hear them once. You will hear them either in a sung or spoken manner. Afterward you must repeat the digits in the same order you heard them. If the digits have been sung, you can choose whether you recite the numbers or sing them back.” A spoken example of a digit span was provided at the beginning of the test. After presentation of each digit sequence, the participant was asked to recall the digits in the same order as presented (they had the free choice to sing or speak). The experimenter wrote down the administration order, the participant’s response, and the chosen modality of the answers (sung or spoken). For each correctly produced sequence (i.e., all presented digits in the same order), one point was awarded. In each condition, the maximum score was eight points.

Figure 3.2

Performance of young and older adults on the musical digit span task



Note. Mean number correctly reproduced digit sequences (± SEM) in the four task conditions for the young and older adults, showing the differences between the groups and between task conditions. * $p < .05$, ** $p < .01$ (one-tailed).

Analyses

A (mixed-model) 2 × 4 repeated-measures analysis of variance (ANOVA) was computed using SPSS (Statistical Package for the Social Sciences, IBM) version 27.0. The between-subject factor was group (two levels: YA versus OA), the within-subject factor was experimental digit span task condition (four levels: spoken, pitch, rhythm, melody), and the dependent variable was experimental digit span task score, with planned follow-up comparisons. For the planned independent-samples *t*-tests to further investigate interaction effects, we computed the one-tailed *p*-value for the pitch, rhythm and melody conditions as we had specific hypotheses regarding the direction of these effects. In addition, to examine whether musical expertise might be a confounder, we conducted an analysis of covariance (ANCOVA) with next to administration order, musical expertise as a covariate, using the Melody Memory test score and the Musical Training subscale score from the Self-Report Inventory of the Gold-MSI. Alpha was set at 0.05 throughout and effect sizes (η_p^2) were reported for all factors.

Results

All assumptions for analysis of variance were met, except for the assumption of sphericity, for which we applied the Huyn-Feldt correction. Figure 3.2 shows the performance on all 4 conditions in the YA and OA (See also Supplementary Table 3.2 [Appendix C] for means and *SD*s).

YA and OA did not differ in their overall performance in general on the experimental digit span task ($F(1,45) = 3.58$, $p = .065$, $\eta_p^2 = .074$). However, both groups' performances differed across the four conditions ($F(2.68,120.37) = 6.10$, $p = .001$, $\eta_p^2 = .119$); planned simple contrasts revealed a better performance in the rhythm versus the spoken condition ($p = .006$, $\eta_p^2 = .155$), rhythm versus pitch ($p = < .001$, $\eta_p^2 = .323$) and rhythm versus melody ($p = .014$, $\eta_p^2 = .127$). No significant differences were found between the pitch and spoken ($p = .101$), melody and spoken ($p = .870$) and melody and pitch conditions ($p = .095$). No significant Group × Condition interaction effect was found ($F(2.68,120.37) = 2.65$, $p = .058$, $\eta_p^2 = .056$). Planned independent-samples *t*-tests revealed a significantly worse performance for the OA compared to YA in the pitch ($t(45) = –2.26$, $p = .015$, $d = 1.44$) and melody conditions ($t(45) = –3.33$, $p = .001$, $d = 1.42$), but no significant differences between YA and OA in the spoken ($t(45) = –.54$, $p = .593$, $d = 1.92$) and rhythm conditions ($t(45) = –.68$, $p = .250$, $d = 1.74$).

Also, we found significantly higher scores for the YA compared to OA on the Gold-MSI Beat Perception test ($t(45) = -2.74$) and the Self-Report Inventory General Sophistication variable ($t(45) = –3.31$) and subscales Active Engagement ($t(45) = –5.41$), Perceptual Abilities ($t(45) = –2.81$), Emotions ($t(45) = –2.47$) and Singing Abilities ($t(45) = –2.89$). Therefore, we only included the Melody Memory test and the subscale Musical Training in the ANCOVA, because the Beat Perception test and the General Sophistication variable and other subscales of the Self-Report Inventory showed a priori group differences, which is problematic for inclusion as a covariate (Miller & Chapman, 2001). The Musical Training subscale reflects the degree to which a person has been musically active (i.e., extent of musical training and practice and degree of self-assessed musicianship, Müllensiefen et al., 2014) during the life-span and the Melody Memory task is also positively correlated to the subscale Musical Training, related to the degree of musical training of a person (Müllensiefen et al., 2014). Finally, to control for possible order effects regarding the order of administration of the conditions, we included Administration Order of the experimental digit span task as a covariate. Musical Training ($F(1,39) = 0.16$, $p = .688$), Melody Memory ($F(1,39) = 3.38$, $p = .073$) and Administration Order ($F(1,39) = .01$, $p = .923$) did not significantly affect the performance on the experimental digit span task.

Discussion

The current study aimed to examine the effects of different musical presentations (i.e., rhythm, pitch, and melody) on working memory performance of cognitively unimpaired YA and OA as measured by a forward digit span task. Additionally, we aimed to clarify the possible effect of musical expertise on the degree of benefit of musical presentation. Results showed that YA and OA performed equally well in general on the experimental digit span on the four conditions (i.e., rhythm, pitch, melody and spoken). In YA and OA, rhythm facilitated digit span performance, whereas pitch and melody did not show any differences as compared to spoken presentation. Additionally, our results showed a significantly worse performance for OA compared to YA in the pitch and melody conditions. Finally, musical training did not affect the degree of benefit of a musical presentation in YA and OA and the administration order of the four conditions of the experimental digit span task did not affect digit span recall.

Consistent with prior research that documented positive effects of musical mnemonics on working memory functioning in university students (e.g., Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019) our hypothesis that both groups would perform best in the rhythm condition was confirmed, suggesting that a rhythmic presentation may indeed positively affect working memory functioning in YA and OA. Thus, we replicate previous results by extending these to a group of young adults that is more representative of the general population (given the higher level of education and higher than average socio-economic status of university students), as well as to a group of cognitively unimpaired older adults. The previously provided explanation that time structure or rhythm facilitates sequential recall by the ability to chunk (e.g., Purnell-Webb & Speelman, 2008; Silverman, 2012) is also supported for older adults.

Contrary to our expectations that both groups would also perform worst in the pitch-varying (i.e., our “pitch” and “melody”) conditions (Silverman, 2007, 2010) we did not find any significant differences between the pitch versus spoken and melody versus spoken conditions in the planned contrast analysis. Possibly, these divergent results can be explained by the complexity of each separate element, that is, a shorter length of our digit sequences and accompanying musical stimuli (i.e., our pitch and melodic sequences) and the combination of accent structures for this specific pairing, resulting in a reduced level of overall complexity (i.e., a “match” or “good fit”) (see chapter 2). Potentially, the combined complexity of the verbal and musical stimuli of Silverman (2007, 2010) in these conditions (i.e., “pitch” and “melody” conditions) may have been too high, resulting in working memory overload.

Furthermore, we expected OA to benefit to a greater extent than YA from rhythmic presentation, as rhythmic presentation may reduce the need to rely on declining working memory and executive resources due to normal ageing (e.g., Hester et al., 2004). However, both groups showed benefits of rhythmic presentation to a similar extent. As both groups consist of relatively high-functioning individuals, and working memory is even more affected in clinical conditions (Baddeley et al., 1991), future research is needed in clinical populations to further investigate this hypothesis.

In turn, we hypothesized that OA might also display faster WM overload when there was only pitch, or a pitch component was added to rhythm (Silverman, 2007, 2010) and indeed our results showed that in OA, as compared to YA, their performance was significantly worse in both pitch and melody conditions. Possibly the addition of pitch in the pitch and the melody conditions, even though this was created in a simple tonal context, can be seen as extra information to be processed, increasing the complexity of the stimulus (see chapter 2) resulting in working memory overload in OA.

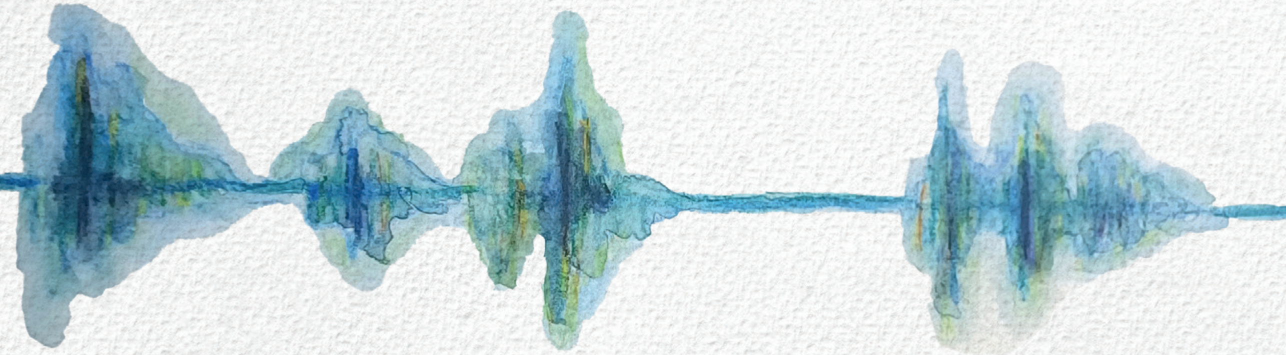
In line with our hypotheses regarding the influence of musical expertise on the beneficial effects of musical presentation of digits, our results showed that musical expertise in YA indeed did not have an influence on the benefit of musical presentation (e.g., Jellison & Miller, 1982; Kilgour et al., 2000; Racette

& Peretz, 2007; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019). We also did not find support for our hypotheses that musically experienced OA would perform better on rhythmically presented material and would show a less detrimental performance on melodically presented material as compared to less musically experienced OA. Finally, in line with previous findings by Müllensiefen et al. (2014), we found that the musical expertise ratings were lower in the OA than the YA.

To conclude, the current study extends previous research findings in students (e.g., Silverman, 2007, 2010, 2012), providing the first findings of the facilitating effect of rhythm in a musical presentation of a working memory task in cognitively unimpaired young and older adults to a similar extent. Potential limitations that may be considered are that in this field of research the possibility of recruitment bias exists, and therefore the findings may not be generalizable to all older adults. Furthermore, due to the cross-sectional nature of our design, the findings may be confounded by possible cohort differences between OA and YA, in terms of life experiences with regard to, for example, education or culture (Harada et al., 2013). As a consequence of our sample size, possible power issues may exist due to the amount of conditions and covariates. Also, we did not examine serial position (i.e., of the digits) effects, being consistently reported in research using digit span tasks (cf., Silverman, 2007, 2010, 2012). Furthermore, the chosen musical parameters of the experimental task might have affected the outcome, potentially limiting the generalizability of the current findings to all musically embedded materials. However, the currently chosen low pitch complexity would arguably only weaken the findings of reduced performance for pitch-based structures in comparison to more complex or random pitch assignment, and are thus unlikely to have led to a spurious result. Finally, the presentation of the musical stimuli was not fully controlled (i.e., performed in a naturalistic setting). These limitations may have attenuated some effects, though, since we adopted a within-subject design for the musical presentation conditions we argue that these would not have affected the outcome of our study.

As working memory is not only affected by normal ageing, but even more so in clinical conditions (Baddeley et al., 1991; Eikelboom et al., 2020), more research aimed at the effects of musical mnemonics is needed, in particular by means of rhythm, thereby focusing on patients with possible working memory disorders (e.g., persons with MCI or Alzheimer's dementia). In this way, future research could complement existing studies showing promising results of musical mnemonics in persons with even severe AD, which to date have mainly focused on improving episodic memory recall (e.g., Oostendorp & Montel, 2014; Ratovohery et al., 2019) also including the role of musical expertise (Baird et al., 2017). Follow-up research conducting a moderation analysis by means of larger groups, in order to examine the effects of musical expertise as a covariate is recommended. Finally, future research could also focus on other verbal material, such as words, as these may activate other verbal WM maintenance strategies (e.g., semantic strategies) as compared to digits (i.e., phonological strategies) (Chevalère et al., 2020).

As serial position (i.e., primacy and recency) effects are consistently reported in digit span tasks, clinicians designing musical mnemonics are recommended to emphasize the middle parts of the musical mnemonic by use of rhythm and to place the most important to-be-remembered information at the beginning or the end of the musical mnemonic (Silverman, 2012; Silverman & Schwartzberg, 2019). Regarding future interventions it is furthermore important to maximize the potential of compensating for memory problems in persons with MCI or AD by personalizing the musical stimulus (e.g., emotional valence, pleasantness, genre, familiarity) to individual aspects (e.g., cognitive capacity, age, musical preferences, expertise, and responsivity) (see chapter 2).



Chapter 4

Effects of musical mnemonics in people with amnestic Mild Cognitive Impairment

---

Published as:
Derks-Dijkman, M. W., Schaefer, R. S., Baan-Wessels, L., van Tilborg, I. A. D. A., & Kessels, R. P. C. (2024). Effects of musical mnemonics on working memory performance in cognitively unimpaired older adults and persons with amnestic mild cognitive impairment. *Journal of Neuropsychology, 18*(2), 286–299. https://doi.org/10.1111/jnp.12342

Abstract

Episodic memory (EM) and working memory (WM) are negatively affected by healthy ageing, and additional memory impairment typically occurs in clinical ageing-related conditions such as amnestic mild cognitive impairment (aMCI). Recent studies on musical mnemonics in Alzheimer's dementia (AD) showed promising results on EM performance. However, the effects of musical mnemonics on WM performance have not yet been studied in (a)MCI or AD. Particularly in (a)MCI the use of musical mnemonics may benefit the optimisation of (working) memory performance. Therefore, in the present study, we examined the effects of musical presentation of digits consisting of pre-recorded rhythms, sung unfamiliar pitch sequences, and their combinations, as compared to spoken presentation. Furthermore, musical expertise was assessed with two perceptual tests and the Self-Report Inventory of the Goldsmiths Musical Sophistication Index. Thirty-two persons with aMCI and 32 cognitively unimpaired older adults (OA) participated in this study. Confirming and extending previous findings in research on ageing, our results show a facilitating effect of rhythm in both cognitively unimpaired OA and persons with aMCI (p = .001, η_p^2 = .158). Furthermore, pitch (p = .048, η_p^2= .062) and melody (p = .012, η_p^2= .098) negatively affected performance in both groups. Musical expertise increased this beneficial effect of musical mnemonics p = .021, η_p^2 = .090). Implications for the future design of music-based memorisation strategies in (a)MCI are discussed.

Introduction

One characteristic of normal cognitive ageing is memory decline. With advancing age episodic memory (EM) declines, and working memory (WM) capacity and efficiency also deteriorates (Nyberg et al., 2012). By definition, the memory performance of older adults who show 'normal' cognitive ageing is in the unimpaired range when compared to age-and education-adjusted normative data, as this ageing-related decline is not the result of neurodegenerative disease. In contrast, cognitive performance in persons with mild cognitive impairment (MCI) is by definition impaired, that is, exceptionally low compared to age- and education-adjusted normative data (cf. Guilmette et al., 2020). Cognitive impairments may be present in one or more cognitive domains. Persons for whom cognitive impairments are in the memory domain are classified as having the amnestic subtype of mild cognitive impairment (aMCI; Petersen et al., 2014). This memory deficit may or may not be accompanied by impairments in other, non-memory domains, and individuals with aMCI are most at risk to develop Alzheimer's dementia (AD) within the next few years (Albert et al., 2011). While most studies to date have focused on EM function in aMCI patients, there is increasing evidence that WM performance, especially in WM tasks with high-executive demands, is also compromised in aMCI patients (e.g., Gagnon & Belleville, 2011; Kirova et al., 2015; van Geldorp et al., 2015).

To date there is no pharmacological treatment available for MCI, while there is some evidence for possible beneficial effects of non-pharmacological interventions (such as cognitive training or physical exercise) (Petersen et al., 2014). One way to improve memory performance and reduce limitations in everyday life is by the use of mnemonics, that is, applying memory strategies in order to ameliorate memory performance, which may promote independent living in cognitively impaired persons (Ross et al., 2022). In their systematic review, Ross et al. (2022) reported several compensation strategies of which the use depended on the cognitive status of the participants, ranging from internal strategies (e.g., verbalization, visualizing, repetition), external strategies (e.g., reminder systems like notes, calendars, lists) to behavioural strategies (e.g., accepting support and reducing expectations). Older adults with cognitive impairment reported the use of these behavioural strategies most frequently. Incorporating music into such non-pharmacological interventions may be promising.

Based on the results of a systematic review in cognitively unimpaired individuals and in individuals with memory impairment, it can be concluded that musical mnemonics may help to learn and remember verbal information (see chapter 2). Musical mnemonics use a musical presentation of the to-be-remembered information (as also described in Ferreri & Verga, 2016), also referred to as 'music as a structural prompt' (Madsen et al., 1975). Melodic songs to teach, for example, motor and academic skills have been applied in educational settings and for therapeutic purposes, with 'the ABC-song' as a well-known example (Wolfe & Hom, 1993). To date, however, studies on musical mnemonics have mainly focused on WM performance in young adults (e.g., Silverman, 2007, 2010, 2012), with a growing body of literature on ageing adults and patient populations with EM impairments, such as AD patients (e.g., Ratovohery et al., 2019; for an overview, see chapter 2). However, to our knowledge, none of the previous studies have focused on the use of musical mnemonics to improve WM performance in (a)MCI or AD.

In previous research in cognitively unimpaired young and older adults (see chapter 3), a modified version of the forward digit span task was used, which was partially based on a previous method described by Silverman (2007). This experimental task was presented in four task conditions: (1) digit sequences sung to a simple unfamiliar isochronous five-tone pitch sequence ('pitch'), (2) sung to a five-tone unfamiliar pitch sequence with a rhythmic pattern with varying durations added ('melody'), (3) spoken to an unfamiliar rhythmic pattern with varying durations ('rhythm'), or (4) presented in the standard way (i.e., spoken at a 1 digit-per-second pace). A facilitating effect of rhythm in both young and older adults was found, and performance was negatively affected in the conditions that included pitch (i.e., the 'pitch' and 'melody' conditions) in older adults only (see chapter 3).

The current study aimed to examine the effects of musical versions of the digit span paradigm on WM performance both in cognitively unimpaired older adults (OA) and persons with aMCI. Specifically, we were interested in which specific aspects of musical presentation were possible key components (i.e., rhythm, pitch or melody). Furthermore, the participant's musical expertise, specifically engagement and listening experience, was taken into account in relation to the possible beneficial effects of the musical mnemonic using the Self-Report Inventory and two subtasks of the Goldsmith Musical Sophistication Index (Gold-MSI, Müllensiefen et al., 2014).

In line with previous findings of Ratovohery et al. (2019) in AD patients, we hypothesized that OA will outperform persons with aMCI on the digit span task in general, regardless of musical presentation. Second, based on previous findings in cognitively unimpaired young and older adults (see chapter 3) and the findings of Silverman (2007, 2010) in students, both OA and persons with aMCI are hypothesized to show the best performance in the 'rhythm' condition and worst in the 'pitch' and 'melodic' conditions. Furthermore, we hypothesized that persons with aMCI might show more benefit from the expected (beneficial) effects of rhythm as compared to OA, the latter having a better preserved WM performance than aMCI patients (see chapter 3), for whom rhythmic presentation may diminish the importance of relying on more limited executive resources due to age-related disorders including (a)MCI and AD (e.g., Gagnon & Belleville, 2011; Kirova et al., 2015) possibly providing additional structure through temporal chunking mechanisms (Purnell-Webb & Speelman, 2008; Silverman, 2012), thus reducing stimulus complexity (that is, the combined complexity of the musical and verbal stimulus together, see chapter 2). Also, based on empirical evidence in OA (chapter 3), we expected that in persons with aMCI – who are expected to have a worse WM performance than OA – faster WM overload would occur in the complex conditions (i.e., the 'pitch' and 'melody conditions'). Possibly explained through only varying pitch (no rhythm – that is – no temporal chunking component) in the 'pitch' condition and the addition of a pitch component to a rhythmic pattern (i.e., in our 'melody' condition) leading to extra information to be processed, with as a result a higher stimulus complexity possibly causing working memory overload (for a model on musical stimulus complexity, see the systematic review presented in chapter 2).

Finally, we expected no moderating effect of musical expertise in OA, based on previous findings in cognitively unimpaired young and older adults (see chapter 3). In chapter 3, we hypothesized that the absence of a moderating effect of musical expertise in OA may have been related to the relatively high-functioning older adults that participated in this study. As the level of education in the present sample is highly similar to that of the sample used in chapter 3, we expect similar results here. However, based on a small body of previous literature on musical mnemonics in AD patients (see chapter 2), we hypothesized that musical expertise may moderate the beneficial effect of musical presentation in persons with aMCI (cf. Baird et al., 2017). That is, musical expertise could make it easier to effectively compensate for their WM impairment through the use of music, possibly by their engrained previous exposure to music offering additional structure, instead of being distracted by the music (causing WM overload).

Materials and methods

Participants

Based on previous research using similar tasks (Silverman, 2010, 2012), and our main aim to compare within-subject condition effects as well as the aMCI patient versus older control performance, we aimed for 30 participants in each group. This sample size enables us to detect small to medium effect sizes ($f^2 = .12$) for the between factors ($1-\beta = .86$), small effect sizes ($f^2 = .02$) for the within factors ($1-\beta = .92$), and small effect sizes ($f^2 = .01$) for the within-between interactions to ($1-\beta = .81$) (G*Power 3.1.9.7, $\alpha = .05$, $r = .7$, Faul et al., 2009). OA were participants who visited the Department of Medical Psychology of the Ziekenhuisgroep Twente (a general hospital located in Almelo and Hengelo, the Netherlands) in the context of the memory clinic, who had no cognitive impairment, or were cognitively unimpaired volunteers. Thirty-two cognitively unimpaired older adults (OA; 11 men, 21 women; age: $M = 72.2$, $SD = 6.8$, range = 65–91) were included. The data of 27 OA participants of these was re-used from a previous study (see chapter 3). OA were included when they had sufficient vision and hearing to perform the neuropsychological tests and were able to understand, read and communicate in Dutch. Exclusion criteria were a diagnosis of mild cognitive impairment (MCI), dementia, a stroke, a psychiatric disease or excessive drug or alcohol use.

We also recruited 32 persons with amnestic mild cognitive impairment (aMCI; 19 men, 13 women; age: $M = 75.0$, $SD = 6.4$, range = 60–87), who were all outpatients of the memory clinic of the Ziekenhuisgroep Twente general hospital in Almelo and Hengelo, the Netherlands. Clinical diagnoses were made in a multidisciplinary setting by a team of geriatricians, neurologists and neuropsychologists, using the results of extensive neuropsychological testing (with all cognitive domains covered), laboratory investigations, neurological examination and neuroimaging data (MRI), the clinical interview with patient and caregiver (assessment of daily functioning) and medical and psychiatric history taking as well as other important (e.g., biographical) information. Fifteen patients met the criteria for single-domain aMCI, 17 were classified as having multiple-domain aMCI (cf. Petersen et al., 2014) and the Clinical Dementia Rating (CDR) was .5 for all patients.

We used the Dutch educational system which is based on education levels, comparable to the classification of education levels of UNESCO (2011), using a 7-point scale (Duits & Kessels, 2014), as years of education are not informative in our educational system. We have listed both education level and estimated years of education for comparison with the Anglo-Saxon educational system for descriptive purposes (Hochstenbach et al., 1998).

Materials

Neuropsychological tests and questionnaires

General cognitive functioning was assessed with the Dutch version of the Montreal Cognitive Assessment (MoCA 7.1; Nasreddine et al., 2005). The Dutch version of the National Adult Reading Test (NART, Schmand et al., 1991) was administered to estimate premorbid verbal intelligence level in all participants. We administered the WAIS-IV Digit Span subtest (Wechsler, 2008) as a descriptive measure of WM functioning. In addition, the Geriatric Depression Scale (GDS-30, Yesavage et al., 1983) was used as an index of depressive symptoms in both groups. Descriptive statistics of the OA and aMCI groups are displayed in Table 4.1.

Experimental digit span task

The experimental digit span task was partly based on a previous method used by Silverman (2007). Here we integrated it with the standard procedure which is also applied in the Digit Span subtests of the WAIS-IV (that is, sequences increasing in length, with two different sequences per length presented, Wechsler, 2008). The task consisted of 32 sequences of mono-syllabic digits (1, 2, 3, 4, 5, 6, 8, 10), excluding the multi-syllabic digits numbers 7 and 9 in Dutch (i.e., 'ze-ven' and 'ne-gen'), as those would have had melodic consequences (i.e., for one number, two tones would have been needed). We assigned the digits pseudo-randomly to the melodies. In each sequence, each digit occurred only once. The digit sequences increased in length (5, 6, 7, 8 digits), starting with two 5-digit sequences, followed by two sequences consisting of 6, 7 and 8 digits respectively. For each length of digit-sequence (i.e., 5, 6, 7, 8 digits), the digits were presented in four conditions: spoken (A), sung to a simple unfamiliar isochronous five-tone pitch sequence ("pitch", B), spoken to an unfamiliar rhythmic pattern with varying durations ("rhythm", C), sung to an unfamiliar five-tone pitch sequence with a rhythmic pattern with varying durations added ("melody", D) (For an example of the scoring form, see Supplementary Table 4.1 [Appendix D]).

Table 4.1

Descriptive statistics of the participants

	Older adults (*N* = 32), *M* (*SD*)	**aMCI (*N* = 32), *M* (*SD*)**	***p*-value**
Age	72.22 (6.78; 65–91)	74.97 (6.36; 60–87)	.099
Sex (men:women)	11:21	19:13	.045
Educational level	5[a] # (1.04)	4# (1.48)	.133
Years of education	11.23[a] (2.83)	11.75 (9.30)	.765
NART-IQ	107.09 (16.37; 73–140)	100.93[b] (19.62; 67–144)	.183
MoCA	26.63 (2.21)	21.17[c] (2.66)	<.001
GDS-30	3.93[d] (3.97)	6.50[b] (4.23)	.018
WAIS-IV digit span			
Forward	8.31 (2.07)	7.91 (1.65)	.389
Backward	7.91 (2.05)	6.81 (1.53)	.019
Sorting	7.66 (1.81)	5.81 (2.60)	.002
Gold-MSI			
Beat Perception	10.84 (2.92)	10.53 (3.14)	.682
Melody Memory	7.22 (2.37)	7.91 (1.97)	.212
Self-Report Inventory			
General Sophistication	54.03 (17.10)	53.16[e] (14.32)	.828
Active Engagement	24.97 (8.47)	21.39 (8.12)	.092
Perceptual Abilities	35.69 (9.08)	37.90 (7.80)	.303
Musical Training	16.59 (8.91)	15.13 (8.36)	.504
Emotions	23.78 (6.67)	23.32 (5.30)	.764
Singing Abilities	23.63 (7.11)	24.55 (5.52)	.568

Note. Mean scores and differences between older adults and persons with aMCI. Standard deviations are shown between parentheses. Between-group differences were computed with independent-samples *t*-tests. A Chi-square test was used to test differences in sex distribution. Differences in the distribution of education level were tested using a Mann-Whitney *U* test. #, Median.

Abbreviations: GDS-30, Geriatric Depression Scale (30-item version); MoCA, Montreal Cognitive Assessment; NART-IQ, NART IQ- estimation; WAIS-IV, Wechsler Adult Intelligence Scale-IV.

[a] Data of one OA were missing.

[b] Data of two aMCI participants were missing.

[c] Data of three aMCI participants were missing.

[d] Data of two OA were missing.

[e] Data of one aMCI participant for the Self-Report Inventory (General Sophistication variable and all subscales) were missing.

The pitch sequences were composed using the pitches C, D, E, G and A (C major key, started on a C, moved upward and returned back to a C). We restricted pitch intervals where possible to a major third or less. In the spoken and pitch conditions only quarter notes (quavers) were used, while quarter notes, eighth and half notes were used in the rhythm and melody conditions (for musical notation of the different conditions, see Figure 4.1).

Figure 4.1

Musical notation of the 8-digit sequences in the four conditions

Note. Music notation of the four task conditions, showing two digit sequences per condition. (A) Spoken condition, (B) Pitch condition, (C) Rhythm condition, (D) Melody condition.

Musical expertise

We assessed musical expertise with a research version (Dutch translation used in chapter 3) of the Self-Report Inventory and two perceptual tests (Beat Perception and Melody Memory) of the Goldsmiths Musical Sophistication Index v1.0 (Gold-MSI, Müllensiefen et al., 2014). The questionnaire consisted of 31 statements on musical engagement and behaviour (agreement with each statement scored on a Likert-scale from one [totally disagree] to seven [totally agree]) and some additional questions (e.g., formal music training, number of hours listening to music per day, number of musical instruments played) and comprised a general index; General Sophistication and the subscales Musical Training, Perceptual Skills, Active Involvement, Emotions and Singing Skills, with good psychometric properties for the English (Cronbach's alpha between .79 and .93 for all five factors and the General Sophistication factor, Müllensiefen et al., 2014) and German version of the questionnaire (Cronbach's alpha between .72 and .91 for all five factors and the general factor; Schaal et al., 2014).

Procedure

All tests were administered in a fixed order, but the four conditions of the musical digit span task were administered in a counterbalanced way (i.e., in one participant the administration order of the conditions might be pitch, rhythm, spoken, melody, while the order in another participant for example might be spoken, pitch, melody, rhythm); resulting in a total of 24 possible administration orders (see Supplementary Table 3.1, [Appendix B]). Assignment to one of the 24 possible orders was random in order to control for order and carry-over (e.g., practice or fatigue) effects. As we intended to include 30 participants per group, then each possible order would have occurred at least once in both an OA and aMCI participant. The stimuli consisted of pre-recorded mp4 sound files played on a computer using a female soprano voice, presented through a previously published procedure (see chapter 3), in which over-ear headphones (Philips SHP6000) were used initially, but a switch was made to speakers (Philips SPA 2200/00) for practical reasons. Beforehand it was checked with the participant whether the participant could hear it well enough and if necessary the volume was adjusted. At the start of the test, a spoken example of a digit sequence was provided as an example. After each presentation of a digit sequence, the participants had to recall the digits exactly in the same order, having the free choice to speak or sing. Participants received as much time as needed to recall the sequences. The experimenter wrote down the response, the modality of the answers (spoken or sung) and the administration order. No feedback was provided. No stopping rule was applied (unless the participant could not complete the task). One point was awarded for each correctly recalled sequence (i.e., all digits in the exact order as presented), resulting in a maximum score of eight points for each condition. All data were stored and analysed in an anonymised way. The study took place in a quiet room in different settings (i.e., Medical Psychology department of Ziekenhuisgroep Twente hospital, or home of the participant), assuring there were no other people, or other possible distractions present. For more details and verbatim instructions see chapter 3.

All participants gave their written informed consent and voluntarily participated in this study. The data collection for this study has been approved by the Ethics Committee of the Faculty of Social Sciences of the Radboud University (ECG2012-1304-025) and the local ethical committee of the Ziekenhuisgroep Twente hospital (September 12, 2016, ZGT16-22).

Analyses

A (mixed-model) 2 × 4 repeated-measures analysis of variance (ANOVA) was computed using SPSS (Statistical Package for the Social Sciences, IBM) version 28.0. The between-subject factor was group (two levels: OA versus aMCI), experimental digit span task condition (four levels: spoken, rhythm, pitch, melody) was the within-subject factor, and the score on the experimental digit span task was the dependent variable, with planned follow-up comparisons. We planned independent-samples *t*-tests based on our specific *a-priori* hypotheses and we used the one-tailed *p*-value as we had specific hypotheses regarding the direction of these effects in the different groups. In addition, to examine the effect of musical expertise and whether administration order might be a confounder, we conducted an analysis of covariance (ANCOVA) with administration order and musical expertise as covariates. We used only the General Sophistication factor of the Gold-MSI as this scale most closely fits our definition of musical expertise, covering the general engagement of a participant with/a participant's interest in music. Effect sizes (η_p^2 or Cohen's *d*) were reported for all factors for the analyses of variance. Alpha was set at .05 throughout, as all comparisons were planned. Effect sizes were interpreted as small, medium and large based on convention (Cohen, 1988; Cohen's *d*: .2, .5, .8, η_p^2: .01, .06, .14 respectively).

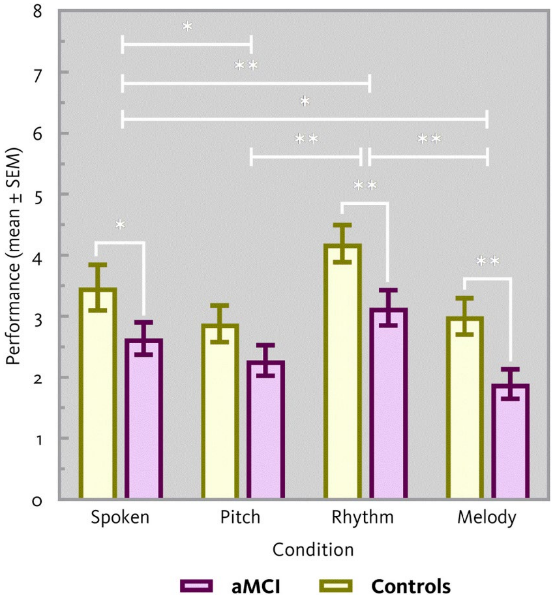
Results

Demographics and mean test values for both groups are shown in Table 4.1. All assumptions for the analysis of variance were met. Figure 4.2 shows the performance in the OA and in persons with aMCI on all four conditions (See also Supplementary Table 4.2 [Appendix E] for means and *SD*s).

Overall, OA outperformed aMCI patients in their performance on the experimental digit span task ($F(1, 62) = 6.77$, $p = .012$, $\eta_p^2 = .098$). Furthermore, the performance of both groups differed across the four conditions ($F(3, 186) = 14.80$, $p \leq .001$, $\eta_p^2 = .193$); planned simple contrasts revealed a better performance in the rhythm versus spoken condition ($p = .001$, $\eta_p^2 = .158$), rhythm versus pitch ($p \leq .001$, $\eta_p^2 = .330$) and rhythm versus melody condition ($p \leq .001$, $\eta_p^2 = .360$). Furthermore, a better performance was found in the spoken versus pitch ($p = .048$, $\eta_p^2 = .062$) and spoken versus melody condition ($p = .012$, $\eta_p^2 = .098$). No significant difference was found between the pitch and melody conditions ($p = .309$, $\eta_p^2 = .017$). No significant Group × Condition interaction effect was found ($F(3, 186) = 1.23$, $p = .300$, $\eta_p^2 = .019$). Planned independent-samples t-tests revealed a significantly worse performance for the aMCI group compared to OA in the spoken ($t(62) = -1.98$, $p = .026$, $d = 1.89$), rhythm ($t(62) = -2.72$, $p = .004$, $d = 1.75$) and melody conditions ($t(62) = -2.79$, $p = .004$, $d = 1.61$) but no significant difference between OA and aMCI in the pitch condition ($t(62) = -1.31$, $p = .097$, $d = 1.62$).

Figure 4.2

Performance of the older adults and aMCI on the musical digit span task



Note. Mean number correctly reproduced digit sequences (± SEM) in the four task conditions for the cognitively unimpaired older adults and persons with aMCI, showing the differences between the groups and between task conditions. *$p < .05$, **$p < .01$ (one-tailed).

We included the General Sophistication factor of the Self-Report Inventory of the Gold-MSI and administration order as covariates in the ANCOVA. Administration Order ($F(1, 57) = .58$, $p = .449$, $\eta_p^2 = .010$) did not significantly affect the performance on the experimental musical digit span task. General Sophistication ($F(1, 57) = 5.63$, $p = .021$, $\eta_p^2 = .090$) significantly affected the performance on the experimental digit span task. *Post-hoc* correlation analysis showed a positive direction of the correlations between General Sophistication and task performance on musically presented materials (spoken: $r = .272$, $p = .031$, rhythm: $r = .368$, $p = .003$, pitch: $r = .214$, $p = .093$, melody: $r = .144$, $p = .259$) (See Supplementary Table 4.3 [Appendix F] for the correlations per group). Despite the significant difference in depressive symptoms ($p = .018$) between both groups, the absolute difference between the groups was small and only four aMCI participants scored in the clinically relevant range. Therefore we argue that the findings are not confounded by group differences in mood.

Discussion

The present study aimed to examine the effects of musical presentations (i.e., pitch, rhythm and melody) of a forward digit span task on WM performance of cognitively unimpaired OA and participants with aMCI. In addition, possible beneficial effects of musical expertise were also assessed. Results showed that OA outperformed participants with aMCI on the experimental digit span task, regardless of musical presentation. Rhythm facilitated digit span performance in both the OA and the aMCI participants, whereas pitch and melody hampered the performance as compared to spoken presentation. Additionally, a significantly worse performance for the aMCI as compared to OA was found in the spoken, rhythm and melody conditions. Finally, musical expertise was shown to contribute to task performance when materials were musically presented.

In line with previously reported positive effects of musical mnemonics on WM performance in university students and cognitively unimpaired young and older adults (e.g., chapter 3; Silverman, 2007, 2010, 2012; Silverman & Schwartzberg, 2014, 2019) our hypothesis concerning the expected beneficial effects of rhythm in both groups was confirmed. Thus, rhythmic presentation positively affects WM performance, not only in cognitively unimpaired OA but also in participants with cognitive impairment (that is, aMCI). Therefore, we replicate and extend previous results, and suggest here that musical mnemonics may also improve WM performance in persons with (mild) cognitive impairment. A possible explanation for these findings is that rhythm or time structure facilitates chunking, which enhances WM performance (e.g., chapter 2 and chapter 3; Silverman, 2012), an explanation that is also supported for persons with aMCI.

In line with our expectations that both groups would also perform worst in our "pitch" and "melody" (that is, pitch-varying) conditions (see chapter 3; Silverman, 2007, 2010) we indeed found a significantly worse performance in the pitch and melody conditions compared to the spoken conditions. We previously argued based on findings of OA compared to younger adults that adding pitch to the pitch and melody conditions – even though created in a predictable tonal context – could result in 'extra' information that needs to be processed, thereby increasing the complexity of the stimulus (see chapter 2) resulting in WM overload, which could also apply here to not only the OA, but also the aMCI participants.

Furthermore, we hypothesized that aMCI would benefit to a larger extent from rhythmic presentation than OA, the latter having a better-preserved WM performance than aMCI patients, thus performing already at a higher level than aMCI and at the level of young adults (see chapter 3). Specifically, rhythmic presentation is thought to decrease the executive task demands, which would especially benefit the cognitively impaired aMCI group (e.g., Gagnon & Belleville, 2011; Kirova et al., 2015). However, both groups showed similar benefits of rhythmic presentation, suggesting that rhythm is an effective element of a musical mnemonic regardless of expected (and observed) differences in WM performance between OA and aMCI.

Also, based on empirical evidence in OA (see chapter 3), we hypothesized that persons with aMCI would experience a faster WM overload in the conditions with only varying pitch (but no rhythm) or a rhythmic pattern with an added pitch component (i.e., our 'melody' condition), as a result of the stimulus complexity. However, planned comparison revealed that both groups did not differ in their performance on the pitch condition. Also, the aMCI patients showed no evident additional performance hindrance in the melody condition. These results suggest that here a higher stimulus complexity results in WM overload regardless of (mild) cognitive impairment.

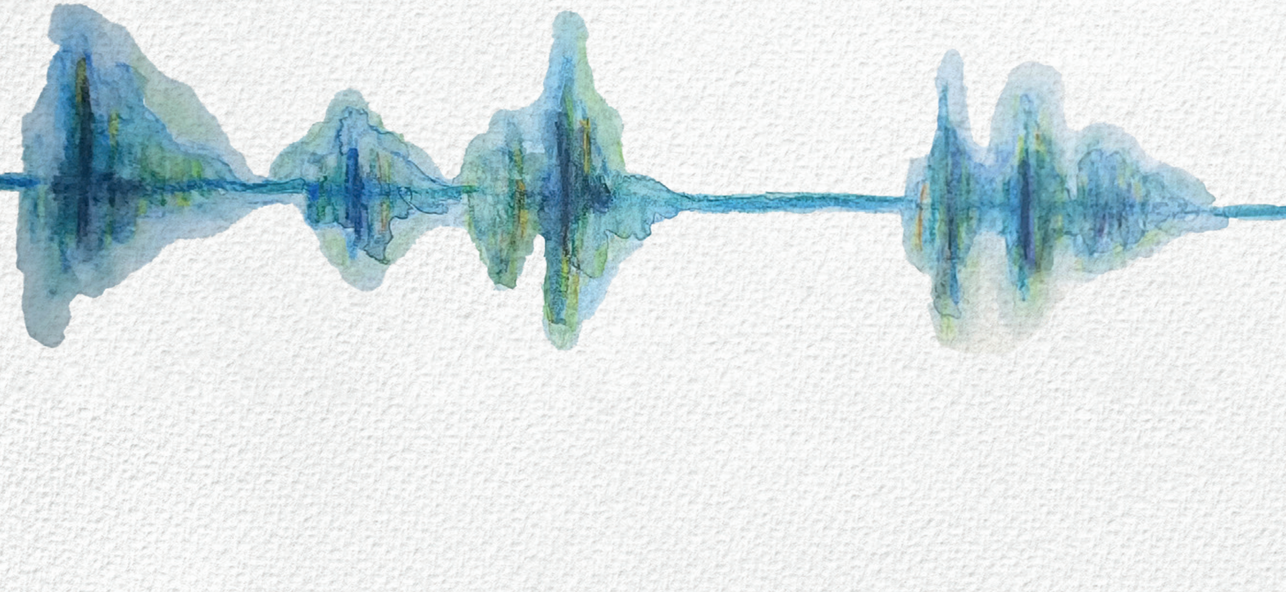
Our results showed that having more musical expertise enhanced the beneficial effect of musical presentation in both the OA (cf. chapter 3) and in aMCI participants (cf. Baird et al., 2017). Possibly, in both OA and aMCI participants, (having more) musical expertise – here formulated as degree of engagement with/interest in music – might have made it easier to effectively recall digits through a musical mnemonic, making it a relevant factor to consider in future research. Inspection of the correlations between musical expertise and the individual conditions shows that more musical expertise is associated with a better performance after spoken and rhythmic presentation (and weakly, but non-significantly correlated with the pitch condition), but – somewhat surprisingly – the weakest correlation was found in the melody condition. This may be in line with the chunking hypothesis, in that chunking may be most feasible in both the spoken and rhythm conditions (to which musical expertise apparently also contributes), but that the melody condition results in WM overload, especially in the individuals with aMCI regardless of their musical expertise (see Supplementary Table 4.3 [Appendix F], showing the correlations per group).

Potential limitations to be considered are that given our modest sample size, power may be limited for the correlational analyses. Next, as our experiment was performed in a naturalistic setting, the presentation of musical stimuli was not fully controlled. However, given our within-subject design regarding the conditions of musical presentation, we argue that these limitations may have attenuated some effects but not affected the outcome of our study. Furthermore, we did not analyse the effects of the serial position of the digits, being often reported in previous research (cf. Silverman, 2007, 2010, 2012). Also, one could argue that our paradigm mainly taps the phonological loop of the working memory system, that is, the maintenance of acoustical and/or verbal information (cf. Baddeley, 2000), and as such predominantly reflects short-term memory rather than the active manipulation aspect of WM (i.e., the central executive [CE] component). However, also in Baddeley and Hitch's view (Baddeley & Hitch, 1974) longer 'forward sequences' may elicit strategic processing, such as chunking, for which the CE is required. Furthermore, previous research has shown that the performance on forward digit span sequences is already reduced in MCI and may therefore benefit from compensation through a musical (that is, rhythmic presentation) mnemonic (Kessels et al., 2011). Alternatively to the chunking hypothesis in accordance with Baddeley's working memory model, the model presented in chapter 2 argues that the musical stimulus (rhythm) and the verbal stimulus (digits) in combination may have resulted in a more cohesive stimulus with a reduced stimulus complexity and thus a lower working memory load due to an enhanced accent structure fit. Finally, although we carefully translated and adapted the Gold-MSI from the English original, the psychometric properties of the Dutch version of this questionnaire need to be established in large normative samples.

Strengths are the use of carefully designed stimuli, and carefully described clinical diagnoses of the aMCI participants. Furthermore, to our knowledge, this is the first study using this type of ‘musical’ digit span task in aMCI participants, thereby extending previous research in students and cognitively unimpaired young and older adults to a cognitively impaired population.

Future research focusing on the effects of musical mnemonics in (a)MCI and AD patients is recommended as both groups might have WM impairments (cf. Kirova et al., 2015), thereby focusing on the enhancement of WM performance, especially by means of rhythm. Open questions include the role of familiarity with the presented rhythms, as well as examining the effects of different types of rhythms (e.g., simple, more complex, related to variations in durations of tones or grouping of tones within the given pulse, see chapter 2). As recommended previously, extending the research from digits to other verbal stimuli, such as words, would also be relevant for future studies (cf. chapter 3). Furthermore, in order to examine the effects of musical expertise, follow-up research conducting a moderation analysis using larger groups is recommended and could include behavioural measures of musical expertise as a covariate.

In conclusion, with the current study, we extend prior research findings in students (e.g., Silverman, 2007, 2010, 2012) and cognitively unimpaired young and older adults (chapter 3) to a cognitively impaired population. Here we provide the first findings of the facilitating effect of rhythm (and hampering effect of pitch and melody) in a musical presentation of a WM task in cognitively unimpaired OA and aMCI participants to a similar extent. Future research is needed to further unravel whether next to rhythm – facilitating temporal chunking – tonal aspects of music could also contribute to chunking the verbal and musical stimulus together (see chapter 2). As rhythm in particular seemed to result in a positive effect on WM performance in both OA and aMCI participants, we recommend using a rhythmically spoken presentation of to-be-remembered information in designing a musical mnemonic together with the individual who experiences memory problems. In daily life, this might be a potentially helpful strategy for remembering a limited amount of information for a short period of time.



Chapter 5

General discussion

In daily life, our memory plays an important role, enabling us to learn, store and remember knowledge and experiences. In cognitive ageing, a decline in memory function is consistently reported (Nyberg et al., 2012), and in clinical ageing-related conditions such as amnestic mild cognitive impairment ([amnestic] MCI), memory impairment typically occurs (Petersen et al., 2014). Compensation strategies, or *mnemonics*, have been found promising to overcome memory decrements. The use of music, more specifically, musical presentation of to-be-remembered information, is also an example of a mnemonic strategy (e.g., Ferreri & Verga, 2016). So far, the body of literature on the effects of musical mnemonics in ageing with and without cognitive impairment is limited, consisting of studies that mostly focused on effects on working memory (WM) and episodic (EM) performance in young adults, and a few studies on EM performance in persons with Alzheimer's dementia (AD) and cognitively unimpaired older adults. In both cognitively unimpaired individuals and individuals with memory impairment, musical mnemonics may help to acquire and remember verbal information.

However, previous research on musical mnemonics yields mixed results. Possible explanations for these conflicting results are related to the heterogeneity in research paradigms used, with regard to the selected verbal stimuli and their musical embedding. To date, only a few studies systematically compared the separate contribution of various musical aspects (i.e., pitch, rhythm, or a combination of both) and examined their effect on WM performance (e.g., Silverman, 2007, 2010, 2012). However, in most previous studies these aspects were not systematically manipulated and compared, making it difficult to determine which specific aspect of music (e.g., rhythm or melody) within the musical presentation may have had an effect. Furthermore, studies differed in the use of familiar or unfamiliar music, and systematic investigation of musical expertise.

Moreover, the effects of musical mnemonics on WM performance had not yet been studied in (amnestic) MCI or AD, although both groups may have WM impairments (e.g., Gagnon & Belleville, 2011; Kirova et al., 2015; van Geldorp et al., 2015) and musical mnemonics may help in the optimisation of their WM performance as well. Therefore, there is a clear need for more research on possible beneficial effects of musical mnemonics in ageing with cognitive impairment, not only with the aim of optimizing EM, but also WM performance, thereby systematically assessing separate contributing aspects of music and taking into account the participants' musical expertise. Since the mechanisms through which music may have an effect are still insufficiently understood, systematic research into these various musical aspects and moderating variables contributes to a further understanding of possible underlaying aiding mechanisms of music for memory.

In this thesis, a newly developed digit span paradigm, that is, the musical digit span task, was introduced, building on a previous paradigm developed by Silverman (2007). The task used in this thesis makes use of digit sequences of increasing lengths (cf. the procedure used in the Wechsler Digit Span tasks; Wechsler, 1955, 2008). The first aim of this thesis was to systematically replicate previous results of studies that have been conducted in university students (Silverman, 2007, 2010, 2012), hypothesizing a superior WM performance in rhythmic than spoken presentation. The studies in this thesis were performed in both cognitively unimpaired young and older adults and individuals with cognitive impairments due to amnestic MCI. Second, I aimed to explore the possible underlying mechanisms through which musical mnemonics may benefit memory performance (differently) in cognitively unimpaired versus impaired individuals. A third aim was to examine the impact of musical expertise on the degree of benefit of musical presentation on WM performance. The current chapter provides an overview of the main results and conclusions, as well as a discussion of the strengths, limitations, clinical implications and recommendations for future research.

Summary of main findings

Chapter 2 addressed the existing literature on effects of musical mnemonics on memory performance by conducting a systematic review in children, cognitively unimpaired young and older adults and persons with cognitive impairment (i.e., [amnestic] MCI or AD). No literature on effects of musical mnemonics on WM performance in cognitively unimpaired older adults or persons with (amnestic) MCI or AD was found. Where the majority of research in cognitively unimpaired young adults showed generally beneficial results, the limited research on children and older adults showed mixed results and in AD, a heterogeneity within the predominantly positive results on EM was found. These mixed outcomes were likely related to inconsistencies in methodological approaches; studies showed a great variety in complexity of verbal stimuli and their musical stimulus embedding, memory domain (i.e., WM and/or EM), memory process (i.e., encoding, maintenance, retrieval) and testing method (immediate or delayed [free or cued] recall or recognition). In most of the studies that systematically compared familiarity of music in cognitively unimpaired participants, an advantage of a familiar melody (or rhythm) was found (in AD, few studies systematically compared familiarity and results were mixed). Furthermore, in most studies that systematically compared musical expertise in cognitively unimpaired participants, no modulating effect of musical expertise was found (in AD, one study found enhanced learning of sung information in AD-musicians vs. AD-non-musicians, Baird et al., 2017). Based on the diverging results of previous research, we formulated a novel theoretical model aiming to capture these differing findings, positing that the effectiveness of musical mnemonics depends on stimulus complexity and personal aspects of persons with(out) cognitive impairment, hereby extending previous work. We argued that the (mis)match between accent structures of the verbal material and musical stimulus together contributes to the 'stimulus complexity', which – together with personal aspects (e.g., age, cognitive ability, musical expertise and -responsivity) and task- and practice specifics (e.g., presentation rate, repetition, level of participation, memory paradigm) – influences the degree of cognitive load, selective attention, and the affective response, respectively resulting in an enhanced, unaffected, or even degraded performance (i.e., WM encoding and long-term memory retrieval). Furthermore, we formulated reporting guidelines for future researchers reporting on musical mnemonics with the aim of better specification of underlying mechanisms of musical mnemonics. Finally, implications for the future design of music-based memorization strategies were discussed.

Chapter 3 presents a study that investigated the effects of different musical presentations (i.e., pitch, rhythm, and melody) of verbal information on WM performance in cognitively unimpaired young versus older adults by using the novel musical digit span task. Musical expertise was assessed with two perceptual tests (Beat Perception and Melody Memory) and the Self-Report Inventory of the Goldsmiths Musical Sophistication Index v1.0 (Gold-MSI, Müllensiefen et al., 2014). Contrary to my hypothesis, young and older adults performed equally well on the musical digit span task on all four conditions (i.e., spoken, pitch, rhythm, melody). Consistent with prior research, the main finding was that rhythm facilitated digit span performance in both groups, which suggests that rhythmic presentation may indeed positively affect WM performance both in cognitively unimpaired young and older adults. Thus, we replicated and extended results of previous research, to young adults (more representative of the general population), and to cognitively unimpaired older adults. In both groups, WM performance in the pitch and melody conditions did not differ compared to spoken presentation. Furthermore, I hypothesized that in older adults (compared to young adults), rhythmic presentation would result in a relatively more improved performance, as rhythmic presentation may reduce the need to rely on declining WM and executive resources (due to normal ageing). Also, I hypothesized that presentations including pitch would result in a worse WM performance only in older adults, possibly due to faster WM overload. However, both groups showed benefits of rhythmic presentation to a similar extent. On the other hand, results indeed showed a significantly worse performance for older adults compared to young adults in the pitch and melody conditions. Finally, musical expertise did not moderate the degree of benefit of musical presentation in both groups, which is in line with prior research in young adults, though in contrast with the formulated hypothesis in older adults.

Finally, **Chapter 4** describes a follow-up study on effects of musical mnemonics on WM performance in memory-impaired persons with amnestic MCI. The aim was to compare different musical presentations (and possible separate contributions of various musical components) to spoken presentation on WM performance by using the same musical digit span task. Furthermore, we again investigated the possible moderating role of musical expertise in degree of benefit of musical presentation. In general, persons with amnestic MCI had significantly worse WM performances on the musical digit span compared to cognitively unimpaired older adults (most of whom were also included in the previous investigation). In line with the results presented in Chapter 3, a beneficial effect of rhythmic presentation was also found in (both cognitively unimpaired older adults and) persons with amnestic MCI, thus further extending these beneficial results of rhythm to a cognitively impaired population. Based on these results, we suggested that musical mnemonics may also improve WM performance in persons with amnestic MCI. Furthermore, pitch and melody (compared to spoken presentation) were found to diminish WM performance in both groups; possibly (adding) pitch resulted in to-be-processed extra information which may have increased stimulus complexity. Contrary to my hypothesis, persons with amnestic MCI benefitted just as much from rhythmic presentation as cognitively unimpaired older adults. Furthermore, again contrasting my hypothesis, the disadvantage of pitch and melody was also comparable in both groups. Partially in line with my hypotheses, in this case, musical expertise increased this beneficial effect of musical presentation in both older adults and persons with amnestic MCI.

In addition, inspection of the correlations between the individual conditions (i.e., spoken, pitch, rhythm, melody) and musical expertise, showed that more musical expertise was associated with a better performance after both spoken and rhythmic presentation (and was weakly but not significantly correlated with the pitch condition). Surprisingly, the weakest correlation was found in the melody condition; possibly this condition resulted in WM overload (especially in aMCI), regardless of musical expertise.

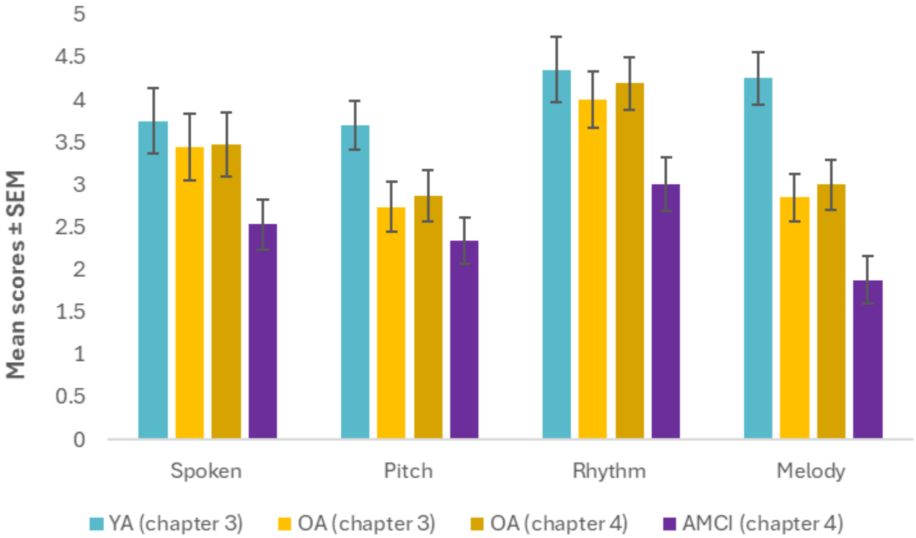
Discussion of main findings

The empirical studies in this thesis replicated and extended previous findings of rhythm in university students (Silverman 2007, 2010, 2012), to cognitively unimpaired young and older adults and persons with amnestic MCI, by using the musical digit span task (first aim). Results showed an advantage of rhythm on WM performance (recall of forward digit span), of which both cognitively unimpaired young and older adults and persons with cognitive impairments (i.e., amnestic MCI) benefitted to a same extent (see Figure 5.1 for a combined overview of the results of both empirical studies of this thesis – keeping in mind that the sample of cognitively unimpaired older adults overlapped substantially between chapter 3 and 4). These results suggest that rhythm (or time structure) is an effective element of a musical mnemonic, possibly facilitating chunking, regardless of age (chapter 3) and expected (and observed) differences in WM performance (between older adults versus persons with amnestic MCI, chapter 4). Furthermore, results showed a performance hindrance in the conditions including pitch on WM performance in cognitively unimpaired older adults (compared to young adults, chapter 3) and both cognitively unimpaired older adults and persons with aMCI (to a similar extent, chapter 4). These results suggest that (addition of) pitch information may increase stimulus complexity resulting in WM overload in ageing, – although apparently – regardless of (mild) cognitive impairment.

These diverging results of rhythm compared to pitch provide a valuable contribution to the theoretical understanding of the underlying mechanisms through which musical mnemonics may benefit WM performance (differently) in cognitively (un)impaired individuals (second aim). Furthermore, these findings may illustrate the importance of taking into account the novel aspects (i.e., stimulus complexity, personal aspects) included in our newly formulated model (see chapter 2). That is, the rhythmic presentation of the digits possibly formed a cohesive stimulus, resulting in an enhanced accent structure fit, reduced stimulus complexity and WM load, resulting in an enhanced WM performance regardless of personal aspects of the participants (i.e., age and cognitive impairment). In contrast, pitch may have impaired WM performance in older adults, regardless of cognitive impairment, due to increased stimulus complexity. Here, the specific tonal context of the notes chosen for the stimulus likely has an influence, which in this case was selected for their coherence (cf. Silverman, 2007). As such, a more complex (or even random) note series would likely impair performance even more.

Figure 5.1

Overview of results of the empirical studies in this thesis



Note. The mean number correctly reproduced digit sequences and standard error of the mean per condition of the musical digit span task. Results for cognitively unimpaired young adults are shown in blue and for cognitively unimpaired older adults in yellow (chapter 3). Results for the (substantially) overlapping sample of cognitively unimpaired older adults in chapter 4 are shown in slightly darker yellow and in purple for persons with aMCI.

Finally, musical expertise did not moderate the degree of benefit of musical presentation in cognitively unimpaired young versus older adults, though a clear beneficial effect of musical expertise was found in our study in cognitively unimpaired older adults and participants with amnestic MCI. This discrepancy may be explained by the fact that compared to the first study (chapter 3), the second study (chapter 4) resulted in more variability across participants, even though the sample of cognitively unimpaired older adults overlapped substantially between chapter 3 and 4. In the latter study, more musical expertise was associated with a better performance in the spoken and rhythm conditions, suggesting that more musical expertise may have contributed to more effective chunking. Although these findings are in contrast to previous literature on musical expertise in cognitively unimpaired young adults, they are in line with findings in AD (Baird et al., 2017), which may suggest that musical expertise might become more important when cognitive functions decline (third aim). Lastly, the influence of musical training may have been even more pronounced for more complex tonal or rhythmic material, with the current, relatively simple tonal context levelling performance over varying degrees of expertise.

Strengths

The musical digit span task has several implications for research on musical mnemonics. The musical digit span task is an adapted version of the musically presented digit spans with a span length of nine digits as reported by Silverman (2007). The design of the musical digit span task – that is, digit sequences with increasing span lengths, starting with a span length of five digits and ending with a maximum of eight digits – may likely have better fitted the participants in our studies, given that a digit sequence of nine digits would presumably have been too challenging for older adults. Furthermore, as a result of this design, there are more measurement points increasing reliability. A relatively small number of previous studies on musical mnemonics have systematically compared the contribution of separate musical components. The systematic manipulation of the musical embedding, that is, counterbalanced presentation of the four conditions (i.e., spoken, pitch, rhythm, and melody) allowed for comparison of separate musical components. Also, the duration of the conditions that did not involve rhythm was highly comparable, which significantly reduces the probability that any differences found can be explained by differences in the duration of the digits presented (e.g., Good et al., 2015; Ludke et al., 2014).

Based on the description of the musical embedding of the digits used by Silverman (2007), the musical stimuli were carefully designed, creating a simple tonal context in the conditions using pitch, and no complex rhythms in the conditions involving rhythm (i.e., the rhythm and melody condition), which may have contributed to a good accent structure fit between the verbal and musical stimuli. Compared to the studies of Silverman (2007, 2010), we found no significant hampering of WM performance in the pitch versus spoken and melody versus spoken conditions in cognitively unimpaired young and older adults (chapter 3). These diverging findings seem to be well explained by the novel model formulated in our review (chapter 2). That is, possibly, compared to the digit spans in the studies of Silverman, our shorter sequence lengths, paired with their musical stimulus embedding (i.e., lower complexity of separate elements) and resulting accent structures may have reduced the level of overall complexity. Altogether, the musical digit span may be valid for measuring effects of musical presentation on WM performance, though some issues remain open for further investigation, and possible improvement.

Limitations

A first limitation to consider is of a statistical nature. As a consequence of the sample sizes of our empirical studies, the number of conditions and covariates included in the analyses may have resulted in limited statistical power, warranting replication in independent larger samples. Also, the novel WM task itself comes with limitations. One such limitation is that the paradigm presumably mainly taps the phonological loop of the WM system, involved in the maintenance of acoustical and/or verbal information (cf. Baddeley, 2000), and thus, predominantly reflects the short-term stores rather than the central executive (CE) WM component, which is recruited in active manipulation. Still, Baddeley and Hitch (1974) argue that the CE is also required in maintenance of longer forward sequences, as these may also elicit strategic processing (e.g., chunking). In addition, previous research has shown that performance on forward sequences is already reduced in individuals with MCI (Kessels et al., 2011), and that this population may therefore benefit from compensation through musical (i.e., rhythmic) presentation. Addition of a backward condition could in theory be an interesting extension of the paradigm. However, this would be complex from a practical perspective, as this would mean that participants would have to sing the same melody backwards. In addition to this being a very artificial task, it would also have consequences for the design of the melody (i.e., to be suitable to be sung backwards the melody must be very simple, thus limiting the options for usable melodies).

With regard to the musical embedding of the digits, the musical digit span task has been designed building on a previous paradigm as presented by Silverman

(2007), using unfamiliar melodies. Possibly, the selected musical embedding, that is, simple unfamiliar melodies with or without rhythm, has affected the outcome, potentially limiting generalization to other musically embedded materials. Also, flowing from the choice to use digit spans with an increasing span length presented with two different digit sequences per length, here a possible interference between the (same) musical stimulus for two consecutive digit spans with different verbal stimuli (i.e., two different digit spans of the same length) may have occurred, most likely in the conditions involving pitch.

Although rhythmically spoken presentation using an unfamiliar rhythmic pattern enhanced the recall of digits, one could argue that this is different from recall of text using a familiar melody (which has a long history, as for example minstrels used music as an aid to convey stories, e.g., Calvert & Tart, 1993), and may in fact rely on different underlying aiding mechanisms of music to enhance memory (see Chapter 2). Thus, the ecological validity of the musical digit span task may be limited, as it is primarily an experimental paradigm in which digit spans are presented sung or (rhythmically) spoken, opposed to the 'common practice' of how music as a mnemonic aid is usually applied, that is, by singing to-be-remembered information to a familiar melody.

Clinical implications

Although the musical digit span task presented in this thesis has little direct clinical relevance, some preliminary clinical recommendations can be given. Based on our beneficial findings of rhythm, we would recommend health-care professionals (such as music therapists) to use a rhythmically spoken presentation of a limited amount of sequential verbal information to enhance WM performance in patients. An everyday example of this is the rhythmic presentation of a telephone number to facilitate chunking (cf. Calvert & Billingsley,1998; Wolfe & Hom, 1993).

Another implication for clinical interventions based on the findings of the systematic review in this thesis, is the importance of creating a musical mnemonic that is actually helpful (i.e., with regard to the degree of stimulus complexity) for the specific individual, given their personal aspects (e.g., age, cognitive ability). A possible approach could include first, the selection a personal memory goal (i.e., something important the individual wishes to remember, for example someone's name (Frankenmolen et al., 2018b), second, creating lyrics with importance for daily life memory functioning (Moussard et al., 2014), and third, the personalization of the musical stimulus (e.g., familiarity, genre) to individual aspects (e.g., cognitive capacity, musical preferences, musical expertise), in order to maximize the potential of compensation for memory problems in everyday life in persons with memory complaints or impairment.

Until now, a few previous studies in AD have shown beneficial effects of musical presentation on EM, suggesting that musical mnemonics may represent a low-cost strategy for improvement of recall in persons with (even severe) AD (e.g., Oostendorp & Montel, 2014; Ratovohery et al., 2019). Music is an enjoyable, arousing activity (Moussard et al., 2014), possibly causing arousal and reward mechanisms, which may contribute to enhanced cognitive performance in AD. Dimitriadis et al. (2024) argued that motivational processes may be part of the underlying aiding mechanisms of music-based interventions (at least when carefully selected music is included, i.e., according to individual preferences or depending on the task demands [e.g., stimulating or soothing]), that in turn can be related to improvements in clinical outcomes or task performance (e.g., sensory dysfunction, vital functions, motor skills, cognition).

To conclude, based on the findings of future research on the effects of musical mnemonics on not only EM, but also WM performance in older individuals with or without cognitive impairment, possible future musical compensatory strategies may be developed and added to the existing body of memory strategies that are taught in memory strategy training that has been proven beneficial for persons with SMC (e.g., Frankenmolen et al., 2018b) and aMCI (e.g., Joosten Weyn-Banningh et al., 2011). It would be an interesting future direction to develop a musical mnemonics training especially tailored to persons with SMC, aMCI and (early) AD (e.g., Oostendorp & Montel, 2014) that focuses on both EM and WM, as next to EM, WM can also be affected in clinical conditions (Kirova et al., 2015).

Future research

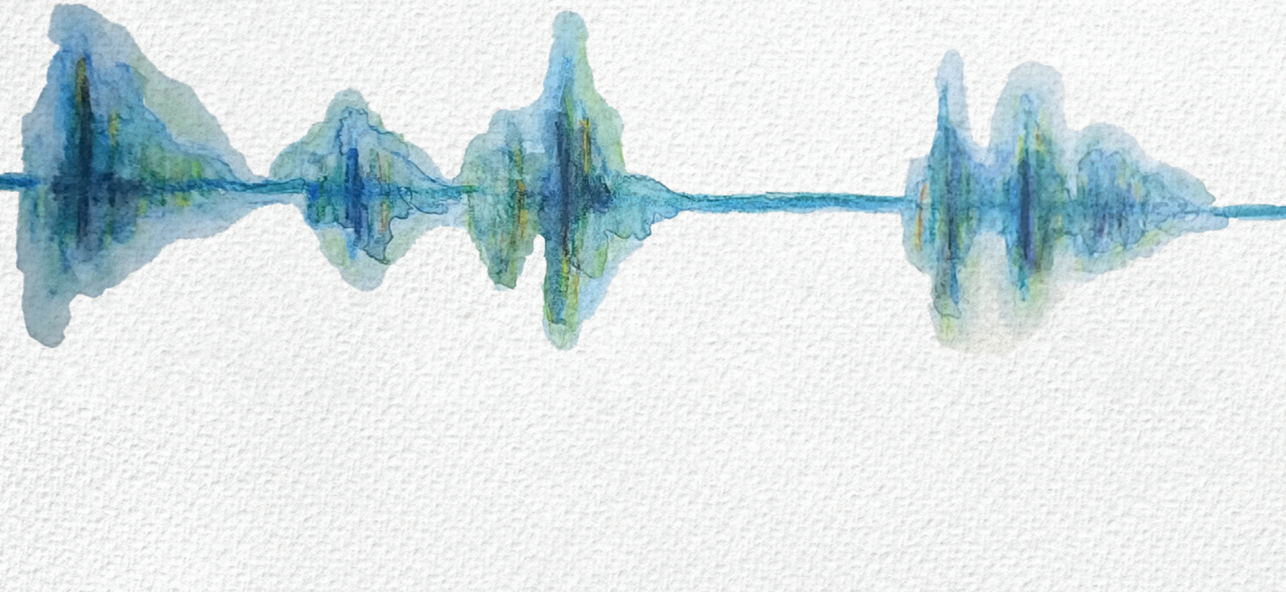
Rhythmic presentation may have a more profound beneficial influence on WM performance in persons with AD as compared to the persons with amnestic MCI in this thesis. Additionally, the greater overall stimulus complexity of pitch may influence WM outcome more negatively in AD as compared to amnestic MCI. As musical presentation may provide additional structure for compromised WM capacity and improve the ability to transfer information to EM (Rainey & Larsen, 2002), future research on the effects of musical mnemonics to compensate for WM impairment in persons with ([amnestic] MCI and) AD is needed.

Future researchers using our model (and reporting guidelines) may test and clarify relationships between overall stimulus complexity and memory outcome, exploring the above assumptions, which may in the end contribute to a further understanding of underlying mechanisms through which musical mnemonics may benefit memory performance (differently) in cognitively impaired individuals. A systematic comparison of aspects of the verbal stimulus (e.g., serial position of digits, Silverman, 2007, 2010, 2012) and musical stimulus embedding (e.g., complexity of rhythm, tonal aspects of the melody, familiarity of music) is recommended. Other aspects that need more thorough investigation include for example the degree of participation at encoding, and the use of a self-composed or imposed musical mnemonic (Moore et al., 2008). Neuro-imaging techniques may shed light on activated neural mechanisms through which musical mnemonics influence cognitive and brain functions and behaviour (see e.g., Sihvonen et al., 2017).

Finally, as in both cognitively unimpaired older adults and persons with aMCI more musical expertise may have supported the effective recall of musically presented digits (i.e., particularly in [rhythmically] spoken conditions, see chapter 4), it can be considered a relevant factor in future research on musical mnemonics in ageing with(out) cognitive impairment (see also Baird et al., 2017). Future (longitudinal) research may shed light on whether musical expertise contributes to cognitive reserve ([CR], Stern et al., 2023), strengthening the ability to use scaffolding mechanisms to compensate for WM decline (Park & Reuter-Lorenz, 2009) in healthy ageing and aMCI. This is relevant, as CR has been found to positively influence cognitive performance even at an advanced age (e.g., Oosterman et al., 2021), and in persons with subjective cognitive decline or mild levels of cognitive impairment (e.g., Jansen et al., 2021).

Concluding remarks

This thesis presents a new theoretical model describing how various important factors (e.g., stimulus complexity, personal aspects) together influence the effectiveness of musical mnemonics on memory performance and a novel paradigm, the musical digit span task, enabling systematic research on effects of musical presentation (and specific contributing aspects of music) on WM performance. Our empirical findings indicate that rhythmic presentation may be potentially helpful for remembering of a limited amount of information for a short period of time, not only for younger persons, but also in older adults with and without cognitive impairment. In particular, based on my experimental findings, a rhythmically spoken presentation of sequential verbal information is recommended when designing a musical mnemonic together with an individual who experiences WM problems. More generally, based on the novel model presented in this thesis, it is recommended to manipulate the complexity of the musical stimulus to match the verbal material to create a good accent structure fit. This may then lower stimulus complexity and likely result in a reduced cognitive load, thus probably improving memory performance. The empirical studies in this thesis can be seen as a first step in the research of musical presentation of verbal information to enhance WM performance in ageing and amnestic MCI. With this thesis, I have contributed to a further understanding of possible aiding mechanisms of musical presentation in the acquisition of new information, not only in ageing without cognitive impairment, but also in cognitively impaired individuals, also taking into account possible moderating effects of the musical expertise of the participants, which may in the end contribute to help older individuals more easily participate in daily life.



Appendices

References

Appendices

Research data management

Dutch summary

Portfolio

Curriculum vitae

List of publications

Dankwoord

Donders Graduate School

References

Albert, M. L., Sparks, R. W., & Helm, N. A. (1973). Melodic intonation therapy for aphasia. *Archives of Neurology, 29*(2),130–1. https://doi.org/10.1001/archneur.1973.00490260074018

Albert, M. S., DeKosky, S. T., Dickson, D., Dubois, B., Feldman, H. H., Fox, N. C., Gamst, A., Holtzman, D. M., Jagust, W. J., Petersen, R. C., Snyder, P. J., Carrillo, M. C., Thies, B., & Phelps, C. H. (2011). The diagnosis of mild cognitive impairment due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia, 7*, 270–279. https://doi.org/10.1016/j. jalz.2011.03.008

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417–423. https://doi.org/10.1016/ S1364-6613(00)01538-2

Baddeley, A. D. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology, 63*(1), 1–29. https://doi.org/10.1146/annurev-psych-120710-100422

Baddeley, A. D., Bressi, S., Della Sala, S., Logie, R., & Spinnler, H. (1991). The decline of working memory in Alzheimer's disease: A longitudinal study. *Brain, 114*(6), 2521–2542. https://doi.org/10.1093/ brain/114.6.2521

Baddeley, A. D., & Hitch, G. J. (1974). *Working memory*. In G. H. Bower (Ed.), The psychology of learning and motivation: Advances in research and theory (pp. 47–89). Academic Press. https://doi.org/10.1016/S0079-7421(08)60452-1

Baird, A., & Samson, S. (2009). Memory for music in Alzheimer's disease: Unforgettable? *Neuropsychology Review, 19*, 85–101. https://doi.org/10. 1007/s11065- 009- 9085-2

Baird, A., Samson, S., Miller, L., & Chalmers, K. (2017). Does music training facilitate the mnemonic effect of song? An exploration of musicians and non-musicians with and without Alzheimer's dementia. *Journal of Clinical and Experimental Neuropsychology, 39*(1), 9–21. https://doi. org/10.1080/13803 395.2016.1185093

Calvert, S. L., & Billingsley, R. L. (1998). Young children's recitation and comprehension of information presented by songs. *Journal of Applied Developmental Psychology, 19*, 97–108. https://doi.org/10.1016/S0193- 3973(99)80030-6

Calvert, S. L., & Tart, M. (1993). Sung versus verbal forms for very long-term, long-term, and short-term verbatim recall. *Journal of Applied Developmental Psychology, 14*, 245–260. https://doi.org/10.1016/0193-3973(93)90035-T

Chazin, S., & Neuschatz, J. S. (1990). Using a mnemonic to aid in the recall of unfamiliar information. *Perceptual and Motor Skills, 71*,1067–1071. https://doi.org/10. 2466/PMS.71.8.1067-1071

Chevalère, J., Lemaire, P., & Camos, V. (2020). Age-related changes in verbal working memory strategies. *Experimental Aging Research, 46*(2), 93–127. https://doi.org/10.1080/0361073X.2020.1716152

Chin, T. C., & Rickard, N. (2012). The Music USE (MUSE) Questionnaire: An instrument to measure engagement in music. *Music Perception, 29*(4), 429–446. https://doi.org/10.1525/mp.2012.29.4.429

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Erlbaum.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1),155–159. https://doi.org/10.1037/0033-2909.112.1.155

Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–86. https://doi.org/10.3758/bf03196772

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24,* 87–114. https://doi.org/10.1017/S0140525X01003922

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11*(6), 671–684. https://doi.org/10.1016/S0022-5371(72) 80001-X

Deason, R. G., Simmons-Stern, N. R., Frustrace, B. S., Ally, B. A., & Budson, A. E. (2012). Music as a memory enhancer: Differences between healthy older adults and patients with Alzheimer's disease. *Psychomusicology: Music, Mind, and Brain, 22*(2), 175. https://doi.org/10.1037/a0031118

De Frias, C. M., Dixon, R. A., & Bäckman, L. (2003). Use of memory compensation strategies is related to psychosocial and health indicators. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 58*(1), 12–22. https://doi.org/10.1093/geronb/58.1.P12

De Wit, L., Chandler, M., Amofa, P., DeFeis, B., Mejia, A., O'Shea, D., Locke, D. E. C., Fields, J. A., & Smith, G. E. (2021). Memory support system training in mild cognitive impairment: Predictors of learning and adherence. *Neuropsychological Rehabilitation, 31*(1), 92–104. https://doi.org/ 10.1080/09602011.2019.1667833

Dickson, D., & Grant, L. (2003). Physics karaoke: Why not? *Physics Education, 4*, 320–323. https://doi.org/10.1088/0031- 9120/38/4/305

Dimitriadis, T., Della Porta, D., Perschl, J., Evers, A. W. M., Magee, W. L., & Schaefer, R. S. (2024). Motivation and music interventions in adults: A systematic review. *Neuropsychological Rehabilitation, 34*(5), 649–678. https://doi.org/10.1080/09602011.2023.2224033

Duits, A., & Kessels, R. P. C. (2014). *Schatten van het premorbide functioneren.* In M. Hendriks, R. Kessels, M. Gorissen, & B. Schmand (Eds.), Neuropsychologische diagnostiek: De klinische praktijk (pp. 177–178). Boom.

Ee, T. J., Piaw, C. Y., & Ying, L. F. (2015). The effect of rhythmic pattern in recalling 10 digit numbers. *Procedia – Social and Behavioral Sciences,185*, 400–404. https://doi.org/10.1016/j.sbspro.2015.03.417

Eikelboom, W. S., Bertens, D., & Kessels, R. P. C. (2020). *Cognitive rehabilitation in normal ageing and individuals with subjective cognitive decline.* In J. DeLuca, N. D. Chiaravalloti, & E. Weber (Eds.), Cognitive rehabilitation and neuroimaging (pp. 37–67). Springer. https://doi.org/10.1007/978-3-030-48382-1_ 3

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*, 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Ferreri, L., & Verga, L. (2016). Benefits of music on verbal learning and memory: How and when does it work? *Music Perception, 34*(2), 167–182. https://doi.org/10.1525/MP.2016.34.2.167

Frankenmolen, N. L., Fasotti, L., Kessels, R. P. C., & Oosterman, J. M. (2018a). The influence of cognitive reserve and age on the use of memory strategies. *Experimental Aging Research, 44*(2), 117–134. https://doi.org/10.1080/0361073X.2017.142247

Frankenmolen, N. L., Overdorp, E. J., Fasotti, L., Claassen, J. A. H. R., Kessels, R. P. C., & Oosterman, J. M. (2018b). Memory strategy training in older adults with subjective memory complaints: A randomized controlled trial. *Journal of the International Neuropsychological Society, 24*(10), 1110–1120. https://doi.org/10.1017/S1355617718000619

Fu, L., Kessels, R. P. C., & Maes, J. H. R. (2020). The effect of cognitive training in older adults: Be aware of CRUNCH. *Aging, Neuropsychology, and Cognition, 27*(6), 949–962. https://doi.org/10.1080/ 13825585.2019.1708251

Gagnon, L. G., & Belleville, S. (2011). Working memory in mild cognitive impairment and Alzheimer's disease: Contribution of forgetting and predictive value of complex span tasks. *Neuropsychology, 25*(2), 226–236. https://doi.org/10.1037/a0020919

Gardiner, J. C., & Thaut, M. (2005). Musical mnemonics training. In M. Thaut & V. Hoemberg (Eds.), Handbook of Neurologic Music Therapy (pp. 294–310). Oxford University Press.

Gfeller, K. (1983). Musical mnemonics as an aid to retention with normal and learning disabled students. *Journal of Music Therapy, 20*(4), 179–189. https://doi.org/10.1093/jmt/20.4.179

Good, A. J., Russo, F. A., & Sullivan, J. (2015). The efficacy of singing in foreign language learning. *Psychology of Music, 43*(5), 627–640. https://doi.org/10.1177/0305735614528833

Guilmette, T. J., Sweet, J. J., Hebben, N., Koltai, D., Mahone, E. M., Spiegler, B. J., Stucky, K., Westerveld, M., & Conference participants (2020). American Academy of clinical neuropsychology consensus conference statement on uniform labeling of performance test scores. *The Clinical Neuropsychologist, 34*, 437–453. https://doi.org/10.1080/13854046.2020.1722244

Harada, C. N., Natelson Love, M. C., & Triebel, K. (2013). Normal cognitive aging. *Clinics in Geriatric Medicine, 29*(4), 737–752. https://doi.org/10.1016/j.cger.2013.07.002

Hébert, S., & Peretz, I. (2001). Are text and tune of familiar songs separable by brain damage? *Brain Cognition, 46*, 169–175. https://doi.org/10.1016/s0278-2626(01)80058-0

Hester, R. L., Kinsella, G. J., & Ong, B. E. N. (2004). Effect of age on forward and backward span tasks. *Journal of the International Neuropsychological Society, 10*(4), 475–481. https://doi.org/10.1017/S1355617704104037

Hochstenbach, J., Mulder, T., van Limbeek, J., Donders, R., & Schoonderwaldt, H. (1998). Cognitive decline following stroke: A comprehensive study of cognitive decline following stroke. *Journal of Clinical and Experimental Neuropsychology, 20*(4), 503–517. https://doi.org/10.1076/jcen.20.4.503.1471

Hudes, R., Rich, J. B., Troyer, A. K., Yusupov, I., & Vandermorris, S. (2019). The impact of memory-strategy training interventions on participant-reported outcomes in healthy older adults: A systematic review and meta-analysis. *Psychological Aging, 34*(4), 587–597. https://doi.org/10.1037/pag0000340

Jansen, M. G., Geerligs, L., Claassen, J. A. H. R., Overdorp, E. J., Brazil, I. A., Kessels, R. P. C., & Oosterman, J. M. (2021). Positive effects of education on cognitive functioning depend on clinical status and neuropathological severity. *Frontiers in Human Neuroscience, 15*, 723728. https://doi.org/10.3389/fnhum.2021.723728

Jellison, J. A. (1976). Accuracy of temporal order recall for verbal and song digit-spans presented to right and left ears. *Journal of Music Therapy, 13*(3), 114–129. https://doi.org/10.1093/jmt/13.3.114

Jellison, J. A., & Miller, N. I. (1982). Recall of digit and word sequences by musicians and non-musicians as a function of spoken or sung input and task. *Journal of Music Therapy, 19*, 194–209. https://doi.org/10.1093/jmt/19.4.194

Jones, M. R. (1976). Time, our lost dimension: Toward a new theory of perception, attention and memory. *Psychological Review, 83*(5), 323–355. https://doi.org/10.1037/0033-295X.83.5.323

Jones, M. R. (1987). Dynamic pattern structure in music: Recent theory and research. *Perception & Psychophysics, 41*, 621–634. https://doi.org/10.3758/bf03210494

Jones, M. R., & Boltz, M. (1989). Dynamic attending and responses to time. *Psychological Review, 96*(3), 459–491. https://doi.org/10.1037/0033-295x.96.3.459

Joosten-Weyn Banningh, L. W., Prins, J. B., Vernooij-Dassen, M. J., Wijnen, H. H., Olde Rikkert, M. G., & Kessels, R. P. C. (2011). Group therapy for patients with mild cognitive impairment and their significant others: Results of a waiting-list controlled trial. *Gerontology, 57*(5), 444–54. https://doi.org/ 10.1159/000315933

Kalenzaga, S., Lamidey, V., Ergis, A. M., Clarys, D., & Piolino, P. (2016). The positivity bias in aging: Motivation or degradation? *Emotion, 16*(5), 602–610. https://doi.org/10.1037/emo0000170

Kessels, R. P. C., Molleman, P. W., & Oosterman, J. M. (2011). Assessment of working-memory deficits in patients with mild cognitive impairment and Alzheimer's dementia using Wechsler's working memory index. *Aging Clinical and Experimental Research, 23*, 487–490. https://doi.org/10.1007/BF03325245

Kessels, R. P. C., Overbeek, A., & Bouman, Z. (2015). Assessment of verbal and visuospatial working memory in mild cognitive impairment and Alzheimer’s dementia. *Dementia & Neuropsychologia, 9*, 301–305. https://doi.org/10.1590/1980-57642015DN93000014

Kilgour, A. R., Jakobson, L. S., & Cuddy, L. L. (2000). Music training and rate of presentation as mediators of text and song recall. *Memory and Cognition, 28*, 700–710. https://doi.org/10.3758/BF03198404

Kirova, A. M., Bays, R. B., & Lagalwar, S. (2015). Working memory and executive function decline across normal aging, mild cognitive impairment, and Alzheimer’s disease. *BioMed Research International 2015*, 748212. https://doi.org/10.1155/2015/748212

Korenman, L. M., & Peynircioglu, Z. F. (2004). The role of familiarity in episodic memory and metamemory for music. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(4), 917–922. https://doi.org/10.1037/0278-7393.30.4.917

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Lehmann, L. A. M., & Seufert, T. (2018). Can music foster learning – Effects of different text modalities on learning and information retrieval. *Frontiers in Psychology, 8*, 2305. https://doi.org/10.3389/fpsyg.2017.02305

Lemaire, P. (2016). Cognitive aging: The role of strategies. Routledge, Psychology Press. https://doi.org/10.4324/ 9781315650999

Lenhard, W. & Lenhard, A. (2016). Computation of effect sizes. [ComputerSoftware]. https://www. psychometrica.de/effect_ size.html. https://doi.org/10.13140/RG.2.2.17823.92329

Lin, H. (n.d.). Retrieved February 25, 2022, from https://www.escal.site

Lipsey, M. W., & Wilson, D. B. (2001). Practical Meta-analysis. Sage Publications.

Ludke, K. M., Ferreira, F., & Overy, K. (2014). Singing can facilitate foreign language learning. *Memory and Cognition, 42*, 41–52. https://doi.org/10.3758/s13421-013-0342-5

Ma, W., Fiveash, A., Margulis, E. H., Behrend, D., & Thompson, W. F. (2020). Song and infant-directed speech facilitate word learning. *Quarterly Journal of Experimental Psychology, 73*(7), 1036–1054. https://doi.org/10.1177/17470 21819 888982

MacDonald, K., Germine, L., Anderson, A., Christodoulou, J., & McGrath, L. M. (2017). Dispelling the myth: Training in education or neuroscience decreases but does not eliminate beliefs in neuromyths. *Frontiers in Psychology, 8*, 1314. https://doi.org/10.3389/fpsyg.2017.01314

Madsen, C. K., Madsen, C. H., Jr., & Michel, D. E. (1975). The use of music stimuli in teaching language discrimination. In C. K. Madsen, R. D. Greer, & C. H. Madsen (Eds.), Research in music behavior: Modifying music behavior in the classroom (pp. 182–190). Teachers College Press.

Mammarella, N., Fairfield, B., & Cornoldi, C. (2007). Does music enhance cognitive performance in healthy older adults? The Vivaldi effect. *Aging, Clinical and Experimental Research, 19*, 394–399. https://doi.org/10.1007/BF03324720

Mas-Herrero, E., Marco-Pallares, J., Lorenzo-Seva, U., Zatorre, R. J., & Rodriguez-Fornells, A. (2013). Individual differences in music reward experiences. *Music Perception, 31*(2), 118–138. https://doi.org/10.1525/mp.2013.31.2.118

McElhinney, M., & Annett, J. M. (1996). Pattern of efficacy of a musical mnemonic on recall of familiar words over several presentations. *Perceptual and Motor Skills, 82*, 395–400. https://doi.org/10. 2466/pms.1996.82.2.395

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review, 63,* 81–97. https://doi.org/10.1037/h0043158

Miller, G. A., & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology, 110*(1), 40. https://doi.org/10.1037/0021-843X.110.1.40

Moore, K. S., Peterson, D. A., O'Shea, G., McIntosh, G. C., & Thaut, M. H. (2008). The effectiveness of music as a mnemonic device on recognition memory for people with multiple sclerosis. *Journal of Music Therapy, 45*, 307–329. https://doi.org/10.1093/jmt/45.3.307

Moussard, A., Bigand, E., Belleville, S., & Peretz, I. (2012). Music as an aid to learn new verbal information in Alzheimer's Disease. *Music Perception, 29*, 521–531. https://doi.org/10.1525/mp.2012.29.5.521

Moussard, A., Bigand, E., Belleville, S., & Peretz, I. (2014). Learning sung lyrics aids retention in normal ageing and Alzheimer's disease. *Neuropsychological Rehabilitation, 24*, 894–917. https://doi.org/10.1080/09602011.2014.917982

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: An index for assessing musical sophistication in the general population. *PLoS One, 9*(2), e89642. https://doi.org/10.1371/journal.pone.0089642

Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., & Chertkow, H. (2005). The Montreal cognitive assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.x

North, A. C., & Hargreaves, D. J. (1995). Subjective complexity, familiarity, and liking for popular music. Psychomusicology: *A Journal of Research in Music Cognition, 14*(1–2), 77–93. https://doi.org/10.1037/h0094090

Nyberg, L., Lovden, M., Riklund, K., Lindenberger, U., & Backman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences, 16*(5), 292–305. https://doi.org/10.1016/j.tics.2012.04.005

Oostendorp, J., & Montel, S. (2014). Singing can enhance episodic memory functioning in elderly people with Alzheimer's disease. *Journal of the American Geriatrics Society, 62*(5), 982–983. https://doi.org/10.1111/jgs.12731

Oosterman, J. M., Jansen, M. G., Scherder, E. J. A., & Kessels, R. P. C. (2021). Cognitive reserve relates to executive functioning in the old-old. *Aging clinical and experimental research, 33*(9), 2587–2592. https://doi.org/10.1007/s40520-020-01758-y

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutronc, I., Hoffmann, T. C., Mulrow, C. D., Schamseerf, L., Tetzlaff, J. M., & Moher, D. (2021a). Updating guidance for reporting systematic reviews: Development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology, 134*, 103–112. https://doi.org/10.1016/j.jclinepi.2021.02.003

Page, M. J., Moher, D., Bossuyt, P. M., Boutronc, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., (...) McKenzie, J. E. (2021b). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *British Medical Journal*, *372*. https://doi.org/10.1136/bmj.n160

Palisson, J., Roussel-Baclet, C., Maillet, D., Belin, C., Ankri, J., & Narme, P. (2015). Music enhances verbal episodic memory in Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology, 37*(5), 503–517. https://doi.org/10.1080/13803395.2015.1026802

Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: Aging and neurocognitive scaffolding. *Annual Review of Psychology, 60*, 173–196. https://doi.org/10.1146/annurev.psych.59.103006.093656

Pauwels, E. K. J., Volterrani, D., Mariani, G., & Kostkiewics, M. (2014). Mozart, music & medicine. *Medical Principles and Practice, 23*(5), 403–412. https://doi.org/10.1159/000364873

Peretz, I. (1996). Can we lose memories for music? The case of music agnosia in a nonmusician. *Journal of Cognitive Neuroscience, 8*, 481–496. https://doi.org/10.1162/jocn.1996.8.6.481

Peretz, I., Radeau, M., & Arguin, M. (2004). Two-way interactions between music and language: Evidence from priming recognition of tune and lyrics in familiar songs. *Memory and Cognition, 32*, 142–152. https://doi.org/10.3758/bf03195827

Petersen, R. C., Caracciolo, B., Brayne, C., Gauthier, S., Jelic, V., & Fratiglioni, L. (2014). Mild cognitive impairment: A concept in evolution. *Journal of Internal Medicine, 275*(3), 214–228. https://doi.org/10.1111/joim.12190

Pizzonia, K. L., & Suhr, J. A. (2022). Systematic review of correlates of internal and external memory strategy use in older adults. *Journal of Applied Gerontology, 41*(5), 1491–1499. https://doi.org/ 10.1177/07334648211065427

Prickett, C. A., & Moore, R. S. (1991). The use of music to aid memory of Alzheimer's patients. *Journal of Music Therapy, 28*(2), 101–110. https://doi.org/10.1093/jmt/28.2.101

Purnell-Webb, P., & Speelman, C. P. (2008). Effects of music on memory for text. *Perceptual and Motor Skills, 106*(3), 927–957. https://doi.org/10.2466/PMS.106.3

Racette, A., & Peretz, I. (2007). Learning lyrics: To sing or not to sing? *Memory and Cognition, 35*, 242–253. https://doi.org/10.3758/BF03193445

Rainey, D. W., & Larsen, J. D. (2002). The effect of familiar melodies on initial learning and long-term memory for unconnected text. *Music Perception, 20*, 173–186. https://doi.org/10.1525/mp.2002.20.2.173

Ratovohery, S., Baudouin, A., Gachet, A., Palisson, J., & Narme, P. (2018). Is music a memory booster in normal aging? The Influence of Emotion. *Memory, 26*(10), 1344–1354. https://doi.org/10.1080/09658211.2018.1475571

Ratovohery, S., Baudouin, A., Palisson, J., Maillet, D., Bailon, O., Belin, C., & Narme, P. (2019). Music as mnemonic strategy to mitigate verbal episodic memory in Alzheimer's disease: Does musical valence matter? *Journal of Clinical and Experimental Neuropsychology, 41*(10), 1060–1073. https://doi.org/10.1080/13803395.2019.1650897

Rauscher, F. H., Shaw, G. L. & Ky, K. N. (1993). Music and spatial task performance. *Nature, 365.* https://doi.org/10.1038/365611a0

Rönnlund, M., Nyberg, L., Bäckman, L., & Nilsson, L.-G. (2005). Stability, growth and decline in adult lifespan development of declarative memory: Cross-sectional and longitudinal data from a population-based study. *Psychology and Aging, 20*(1), 3–18. https://doi.org/10.1037/0882-7974.20.1.3

Ross, S. D., Hofbauer, L. M., & Rodriguez, F. S. (2022). Coping strategies for memory problems in everyday life of people with cognitive impairment and older adults: A systematic review. *International Journal of Geriatric Psychiatry, 37*, 1–18. https://doi.org/10.1002/gps.5701

Rukholm, V. N., Helms-Park, R., Odgaard, E. C., & Smyth, R. (2018). Facilitating lexical acquisition in beginner learners of Italian through spoken or sung lyrics. *The Canadian Modern Language Review, 74*(1), 153–175. https://doi.org/10.3138/cmlr.3789

Sala, G., & Gobet, F. (2020). Cognitive and academic benefits of music training with children: A multilevel meta-analysis. *Memory and Cognition, 48*, 1429–1441. https://doi.org/10.3758/s13421-020- 01060-2

Samson, S., Dellacherie, D., & Platel, H. (2009). Emotional power of music in patients with memory disorders: Clinical implications of cognitive neuroscience. *Annals of the New York Academy of Sciences,1169*, 245–255. https://doi.org/10.1111/j.1749- 6632.2009.04555.x

Särkämö, T., Tervaniemi, M., Laitinen, S., Forsblom, A., Soinila, S., Mikkonen, M., Autti, T., Silvennoinen, H. M., Erkkilä, J., Laine, M., Peretz, I., & Hietanen, M. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain, 131*(3), 866–76. https://doi.org/ 10.1093/brain/awn013

Schaal, N. K., Bauer, A. K. R., & Müllensiefen, D. (2014). Der Gold-MSI: Replikation und Validierung eines Fragebogeninstrumentes zur Messung Musikalischer Erfahrenheit anhand einer deutschen Stichprobe. *European Society for the Cognitive Sciences of Music, 18*, 1–25. https://doi.org/10.1177/1029864914541851

Schellenberg, S., & Moore, R. S. (1985). The effect of tonal-rhythmic context on short-term memory of rhythmic and melodic sequences. *Bulletin of the Council for Research in Music Education, 85*, 207–217.

Schellenberg, E. G., & Weiss, M. W. (2013). Music and cognitive abilities. In: D. Deutsch (Ed.), Psychology of music (pp. 499–550). Elsevier. https://doi.org/10.1016/B978-0-12-381460-9.00012-2

Schmand, B., Bakker, D., Saan, R., & Louman, J. (1991). De Nederlandse Leestest voor Volwassenen: Een maat voor het premorbide intelligentieniveau. *Tijdschrift voor Gerontologie en Geriatrie, 22*(1), 15–19.

Schön, D., Boyer, M., Moreno, S., Besson, M., Peretz., I., & Kolinsky, R. (2008). Songs as an aid for language acquisition. *Cognition, 106*, 975–983. https://doi.org/10.1016/j.cognition.2007.03.005

Serafine, M. L., Crowder, R. G., & Repp, B. H. (1984). Integration of melody and text in memory for songs. *Cognition, 16*, 285–303. https://doi.org/10.1016/0010-0277(84)90031-3

Serafine, M. L., Davidson, J., Crowder, R. G., & Repp, B. H. (1986). On the nature of melody-text integration in memory for songs. *Journal of Memory and Language, 25*, 123–135. https://doi.org/10.1016/0749- 596X(86)90025-2

Sihvonen, A. J., Särkämö, T., Leo, V., Tervaniemi, M., Altenmüller, E., & Soinila, S. (2017). Music-based interventions in neurological rehabilitation. *The Lancet, 16*(8), 648–660. https://doi.org/10.1016/S1474-4422(17)30168-0

Silverman, M. J. (2007). The effect of paired pitch, rhythm and speech on working memory as measured by sequential digit recall. *Journal of Music Therapy, XLIV*(4), 415–427. https://doi.org/10.1093/jmt/44.4

Silverman, M. J. (2010). The effect of pitch, rhythm and familiarity on working memory and anxiety as measured by digit recall performance. *Journal of Music Therapy, XLVI, I*(1), 70–83. https://doi.org/10.1093/jmt/47.1.70

Silverman, M. J. (2012). Effects of melodic complexity and rhythm on working memory as measured by digit recall performance. *Music and Medicine, 4*(1), 22–27. https://doi.org/10.1177/1943862111424415

Silverman, M. J., Bourdaghs, S. W., & Schwartzberg, E. T. (2021). Effects of visual and aural presentation styles and rhythm on working memory as measured by monosyllabic sequential digit recall. *Psychological Reports, 124*(3), 1282–1297. https://doi.org/10.1177/0033294120930974

Silverman, M. J., & Schwartzberg, E. T. (2014). Effects of voice timbre and accompaniment on working memory as measured by sequential monosyllabic digit recall performance. *Journal of Music Therapy, 51*(2), 171–185. https://doi.org/10.1093/jmt/thu009

Silverman, M. J., & Schwartzberg, E. T. (2019). Effects of visual and auditory presentation styles and musical elements on working memory functioning as measured by monosyllabic sequential digit recall. *Psychological Reports, 122*(4), 1297–1312. https://doi.org/10.1177/0033294118781937

Simmons-Stern, N. R., Budson, A. E., & Ally, B. A. (2010). Music as a memory enhancer in patients with Alzheimer's disease. *Neuropsychologia, 48*, 3164–3167. https://doi.org/10.1016/j.neuropsychologia.2010.04.033

Simmons-Stern, N. R., Deason, R. G., Brandler, B. J., Frustace, B. J., O'Connor, M. K., Ally, B. A., & Budson, A. E. (2012). Music based memory enhancement in Alzheimer's disease: Promise and limitations. *Neuropsychologia, 50*, 3295–3303. https://doi.org/10.1016/j.neuropsychologia.2012.09.019

Sloboda, J. A. (1985). The musical mind: The cognitive psychology of music. Clarendon Press.

Squire, L. R. (2004). Memory systems of the brain: A brief history and current perspective. *Neurobiology of Learning and Memory, 82*(3), 171–7. https://doi.org/10.1016/j.nlm.2004.06.005

Stern, Y., Albert, M., Barnes, C. A., Cabeza, R., Pascual-Leone, A., & Rapp, P. R. (2023). A framework for concepts of reserve and resilience in aging. *Neurobiology of Aging*, *124*, 100–103. https://doi.org/10.1016/j.neurobiolaging.2022.10.015

Stoffer, T. H. (1985). Representation of phrase structure in the perception of music. *Music Perception, 3*(2), 191–220.

Tamminen, J., Rastle, K., Darby, J., Lucas, R., & Williamson, V. J. (2017). The impact of music on learning and consolidation of novel words. *Memory, 25*(1), 107–121. https://doi.org/10.1080/09658211.2015

Thalmann, M., Souza, A. S., & Oberauer, K. (2019). How does chunking help working memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 45*(1), 37–55. https://doi.org/ 10.1037/xlm0000578

Thampi, N., Longtin, Y., Peters, A., Pittet, D., & Overy, K. (2020). It's in our hands: A rapid, international initiative to translate a hand hygiene song during the COVID-19 pandemic. *Journal of Hospital Infection*, *105*(3), 574–576. https://doi.org/10.1016/j.jhin.2020.05.003

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, mood, and the Mozart effect. *Psychological Science, 12*(3), 248–251. https://doi.org/10.1111/1467-9280.00345

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson, *Organization of memory.* Academic Press.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80*(5), 352–373.

Uanhoro, J. O. (2017). Effect size calculators. [Computer software]. Retrieved February 25, 2022, from https://effect-size-calculator.herokuapp.com

UNESCO. (2011). International Standard Classification of Education ISCED 2011. Montreal, QC, Canada: UNESCO Institute for Statistics.

Van den Bosch, I., Salimpoor, V. N., & Zatorre, R. J. (2013). Familiarity mediates the relationship between emotional arousal and pleasure during music listening. *Frontiers in Human Neuroscience, 7*, 534. https://doi.org/10.3389/fnhum.2013.00534

Van Geldorp, B., Heringa, S. M., van den Berg, E., Olde Rikkert, M. G., Biessels, G. J., & Kessels, R. P. C. (2015). Working memory binding and episodic memory formation in aging, mild cognitive impairment, and Alzheimer's dementia. *Journal of Clinical and Experimental Neuropsychology, 37*(5), 538–548. https://doi.org/10.1080/13803395.2015.1037722

Van Heugten, C. M., Ponds, R. W. H. M., & Kessels, R. P. C. (2016). Brain training: Hype or hope? *Neuropsychological Rehabilitation, 26*, 639–644. https://doi.org/10.1080/09602011.2016.1186101

Verga, L., Bigand, E., & Kotz, S. A. (2015). Play along: Effects of music and social interaction on word learning. *Frontiers in Psychology, 6*, 1316. https://doi.org/10.3389/fpsyg.2015.01316

Wagner, I. C., Konrad, B. N., Schuster, P., Weisig, S., Repantis, D., Ohla, K., Kühn, S., Fernández, A., Steiger, A., Lamm, C., Czisch, M., & Dresler, M. (2021). Durable memories and efficient neural coding through mnemonic training using the method of loci. *Science Advances, 7*(10), 1–16. https://doi.org/10.1126/sciadv.abc7606

Wallace, W. T. (1994). Memory for music: Effect of melody on recall of text. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 1471–1485. https://doi.org/10.1037/0278-7393.20.6.1471

Wechsler, D. (1955). *Manual for the Wechsler Adult Intelligence Scale.* Psychological Corporation.

Wechsler, D. (2008). Wechsler Adult Intelligence Scale – Fourth Edition: Administration and scoring manual. San Antonio, TX: Pearson Assessment.

Wilson, S. J., Parsons, K., & Reutens, D. C. (2006). Preserved singing in aphasia: A case study of the efficacy of Melodic Intonation Therapy. *Music Perception, 24*(1), 23–26. https://doi.org/10.1525/mp.2006.24.1.23

Wolfe, D. E., & Hom, C. (1993). Use of melodies as structural prompts for learning and retention of sequential verbal information by preschool students. *Journal of Music Therapy, 30*, 100–118. https://doi.org/10.1093/jmt/30.2.100

Yalch, R. F. (1991). Memory in a jingle jungle: Music as a mnemonic device in communicating advertising slogans. *Journal of Applied Psychology, 76*(2), 268–275. https://doi.org/10.1037/0021-9010.76.2.268

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1983). Development and validation of geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research, 17*, 37–49. https://doi.org/10.1016/0022-3956(82)90033-4

Zhang, X., Li, J., & Du, Y. (2022). Melodic Intonation Therapy on non-fluent aphasia after stroke: A systematic review and analysis on clinical trials. *Frontiers in Neuroscience, 15*, 753356. https://doi.org/10.3389/fnins.2021.753356

Appendix A

Supplementary table 2.1

Expanded version of the characteristics of the studies included in the systematic review examining effects of music on memory functioning

Article	Musical stimulus embedding			Broader study results
	Learning phase			
	Individually/group	Active/ passive	Recording/ live	
Baird et al., 2017	Individually	Passive	Recording	L: AD NMu sung < spoken AD Mu > NMu DR & Re: Mu OA = Mu AD
Calvert & Billingsley, 1998	Exp. 1: Small groups	Passive & active	Recording	Exp. 1: No paradigm of interest > Rep French sung > spoken, Rep English sung = spoken
	Exp. 2: Individually	Passive	Live	Exp. 2: Sung < prose
Calvert & Tart, 1993	Small groups	Passive	Recording	Exp. 1: No paradigm of interest > naturalistic study Exp. 2: STR + LTR: SE: Sung = spoken RE: Sung > spoken
Chazin & Neuschatz, 1990	Individually	Passive & active	Recording	IR: Sung > spoken DR: Sung = spoken
Deason et al., 2012	Individually	Passive	Recording	Re: Sung = spoken
Gfeller, 1983	Individually	Passive & active	Recording	Exp. 1: SR: Sung < spoken Exp. 2: ER: Sung > spoken
Good et al., 2015	Classroom	Passive & active	Live	IP: Sung > spoken IT: Sung > spoken IR: Sung > spoken DR: Sung > spoken DT: Sung = spoken
Jellison, 1976	Individually	Passive	Recording	Sung > spoken Sung: ME > NME
Jellison & Miller, 1982	Individually	Passive	Recording	Sung < spoken digit span Sung = spoken word span OR: ME = NME ME > NME SeR verbal material

Supplementary table 2.1

Continued

Article	Musical stimulus embedding			Broader study results
	Learning phase			
	Individually/group	Active/ passive	Recording/ live	
Kilgour et al., 2000	Individually	Passive	Recording	Exp. 1: sung + sung with piano prelude > spoken (IR & DR) Exp. 2 & 3: sung < spoken ME>NME verbal material
Lehmann & Seufert, 2018	Classroom	Passive	Recording	R: Visual > sung R: Visual > spoken R: Sung = spoken (‘only differed on a descriptive level…’) C: Sung > visual C: Spoken = visual C: Sung = spoken
Ludke et al., 2014	Individually	Passive & active	Recording	Sung > spoken Hungarian (IR & DR)
Ma et al., 2020	Individually	Passive	Recording	WL: Sung & IDS > ADS Delayed Recall: Sung & IDS > ADS UF = F
McElhinney & Annett, 1996	Small groups	Passive	Recording	1 x: Sung = spoken 2 & 3 x: Sung > spoken
Moussard et al., 2012	Individually	Passive & active	Recording	IL: Sung UF < spoken IL: Sung HF & LF > Sung UF RL UF + F: Sung > spoken
Moussard et al., 2014	Individually	Passive & active	Recording	IR: Sung = spoken DR: Sung > spoken, OA: F, AD: F & UF
Oostendorp & Montel, 2014	N.R.	Active	Live	FR + CR: Sung > spoken
Palisson et al., 2015	Individually	Passive & active	Recording	IR: Sung > spoken & SME DR: Sung > spoken & SME
Prickett & Moore, 1991	Individually	Active	Live	WR: F song > new song/ F or new spoken WR: F m% = 71.8 vs. new m% = 42.19
Purnell-Webb & Speelman, 2008	Individually	Passive	Recording	Exp. 1: R: Rhy (UF/F) > spoken & UF melody Exp. 1: Rhy (UF/F) = Melody (F)

Supplementary table 2.1

Continued

Article	**Musical stimulus embedding**			**Broader study results**
	Learning phase			
	Individually/group	**Active/ passive**	**Recording/ live**	
Racette & Peretz, 2007	Individually	Passive & active	Recording	Exp. 1: IR & DR: Spoken = Sung Exp. 2: No paradigm of interest
Rainey & Larsen, 2002	Individually	Passive	Recording	Exp. 1 & 2: IL Sung = spoken Exp. 1 & 2: RL Sung > spoken
Ratovohery et al., 2018	Individually	Passive & active	Recording	EM YA > OA OA IR + DR: Sung PV > spoken
Ratovohery et al., 2019	Individually	Passive & active	Recording	OA > AD AD Encoding + IR + DR (10 min & 24 hour): Sung > spoken AD encoding: PV > NV OA R: PV > NV
Rukholm et al., 2018	Classroom	Passive	Recording	Productive & receptive learning: Sung/HE > Sung/ LE, P/HE & P/LE
Schön et al., 2008	Individually	Passive	Recording	Exp. 2 (sung constant syllable-pitch mapping > Exp. 1 (spoken) Exp. 3 (sung variable syllable-pitch mapping) > Exp. 1 (spoken) Exp. 3 (sung variable syllable-pitch mapping) < Exp. 2 (sung constant syllable-pitch mapping)
Silverman, 2007	Individually	Passive	Recording	Rhy > spoken ME > NME verbal material
Silverman, 2010	Individually	Passive	Recording	Rhy + F - ME > NME verbal material
Silverman, 2012	Individually	Passive	Recording	Rhy > NRhy ME = NME

Supplementary table 2.1

Continued

Article	Musical stimulus embedding			Broader study results
	Learning phase			
	Individually/group	**Active/ passive**	**Recording/ live**	
Silverman & Schwartzberg, 2014	Individually	Passive	Recording	M > Fe voice Piano, N Acc > guitar ME = NME
Silverman & Schwartzberg, 2019	Individually	Passive	Recording	Au > V + Au Au: Melody = sung = spoken V + Au: Sung > spoken, Melody > spoken, Sung = Melody ME = NME
Simmons-Stern et al., 2010	Individually	Passive	Recording	AD Re Sung > spoken
Simmons-Stern et al., 2012	Individually	Passive	Recording	GC Sung > spoken: OA & AD SC Sung = spoken FA: Sung > spoken: AD
Tamminen et al., 2017	Individually	Passive	Recording	R: Sung = spoken Re: Sung = spoken IML: Sung F > spoken
Wallace, 1994	Individually	Passive	Recording	Exp. 1: 3 vs Sung (OM) > spoken Exp. 2: 3 vs Sung (OM) > rhythmic spoken Exp. 3: 1 vs Sung < spoken Exp. 4: 3 vs Sung (OM) > 3 vs sung (DM) or spoken
Wolfe & Hom, 1993	Individually	Passive	Live	L: Sung F > UF & spoken IR: Sung = spoken Ret: Sung = spoken

Supplementary table 2.1

Continued

Article	Musical stimulus embedding			Broader study results
	Learning phase			
	Individually/group	Active/ passive	Recording/ live	
Yalch, 1991	Exp. 1: Classroom	Passive	Exp. 1: No paradigm of interest: List of slogans (jingle/ no jingle format)	Exp. 1: Aided Recall: Jingle > No Jingle Exp. 1: Passive Recognition: Jingle = No Jingle
	Exp. 2: Small groups		Exp. 2: Recording	Exp. 2: Aided Recall: Jingle > No Jingle Exp. 2: Passive Recognition: Jingle > No Jingle Exp. 2: Interaction: Jingle Aided Recall > Jingle Passive Recognition Exp. 2: Interaction: Jingle Aided Recall One Exposure > Two exposures

APPENDIX B

Supplementary table 3.1

Grid showing all possible administration orders with different combinations of the four conditions of the musical digit span task (i.e., spoken, pitch, rhythm, melody)

1.	2.	3.	4.	5.	6.
Spoken	Spoken	Spoken	Spoken	Spoken	Spoken
Pitch	Pitch	Rhythm	Rhythm	Melody	Melody
Melody	Rhythm	Melody	Pitch	Pitch	Rhythm
Rhythm	Melody	Pitch	Melody	Rhythm	Pitch

7.	8.	9.	10.	11.	12.
Pitch	Pitch	Pitch	Pitch	Pitch	Pitch
Melody	Melody	Spoken	Spoken	Rhythm	Rhythm
Rhythm	Spoken	Rhythm	Melody	Melody	Spoken
Spoken	Rhythm	Melody	Rhythm	Spoken	Melody

13.	14.	15.	16.	17.	18.
Rhythm	Rhythm	Rhythm	Rhythm	Rhythm	Rhythm
Melody	Melody	Spoken	Spoken	Pitch	Pitch
Pitch	Spoken	Melody	Pitch	Spoken	Melody
Spoken	Pitch	Pitch	Melody	Melody	Spoken

19.	20.	21.	22.	23.	24.
Melody	Melody	Melody	Melody	Melody	Melody
Spoken	Spoken	Pitch	Pitch	Rhythm	Rhythm
Pitch	Rhythm	Rhythm	Spoken	Pitch	Spoken
Rhythm	Pitch	Spoken	Rhythm	Spoken	Pitch

APPENDIX C

Supplementary table 3.2

Descriptive statistics for the results by condition and by group

	Spoken		Pitch		Rhythm		Melody		
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*n*
YA	3.75	1.74	3.70	1.26	4.35	1.73	4.25	1.41	20
OA	3.44	2.04	2.74	1.56	4.00	1.75	2.85	1.43	27
Total	3.57	1.91	3.15	1.50	4.15	1.73	3.45	1.57	47

APPENDIX D

Supplementary table 4.1

Example of scoring form of the musical digit span

Item	Sequence	Response	Score	Item score
1. P	4 – 5 – 6 – 3 – 8		0 1	0 1 2
P	1 – 3 – 6 – 8 – 4		0 1	
2. M	2 – 4 – 5 – 10 – 3		0 1	0 1 2
M	5 – 3 – 2 – 1 – 10		0 1	
3. R	8 – 5 – 1 – 3 – 6		0 1	0 1 2
R	3 – 4 – 10 – 2 – 8		0 1	
4. S	6 – 8 – 2 – 3 – 1		0 1	0 1 2
S	10 – 2 – 5 – 4 – 8		0 1	
5. P	6 – 3 – 4 – 8 – 5 – 10		0 1	0 1 2
P	1 – 4 – 2 – 5 – 3 – 8		0 1	
6. M	10 – 1 – 2 – 4 – 5 – 3		0 1	0 1 2
M	8 – 10 – 2 – 6 – 5 – 4		0 1	
7. R	4 – 2 – 8 – 3 – 5 – 6		0 1	0 1 2
R	6 – 1 – 4 – 2 – 10 – 8		0 1	
8. S	3 – 2 – 8 – 10 – 4 – 6		0 1	0 1 2
S	2 – 1 – 8 – 6 – 4 – 5		0 1	
9. P	6 – 3 – 4 – 1 – 8 – 5 – 10		0 1	0 1 2
P	1 – 4 – 2 – 5 – 6 – 3 – 8		0 1	
10. M	10 – 1 – 2 – 4 – 5 – 3 – 6		0 1	0 1 2
M	8 – 10 – 2 – 3 – 6 – 5 – 4		0 1	
11. R	5 – 3 – 8 – 6 – 4 – 2 – 1		0 1	0 1 2
R	2 – 6 – 4 – 10 – 5 – 3 – 8		0 1	
12. S	3 – 2 – 8 – 10 – 4 – 6 – 5		0 1	0 1 2
S	10 – 2 – 1 – 8 – 6 – 4 – 5		0 1	
13. P	2 – 3 – 5 – 6 – 10 – 1 – 8 – 4		0 1	0 1 2
P	4 – 2 – 10 – 1 – 3 – 5 – 6 – 8		0 1	
14. M	10 – 3 – 6 – 2 – 4 – 8 – 1 – 5		0 1	0 1 2
M	8 – 1 – 2 – 3 – 10 – 5 – 4 – 6		0 1	
15. R	10 – 4 – 3 – 6 – 5 – 1 – 8 – 2		0 1	0 1 2
R	1 – 2 – 5 – 8 – 10 – 6 – 3 – 4		0 1	
16. S	5 – 6 – 8 – 2 – 4 – 3 – 1 – 10		0 1	0 1 2
S	1 – 3 – 5 – 8 – 6 – 2 – 10 – 4		0 1	

Note. Score form (one of 24 administration orders). The four conditions are abbreviated with S, ‘spoken’; P, ‘pitch’; R, ‘rhythm’ and M, ‘melody’.

APPENDIX E

Supplementary table 4.2

Descriptive statistics for the results by condition and by group

	Spoken		Pitch		Rhythm		Melody		
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***n***
OA	3.47	2.11	2.87	1.70	4.19	1.71	3.00	1.69	32
aMCI	2.53	1.65	2.34	1.54	3.00	1.78	1.88	1.54	32
Total	3.00	1.94	2.61	1.63	3.59	1.83	2.44	1.70	64

APPENDIX F

Supplementary table 4.3

Correlations between the Gold-MSI General Sophistication subscale and the performances on the four conditions of the musical digit span

	***Total* (*N = 63*)**	***OA* (*N = 32*)**	***aMCI* (*N = 31*)**
Condition	**Gold-MSI General Sophistication**	**Gold-MSI General Sophistication**	**Gold-MSI General Sophistication**
Spoken	.272*	.322	.196
Pitch	.214	.222	.199
Rhythm	.368**	.511**	.228
Melody	.144	.219	.039

Note. Pearson correlations. *$p<.05$, **$p<.01$.

Research data management

The studies within this thesis were part of an external PhD studentship of the Radboud University (Nijmegen) and Leiden University. This research followed the applicable laws and ethical guidelines. Research Data Management adhered to the FAIR principles (findable, accessible, interoperable, re-usable). The paragraphs below specify in detail how this was achieved.

Ethics

The empirical studies in this thesis based on data collected in human participants, were conducted in accordance with the principles of the Declaration of Helsinki.

Research in **chapters 3** and **4** was approved by the local ethics committee of ZGT (September 12, 2016, ZGT16-22) and Radboud University (ECG2012-1304-025).

Findable, accessible

For **chapters 3** and **4** the original documents of the behavioural examination (paper data) are archived at the ZGT hospital, Almelo, and will be maintained for 15 years. Access to these data can be obtained by contacting Dr. I.A.D.A. van Tilborg (medischepsychologie@zgt.nl) employed at the Medical Psychology department of the ZGT hospital. Informed consent was obtained on paper. These forms are separately archived at the ZGT hospital, Almelo, and will also be maintained for 15 years. Data cannot be shared in a public repository, since the informed consent form participants signed upon recruitment did not contain a statement on anonymous publication of their data, for which explicit consent is required (EU General Data Protection Regulation 2016/679). The auditory stimuli (mp4 sound files) of the musical digit span task used in the experiments conducted in **chapters 3** and **4** are available via the Donders Institute Repository (https://doi.org/10.34973/dxq4-a452).

Interoperable, re-usable

Paper data are stored in their original form. Digital data are stored in an IBM SPSS data file version (compliant with versions 26.0 and higher). Results are reproducible using the provided methodological descriptions and study-specific auditory stimuli (Donders Institute Repository).

Privacy

For **chapters 3** and **4,** digital participant data are stored in an anonymous SPSS database using a participant numbering system (a number is assigned to the research data from a given participant instead of the participants name). Access to these data can be obtained by contacting R.P.C. Kessels (roy.kessels@donders.ru.nl). The data are stored for at least 15 years.

Nederlandse samenvatting

Muzikale presentatie van te onthouden verbale informatie met als doel het geheugen te ondersteunen, wordt ook wel 'muziek als structurele prompt' genoemd. Muzikale geheugensteuntjes (*musical mnemonics*) worden regelmatig toegepast in het onderwijs bij het aanleren van schoolse en sociale vaardigheden. Een voorbeeld is het ABC-lied, waarin het alfabet wordt gezongen op de bekende melodie van 'Twinkle, twinkle, little star' ter ondersteuning van het aanleren van de volgorde van de letters. Een ander recent voorbeeld is het ‘handen-was-lied’, dat werd ontworpen op de bekende melodie van ‘Vader Jacob’ ten tijde van de coronapandemie, met als doel het aanleren van de juiste handen was routine aan kinderen over de hele wereld.

Het idee dat muziek de cognitieve functies kan verbeteren bestaat al lang en is wijdverbreid. Gebaseerd op dit idee, wordt muziek niet alleen op scholen, maar ook in de klinische praktijk gebruikt met als doel het verbeteren van neuropsychologische problemen, zoals bijvoorbeeld in Melodic Intonation Therapy bij afasie. Bij patiënten met een beroerte, maar ook bij andere hersenaandoeningen die de cognitieve prestaties beïnvloeden (bijvoorbeeld multiple sclerose), wordt muziek ook gebruikt om (onder andere) het geheugen te ondersteunen, ook wel musical mnemonics training (MMT) genoemd.

Ondanks het wijdverbreide gebruik van muzikale geheugensteuntjes, is het empirische bewijs over de effecten ervan bij mensen met of zonder cognitieve stoornissen nog steeds beperkt. Eerdere studies naar de effecten van muzikale geheugensteuntjes op het geheugen zijn grotendeels uitgevoerd bij jongvolwassenen zonder cognitieve beperkingen en slechts een beperkt aantal studies heeft systematisch de mogelijk bijdragende aspecten van afzonderlijke muzikale componenten op de geheugenprestatie gemanipuleerd en vergeleken, waardoor het moeilijk is om te bepalen welk specifiek aspect van muziek (bijv. ritme of melodie) binnen de muzikale presentatie een effect kan hebben gehad.

Eerder onderzoek dat wel systematisch de effecten van afzonderlijke muzikale componenten (d.w.z. toonhoogte, ritme en melodie) heeft vergeleken, toonde een consistent positief effect van ritmische presentatie op de werkgeheugenprestatie bij universitaire studenten. Mogelijk heeft toevoeging van ritme of tijdsstructuur chunking-mechanismen gefaciliteerd (d.w.z. het groeperen van verschillende gepresenteerde stimuli tot een enkele eenheid, of ‘chunk’, met als doel de werkgeheugenbelasting te verminderen). Daarentegen hadden onbekende melodieën een negatief effect op de werkgeheugenprestatie, mogelijk als gevolg van overbelasting van het werkgeheugen.

Niet alleen als we naar school gaan of studeren, maar ook als we ouder worden speelt ons geheugen een belangrijke rol in ons dagelijks leven bij het leren, opslaan en onthouden van kennis en ervaringen. Gezonde veroudering gaat echter gepaard met een achteruitgang in ons geheugen, waarbij er aanzienlijke interindividuele verschillen bestaan in de mate (en aard) van cognitieve veranderingen tijdens de levensloop. De grootste mate van geheugenachteruitgang wordt gezien in het *episodisch geheugen*, een onderdeel van het lange termijn geheugen. Dit is het alledaags geheugen, dat geactiveerd wordt wanneer je je bijvoorbeeld probeert te herinneren wat je gisteren gegeten hebt of terugdenkt aan een vakantie een paar jaar geleden. Echter, het *werkgeheugen*, het vermogen om een beperkte hoeveelheid informatie voor korte tijd vast te houden en te kunnen bewerken, gaat ook achteruit in cognitieve veroudering. Het werkgeheugen is bijvoorbeeld betrokken bij het een aantal keer herhalen van een telefoonnummer in je hoofd, terwijl je naar een pen zoekt om het op te schrijven.

Ondanks de leeftijdsgebonden achteruitgang van zowel het episodisch geheugen als het werkgeheugen, presteren oudere volwassenen zonder cognitieve stoornissen per definitie binnen het normale bereik op formele geheugentests (in vergelijking met voor leeftijd en opleiding gecorrigeerde normgegevens). Daarentegen zijn bij personen met een *milde cognitieve stoornis* (MCI) de cognitieve prestaties op neuropsychologische tests per definitie op stoornisniveau in vergelijking met voor leeftijd en opleiding gecorrigeerde normgegevens. Voorgaande wordt tevens onderbouwd door subjectief ervaren cognitieve achteruitgang door de persoon met een milde cognitieve stoornis zelf, of hun dierbaren. Mensen met het *amnestische* subtype van milde cognitieve stoornis zijn het meest kwetsbaar voor uiteindelijke progressie naar Alzheimer dementie. Er is daarnaast echter toenemend bewijs dat in amnestische milde cognitieve stoornis niet alleen het episodisch geheugen, maar ook het werkgeheugen is aangedaan. Bij mensen met een milde cognitieve stoornis is echter het zelfstandig functioneren in het dagelijks leven per definitie behouden, in contrast met ouderen gediagnosticeerd met Alzheimer dementie.

Er zijn tot op heden geen bewezen effectieve farmacologische behandelopties voor ouderen met een (amnestische) milde cognitieve stoornis beschikbaar. Er is enig bewijs voor effecten van niet-farmacologische interventies zoals lichaamsbeweging of cognitieve training (d.w.z. behandeling gericht op herstel, met als doel verbetering van de geheugenfunctie), maar grotere randomized controlled trials zijn nodig om de effectiviteit hiervan verder te onderzoeken. De geheugenproblemen die ouderen met milde cognitieve stoornissen ervaren in het dagelijks leven (ook al functioneren ze nog zelfstandig) kunnen echter mogelijk worden verbeterd door het gebruik van geheugenstrategieën, hetgeen mogelijk hun onafhankelijkheid verder bevordert. Een geheugenstrategie wordt gebruikt ter compensatie van geheugenachteruitgang. Sommige geheugenstrategieën zijn heel bekend, zoals het gebruik van een agenda om afspraken te onthouden als voorbeeld van een externe strategie, of het maken van een visuele associatie tussen een aspect van iemands verschijning en hun naam om deze beter te kunnen onthouden, als voorbeeld van een interne strategie.

Niet alleen bij mensen met een milde cognitieve stoornis, maar ook bij mensen met subjectief ervaren cognitieve klachten helpt het gebruik van geheugenstrategieën bij het verbeteren van geheugenprestaties in het dagelijks leven. Tenslotte kan ook bij normale veroudering het gebruik van geheugenstrategieën leiden tot een verbetering van onder andere de geheugenprestaties, welzijn en kwaliteit van leven. Interessant is dat het gebruik van muzikale geheugensteuntjes ook een voorbeeld is van een geheugenstrategie die ouderen spontaan rapporteren te gebruiken.

Pas recentelijk echter zijn er enkele studies uitgevoerd naar de effecten van muzikale geheugensteuntjes in normale veroudering en bij ouderen met cognitieve stoornissen, zoals personen met Alzheimer dementie, waarbij de nadruk vooral lag op het episodisch geheugen. Er kan echter worden gesteld dat het ook belangrijk is om aandacht te besteden aan het verbeteren van de werkgeheugenprestatie, aangezien deze ook afneemt met het ouder worden, aangetast kan zijn bij een amnestische milde cognitieve stoornis en muzikale presentatie extra structuur kan bieden bij een beperkte werkgeheugencapaciteit en mogelijk het vermogen om informatie over te dragen naar het episodisch geheugen kan verbeteren. Voor zover wij weten, zijn er geen eerdere studies die zich hebben gericht op de effecten van muzikale geheugensteuntjes op de werkgeheugenprestatie bij ouderen met een amnestische milde cognitieve stoornis of Alzheimer dementie.

In dit proefschrift introduceren we een nieuw ontwikkeld paradigma, de muzikale cijferreeksentaak, voortbouwend op een eerder beschreven paradigma in de literatuur. De taak maakt gebruik van cijferreeksen van toenemende lengte (de procedure die wordt gebruikt in de Wechsler Digit Span-taken). Het primaire doel van dit proefschrift was het verkrijgen van inzicht in de effecten van muzikale geheugensteuntjes in zowel normale als pathologische veroudering. Doel daarbij was om de eerdere resultaten van studies die zijn uitgevoerd bij universitaire studenten systematisch te repliceren, met als hypothese dat ritmische presentatie leidt tot een betere werkgeheugenprestatie vergeleken met gesproken presentatie. De studies in dit proefschrift werden uitgevoerd bij jongvolwassenen en ouderen zonder cognitieve stoornissen en ouderen gediagnosticeerd met een amnestische milde cognitieve stoornis. Ten tweede wilde ik de onderliggende mechanismen onderzoeken waardoor muzikale geheugensteuntjes het geheugen (op mogelijk verschillende manieren) kunnen verbeteren in veroudering al dan niet met cognitieve beperkingen, door middel van een systematisch review enerzijds en empirische studies anderzijds. Een derde doel was om de impact van muzikale expertise op de mate van profijt van muzikale presentatie op de werkgeheugenprestatie te onderzoeken.

Hoofdstuk 2 presenteert een systematische review naar de effecten van muzikale presentatie op zowel het episodisch als werkgeheugen bij kinderen, jongvolwassenen en in normale en pathologische veroudering (d.w.z. [amnestische] milde cognitieve stoornis, of Alzheimer dementie). Er werd geen literatuur gevonden aangaande effecten van muzikale presentatie op het werkgeheugen bij ouderen zonder cognitieve stoornissen, personen met een (amnestische) milde cognitieve stoornis of Alzheimer dementie. De resultaten toonden over het algemeen gunstige resultaten van muzikale presentatie bij jongvolwassen en gemengde resultaten bij kinderen en ouderen zonder cognitieve stoornissen. Er werd een heterogeniteit binnen de overwegend positieve resultaten van een beperkt aantal studies gericht op effecten van muzikale presentatie op het episodisch geheugen bij mensen met Alzheimer dementie gevonden. Studies lieten gemengde resultaten zien met betrekking tot de specifieke bijdrage van afzonderlijke muzikale componenten. In de meeste studies waarin de bekendheid met de muziek bij volwassenen zonder cognitieve stoornissen systematisch werd vergeleken, werd een voordeel van een bekende melodie (of ritme) gevonden (slechts enkele studies naar Alzheimer dementie vergeleken systematisch de bekendheid met de muziek; de resultaten waren gemengd). In de meeste studies waarin de muzikale expertise van volwassenen zonder cognitieve stoornissen systematisch werd vergeleken, werd geen modererend effect van muzikale expertise gevonden (één studie vond bij mensen met Alzheimer dementie een verbeterd leren van gezongen informatie in musici versus niet-musici). Op basis van deze uiteenlopende resultaten van eerder onderzoek hebben we een nieuw theoretisch model geformuleerd dat beschrijft hoe verschillende belangrijke factoren (bijvoorbeeld de algehele complexiteit van de stimulus en persoonlijke aspecten) samen de effectiviteit van muzikale presentatie op de geheugenprestaties beïnvloeden, waarmee we eerder werk hebben uitgebreid.

In **hoofdstuk 3** hebben we de resultaten van eerder onderzoek onder universitaire studenten gerepliceerd en uitgebreid naar jongvolwassenen - representatiever voor de algemene bevolking - en naar ouderen zonder cognitieve stoornissen. Er is onderzocht in hoeverre verschillende muzikale presentaties (d.w.z. toonhoogte, ritme en melodie) van verbale informatie effect hebben op de werkgeheugenprestatie van jongvolwassenen en ouderen met behulp van de nieuwe muzikale cijferreeksentaak. Muzikale expertise werd beoordeeld met behulp van twee perceptuele tests en een zelfrapportagevragenlijst uit een testbatterij naar muzikale expertise. De resultaten lieten zien dat beide groepen in vergelijkbare mate voordeel van ritmische presentatie hadden op hun werkgeheugenprestatie. Aan de andere kant werd de werkgeheugenprestatie van ouderen in vergelijking met de jongvolwassenen in de toonhoogte- en melodie conditie negatief beïnvloed. Ten slotte had muzikale expertise geen invloed op de mate van voordeel van muzikale presentatie in beide groepen.

In **hoofdstuk 4** is onderzocht of ouderen gediagnosticeerd met een amnestische milde cognitieve stoornis ook profiteren van muzikale (d.w.z. ritmische) aanbieding, opnieuw gebruikmakende van de muzikale cijferreeksentaak. Ouderen met een amnestische milde cognitieve stoornis hadden net zo veel profijt van ritmische presentatie als ouderen zonder cognitieve stoornissen. Ook het nadeel van presentatie met behulp van toonhoogte en melodie was vergelijkbaar in beide groepen. Mogelijk resulteerde (het toevoegen van) toonhoogte in extra te verwerken informatie, wat de complexiteit van de stimulus kan hebben vergroot. Op basis van deze resultaten stelden we dat ritmische presentatie ook de werkgeheugenprestatie bij ouderen met een amnestische milde cognitieve stoornis kan verbeteren. Muzikale expertise versterkte dit gunstige effect van muzikale presentatie bij zowel ouderen met als zonder cognitieve stoornissen (i.t.t. de resultaten bij jongvolwassenen), hetgeen suggereert dat muzikale expertise mogelijk meer een rol gaat spelen wanneer het cognitief functioneren achteruitgaat.

In **hoofdstuk 5** zijn de bevindingen van de huidige studies bediscussieerd, sterke kanten, beperkingen en klinische implicaties belicht en aanbevelingen voor vervolgonderzoek besproken. Ritmische presentatie verbeterde zowel de werkgeheugenprestatie van jongeren als ouderen met en zonder cognitieve stoornissen, hetgeen suggereert dat ritmische presentatie vermoedelijk een effectief element is van een geheugensteun (mogelijk door activering van chunking-mechanismen), ongeacht de gevolgen van normale of pathologische veroudering (d.w.z. amnestische milde cognitieve stoornis). Toevoeging van toonhoogte beïnvloedde de werkgeheugenprestaties van ouderen met en zonder cognitieve stoornissen echter negatief; deze bevindingen zijn aan de hand van factoren uit het nieuwe theoretische model belicht. In tegenstelling tot de bevindingen van eerder onderzoek bij jongvolwassenen, vonden we dat bij ouderen met en zonder cognitieve stoornissen muzikale expertise een gunstig modererend effect had op de mate van profijt van muzikale (d.w.z. ritmische) presentatie (mogelijk bijdragend aan meer effectief chunken), hetgeen suggereert dat muzikale expertise een belangrijke rol zou kunnen spelen, wanneer cognitieve functies achteruitgaan.

Ondanks dat de studies in dit proefschrift hebben bijgedragen aan inzicht in onderliggende werkingsmechanismen van muzikale geheugensteuntjes in veroudering met en zonder cognitieve stoornissen, hebben de studies ook enkele beperkingen. Als gevolg van de steekproefomvang in onze empirische studies, heeft het aantal condities en covariaten dat werd meegenomen in de analyses mogelijk geresulteerd in een beperkte statistische power, hetgeen vraagt om replicatie van de huidige bevindingen in toekomstig onderzoek met grotere steekproefomvang. De muzikale cijferreeksentaak zelf heeft ook beperkingen; één daarvan is dat de taak vermoedelijk vooral een beroep doet op het 'opslag'- en minder op het 'bewerk'-aspect van het werkgeheugen. Verder generaliseren onze resultaten mogelijk beperkt naar andere muzikale geheugensteuntjes, gegeven de gekozen muzikale inbedding van de cijferreeksen. Tenslotte is de ecologische validiteit beperkt, aangezien het een experimenteel onderzoekparadigma is waarin cijferreeksen gezongen of ritmisch gesproken worden gepresenteerd, hetgeen verschilt van hoe mensen een muzikaal geheugensteuntje in het dagelijks leven mogelijk geneigd zijn te gebruiken (d.w.z. hetgeen dat onthouden moet worden zingen op een hen al bekende melodie).

Op basis van de empirische bevindingen in dit proefschrift aangaande de muzikale cijferreeksentaak - die echter weinig directe klinische relevantie heeft – kunnen enkele voorlopige klinische aanbevelingen worden gedaan. Op basis van onze gunstige bevindingen met betrekking tot ritme, raden we zorgverleners (zoals muziektherapeuten) aan om een ritmisch gesproken presentatie van een beperkte hoeveelheid verbale informatie te gebruiken om de werkgeheugenprestaties van patiënten te verbeteren. Een alledaags voorbeeld hiervan is de ritmische presentatie van een telefoonnummer om chunking te vergemakkelijken. Een bredere implicatie voor klinische interventies voortvloeiend uit ons theoretisch model, is het belang van het creëren van een muzikaal geheugensteuntje dat daadwerkelijk helpend is (d.w.z. met betrekking tot de mate van complexiteit van de stimulus) voor de specifieke persoon (gegeven bijvoorbeeld zijn of haar leeftijd, cognitieve vaardigheden). Het ontwikkelen van een muzikale geheugenstrategietraining speciaal afgestemd op personen met subjectief ervaren cognitieve klachten, amnestische milde cognitieve stoornis en (beginnende) Alzheimer dementie, die zich niet alleen richt op het episodisch geheugen, maar ook op het werkgeheugen, beschouw ik als toekomstmuziek.

Onderzoek met de muzikale cijferreeksentaak bij personen met Alzheimer dementie kan inzicht verschaffen in of ritmische presentatie nog meer effect zou kunnen sorteren bij personen met dementie. Toekomstige onderzoekers wordt geadviseerd bij het onderzoeken van bovenstaande hypothesen ons theoretisch model en de rapportagerichtlijnen te gebruiken en tevens aspecten van de verbale stimulus en muzikale inbedding systematisch te vergelijken, hetgeen uiteindelijk kan bijdragen aan een beter begrip van de onderliggende mechanismen waardoor muzikale geheugensteuntjes de geheugenprestaties kunnen verbeteren bij personen met cognitieve stoornissen. Aangezien zowel bij cognitief intacte ouderen als bij personen met aMCI meer muzikale expertise mogelijk heeft bijgedragen aan het effectief herinneren van muzikaal gepresenteerde cijfers (d.w.z. met name in ritmisch gesproken omstandigheden, zie hoofdstuk 4), kan dit worden beschouwd als een relevante factor in toekomstig onderzoek naar muzikale geheugensteuntjes bij veroudering met en zonder cognitieve stoornissen. Longitudinaal onderzoek kan mogelijk verhelderen of muzikale expertise bijdraagt aan cognitieve reserve. Dit is relevant, aangezien is gebleken dat cognitieve reserve een positieve invloed heeft op de cognitieve prestaties, zelfs op hoge leeftijd en bij personen met subjectieve cognitieve achteruitgang of milde cognitieve stoornissen.

Conclusie

Dit proefschrift presenteert een nieuw theoretisch model dat beschrijft hoe verschillende belangrijke factoren (bijv. de algehele stimuluscomplexiteit van de muzikale en verbale stimulus samen, persoonlijke aspecten) samen de effectiviteit van muzikale geheugensteuntjes op de geheugenprestatie beïnvloeden en een nieuw paradigma, de muzikale cijferreeksentaak, waarmee de afzonderlijke bijdrage van diverse aspecten van muzikale presentatie (d.w.z. toonhoogte, ritme, melodie) op het werkgeheugen systematisch kan worden onderzocht. Onze empirische bevindingen wijzen erop dat ritmische presentatie mogelijk nuttig kan zijn voor het onthouden van een beperkte hoeveelheid informatie gedurende een korte periode, niet alleen voor jongere personen, maar ook voor oudere volwassenen met en zonder cognitieve stoornissen. Op basis van mijn experimentele bevindingen wordt met name een ritmisch gesproken presentatie van te onthouden informatie aanbevolen bij het ontwerpen van een muzikale geheugensteun samen met een persoon die werkgeheugenproblemen heeft. Meer in het algemeen raden we op basis van het nieuwe theoretische model aan om de complexiteit van de muzikale stimulus aan te passen aan het verbale materiaal om een goede accentstructuur te creëren. Zo kan mogelijk de algehele stimuluscomplexiteit worden verminderd, hetgeen vermoedelijk resulteert in een gereduceerde cognitieve belasting, waardoor de geheugenprestatie waarschijnlijk wordt verbeterd. De empirische studies in dit proefschrift kunnen worden gezien als een eerste stap in het onderzoek naar muzikale presentatie van verbale informatie om het werkgeheugen bij ouderen en mensen met amnestische MCI te verbeteren. Met dit proefschrift heb ik bijgedragen aan een beter begrip van mogelijke ondersteunende mechanismen van muzikale presentatie bij het verwerven van nieuwe informatie, niet alleen bij veroudering zonder cognitieve stoornissen, maar ook bij personen met cognitieve stoornissen, waarbij ook rekening wordt gehouden met mogelijke modererende effecten van de muzikale expertise van de deelnemers, wat uiteindelijk kan bijdragen aan het vergemakkelijken van de deelname van ouderen aan het dagelijks leven.

Portfolio

Courses and workshops		Organizer
2023	Donders Graduate School Day 2	Donders Graduate School
2022	Donders Graduate School Day	Donders Graduate School
2022	Donders Graduate School Day Scientific Integrity course	Donders Graduate School
2021	Donders Graduate School Introduction Day	Donders Graduate School

Presentations at (inter)national conferences	
Aug. 2024	Global Neuropsychology Congress, Porto [poster]. ‘Effects of musical mnemonics on working memory performance in healthy ageing and amnestic Mild Cognitive Impairment’.
Jun. 2024	The Neurosciences and Music | VIII, Helsinki [poster]. ‘Musical presentation of verbal information improves working memory performance in healthy ageing and amnestic mild cognitive impairment’.
Sep. 2023	8th Scientific Meeting of the Federation of European Societies of Neuropsychology [FESN], Thessaloniki [e-poster]. ‘Effects of musical presentation on verbal working memory span in ageing and Mild Cognitive Impairment: It goes with a swing’.
Mar. 2023	NVN Voorjaarsconferentie [poster and pitch]. ‘Effects of musical presentation on verbal working memory span in ageing and Mild Cognitive Impairment: It goes with a swing’.

Curriculum vitae

Marije Dijkman was born on July 8, 1986, in Velp (Gelderland), The Netherlands. She completed her secondary education (gymnasium) at Stedelijk Gymnasium Arnhem in 2004. Afterward, she took a year private violin and piano lessons in preparation to a conservatory study. Thereafter she started with Psychology at the Radboud University Nijmegen, combined with Musicology at the Utrecht University. She specialized in Neuropsychology and Rehabilitation Psychology and combined this with studying violin (Chris Duindam) at the Tilburg Conservatory. In 2009, she commenced her clinical internship at the Centre of Excellence for Neuropsychiatry of the Vincent van Gogh Institute for Psychiatry in Venray. Afterwards, she completed her master thesis on assessment of social cognition in 17q21.31 microdeletion syndrome. She gained her Master's degree in Psychology *cum laude* in 2010 and started working as a psychologist at the Centre of Excellence for Neuropsychiatry of the Vincent van Gogh. Combined with her clinical work, she performed scientific research at the department of Medical Psychology of Radboudumc Nijmegen, focused on prognostic factors for recovery after TBI. In 2012, she enrolled in the post-master health-care psychology training program at the department of Medical Psychology of VieCuri Medical Centre Venlo and Venray and at PEPAS (Venray) which she completed in December 2014. From 2014 to 2016 she worked as a health psychologist at the ZGT hospital in Almelo and Hengelo. In 2016 she enrolled in the post-master specialist program in clinical neuropsychology and started with (patient-bound) research on the effects of musical mnemonics on working memory performance in older adults with and without cognitive impairment in the context of the memory clinic at the Medical Psychology Department of ZGT. As a result, she started her dissertation research in 2021 as an external PhD-student, embedded within the Donders Institute for Brain, Cognition and Behaviour of Radboud University in Nijmegen in collaboration with the Health, Medical and Neuropsychology unit in the Institute for Psychology of Leiden University. She combined her scientific research with clinical work as a health psychologist at the Diagnostic Centre of GGNet (2021) and is since 2022 employed as a health psychologist at the Klimmendaal Rehabilitation Centre in Zutphen.

Marije Dijkman werd op 8 juli 1986 geboren te Velp (Gelderland). Na het behalen van haar gymnasiumdiploma aan het Stedelijk Gymnasium te Arnhem, volgde ze een jaar viool- en pianolessen bij gepensioneerde conservatoriumdocenten, ter voorbereiding op een toelating tot het conservatorium. Nadien startte ze met de opleiding Psychologie aan de Radboud Universiteit Nijmegen, hetgeen ze combineerde met Muziekwetenschappen aan de Universiteit Utrecht. Ze koos vervolgens de afstudeerrichting Neuro- en Revalidatiepsychologie en combineerde dit met vioollessen bij Chris Duindam aan het Fontys Conservatorium te Tilburg. In 2009 startte ze met haar klinische stage bij het Topklinisch Centrum voor Neuropsychiatrie van het Vincent van Gogh Instituut voor geestelijke gezondheidszorg, te Venray. Vervolgens schreef ze aldaar ook haar masterthese, een multiple case studie naar sociale cognitie bij het 17q21.31 microdeletie syndroom. In 2010 behaalde zij haar master Psychologie *cum laude* en na haar afstuderen werkte ze als psycholoog bij het Topklinisch Centrum voor Neuropsychiatrie. Gecombineerd met haar klinische werk, was zij gedurende een jaar werkzaam binnen een project gericht op prognostische factoren voor herstel na traumatisch hersenletsel, op de afdeling Medische Psychologie van het Radboudumc Nijmegen. In 2012 werd zij toegelaten tot de opleiding tot gezondheidszorgpsycholoog bij de RINO-Zuid te Eindhoven, waarbij ze werkzaam was op de afdeling Medische Psychologie van het VieCuri Medisch Centrum te Venlo en Venray en bij PEPAS te Venray, die ze met succes afrondde in December 2014. Van 2014 tot 2016 was zij werkzaam als gezondheidszorgpsycholoog op de afdeling Medische Psychologie van de Ziekenhuisgroep Twente, te Almelo en Hengelo. In 2016 werd zij toegelaten tot de specialistenopleiding tot klinisch neuropsycholoog en startte met patiëntgebonden onderzoek naar de effecten van muzikale presentatie op de werkgeheugenprestatie van ouderen met en zonder geheugenstoornissen, op de geheugenpoli van de afdeling Medische Psychologie van het ZGT. Als resultaat daarvan startte ze in 2021 met haar patiëntgerichte promotieonderzoek als buitenpromovenda, ingebed in het Donders Instituut voor Brein, Cognitie en Gedrag van de Radboud Universiteit Nijmegen in samenwerking met de sectie Gezondheids-, Medische en Neuropsychologie van het Instituut Psychologie van de Universiteit Leiden. Zij combineerde vervolgens haar wetenschappelijk onderzoek met klinisch werk als GZ-psycholoog bij het Diagnostiek Centrum van GGNet (2021) en is sinds 2022 werkzaam als GZ-psycholoog bij revalidatiecentrum Klimmendaal in Zutphen.

List of publications

This thesis

Derks-Dijkman, M. W., Schaefer, R. S., Baan-Wessels, L., van Tilborg, I. A. D. A., & Kessels, R. P. C. (2024). Effects of musical mnemonics on working memory performance in cognitively unimpaired older adults and persons with amnestic mild cognitive impairment. *Journal of Neuropsychology, 18*(2), 286–299.

Derks-Dijkman, M. W., Schaefer, R. S., & Kessels, R. P. C. (2024). Musical mnemonics in cognitively unimpaired individuals and individuals with Alzheimer's dementia: A systematic review. *Neuropsychology Review, 34*, 455–477.

Derks-Dijkman, M. W., Schaefer, R. S., Stegeman, M. L., van Tilborg, I. A. D. A., & Kessels, R. P. C. (2023). Effects of musical mnemonics on working memory performance in cognitively unimpaired young and older adults. *Experimental Aging Research, 49*(4), 307–320.

Other publications

Egger, J. I. M., Wingbermühle, E., Verhoeven, W. M. A., **Dijkman, M.**, Radke, S., de Bruijn, E. R. A., de Vries, B., Kessels, R. P. C., & Koolen, D. (2013). Hypersociability in the behavioral phenotype of 17q21.31 microdeletion syndrome. *American Journal of Medical Genetics, 161*, 21–26.

Dankwoord

Al vanaf jonge leeftijd heb ik een passie voor muziek. Als zesjarig meisje wist ik meteen dat ik viool wilde gaan spelen en dat deed ik dan ook regelmatig al om zes uur 's ochtends. Na de middelbare school wilde ik erg graag aan het conservatorium gaan studeren. Uiteindelijk koos ik na enige ontmoediging vanwege het beroepsperspectief voor de psychologie, waarbij al snel mijn interesse in de neuropsychologie gewekt werd. Mijn passie voor muziek en interesse in de neuropsychologie heb ik in mijn studietijd altijd zoveel mogelijk geprobeerd naast elkaar te laten bestaan. Hoe mooi is het dan om de kans te hebben gekregen dit in dit proefschrift eindelijk met elkaar te mogen verweven? Gaandeweg dit traject hebben veel bijzondere mensen op verschillende manieren hieraan een bijdrage geleverd; zonder jullie steun, aanmoediging, geduld en vertrouwen had ik dit niet voor elkaar gekregen!

Allereerst ben ik alle deelnemers aan dit onderzoek erg dankbaar voor hun vertrouwen in ons streven om door middel van het doen van wetenschappelijk onderzoek naar geheugenstrategieën de toekomstige zorg voor mensen met geheugenklachten te verbeteren en de bijdrage die zij daaraan hebben geleverd.

Heel dankbaar ben ik voor de begeleiding die ik heb gekregen binnen mijn buitenpromotie van mijn promotor prof. dr. Roy Kessels en copromotor dr. Rebecca Schaefer. Dit proefschrift is in het bijzonder te danken aan jullie betrokken begeleiding en deskundigheid. Onderweg leerde ik onder andere perspectief nemen, schrijven en tegelijkertijd het tempo bewaken als ook mijn rust te bewaren. Als ik het overzicht even kwijt was, herinnerden jullie mij aan de compositie in zijn geheel – die promotie heet – en hielpen de juiste keuzes, prioriteren, niet te veel tegelijk en kleine stappen om weer in de maat te gaan spelen. Ik kijk heel positief en dankbaar op dit promotietraject terug!

Roy, ik wil je graag bedanken voor het vertrouwen dat je mij hebt geschonken en de belangrijke rol die je op verschillende momenten hebt gespeeld in mijn professionele loopbaan, al vanaf de begeleiding van mijn scriptie. In het bijzonder wil ik je bedanken voor de begeleiding van mijn promotieonderzoek als buitenpromovenda, ik heb jouw betrokkenheid, positiviteit, pragmatische benadering en snelle, waardevolle reacties altijd enorm gewaardeerd. Daarnaast wist jij bij mijn 'momenten van backfire' wijselijk op het even laten afkoelen van de motor aan te sturen, in plaats van op een te vroegtijdige herstart, doorrijden of andere onverstandige zetten. Dankzij jouw vertrouwen in mij, wist je mij uit te dagen om uitdagingen te omarmen en dit heeft er ook toe geleid dat ik mij op persoonlijk vlak verder kon ontwikkelen. Zo weet ik nog goed hoe zenuwachtig ik was voor een pitch tijdens een voorjaarscongres van de Nederlandse Vereniging voor Neuropsychologie, waar jij eerst niet bij zou kunnen zijn, maar uiteindelijk toch was om mij te steunen. Ik bewonder jouw analytische denken, enorme kennis, overzicht en vermogen om kernachtig te formuleren. Ik ben enthousiast over onze toekomstige inspanningen op het gebied van onderzoek die nog gaan volgen!

Rebecca, graag wil ik je bedanken voor jouw begeleiding van dit promotietraject, waarbij ik me door jouw deskundigheid, relativering en humor gesteund mocht voelen. Ik bewonder jouw uitgebreide expertise op het gebied van onderzoek dat zich bevindt op het grensvlak van muziek en neuropsychologie en de inzet daarvan in de gezondheidszorg. Omdat dit promotietraject in coronatijd startte en Leiden, Nijmegen en Vorden qua afstand lastig te overbruggen waren, spraken we elkaar vrijwel altijd online. Onze eerste live ontmoeting was grappig genoeg op Schiphol, waar je me opzocht toen ik – een tikkeltje zenuwachtig – begon aan mijn eerste vliegreis ´alleen´. Ik heb genoten van het The Neurosciences en Music congres in Helsinki en het was erg inspirerend jouw promovendi daar te ontmoeten. Ik kijk uit naar onze verdere samenwerking binnen onderzoek op het grensvlak van muziek en neuropsychologie, samen met Roy!

Leden van de manuscriptcommissie, prof. dr. H. Bekkering, prof. dr. A. Postma en dr. M. Sadakata, bedankt voor het beoordelen van dit proefschrift.

Voorafgaand aan het schrijven van dit proefschrift, toen ik werkzaam was binnen de Ziekenhuisgroep Twente op de afdeling Medische psychologie, heeft de dataverzameling van dit onderzoek plaatsgevonden. De Raad van Bestuur en het wetenschapsbureau van de Ziekenhuisgroep Twente wil ik graag bedanken voor het faciliteren van het wetenschappelijk onderzoek binnen de organisatie. Binnen ZGT heb ik mogen samenwerken met veel fijne collega's.

Allereerst Ilse, graag wil ik je bedanken voor de dagelijkse begeleiding ten tijde van de opzet en uitvoer van mijn onderzoek. Ik heb bewondering voor jouw uitgebreide kennis en enorme toewijding. Maaike, ik wil je bedanken voor jouw warmte, de gezelligheid en de steun die ik ervaren heb toen we collega's waren. Daarnaast ben ik alle psychologisch medewerkers erg dankbaar voor het testen van de deelnemers aan dit onderzoek met de onderzoekstaken van onze studies. Tevens wil ik mijn scriptiestagiaires Maike, Maartje en Lisa hartelijk bedanken voor hun hulp en enthousiasme bij het werven en testen van de deelnemers aan onze studies.

Na mijn werk in het ziekenhuis was ik nog kortdurend werkzaam binnen het Diagnostiek Centrum van GGNet. Monique, wat een lieve, warme en prettige collega was jij! Zo fijn om ook in de toekomst bij elkaar betrokken te blijven. Na deze uitstap naar de GGZ heb ik de overstap naar de revalidatie gemaakt, waar ik me binnen team Zutphen van Klimmendaal gelijk welkom en op mijn plek voelde. Wat een fijn team met hart voor de patiënt, korte lijnen en een prettige samenwerking! Ik kan helaas niet iedereen hier noemen, maar wil een paar mensen er graag uitlichten.

Wietske, ik wil je heel graag bedanken voor alles wat ik van jou onderweg heb mogen leren. Ik bewonder je niet alleen als collega, maar ook om wat voor mooi mens je bent en in hoe jij omgaat met alles wat komt kijken bij de zorg voor een kind voor wie gezondheid helaas niet vanzelfsprekend is. Ik voel me erg gesteund door jouw openheid hierover en het wederzijds kunnen delen van ervaringen geeft me troost. Madelon, ook jou wil ik heel graag bedanken voor de prettige samenwerking die we altijd hebben gehad. Jouw levenswijsheid en visie op de patiënt sterkten mij daar waar ik wel eens twijfelde. Manon, met jou erbij vind ik het altijd gezellig, ik waardeer je humor sterk en we gaan vast nog regelmatig aan de wandel (of zelfs een rondje hardlopen wellicht?). Lieve Elske, ook met jou heb ik het altijd heel prettig samenwerken gevonden, wie weet waar onze wegen in de toekomst weer kruisen!

Ten tijde van deze buitenpromotie waren er een aantal Donders Graduate School dagen. Inspirerende dagen, waar ik een aantal andere ‘bijzondere eenden in de bijt’ (lees: buitenpromovenda’s) ontmoette. Iris en Astrid, ik ben er graag bij zodra ook jullie zover zijn!

Lieve Dymphie en Renée, we leerden elkaar kennen tijdens onze stage binnen het Topklinisch centrum voor Neuropsychiatrie van Vincent van Gogh en zijn altijd vriendinnen gebleven. Ik kijk nog altijd met een glimlach op onze gezamenlijke stagetijd terug. Toen ik trouwde stonden jullie als bruidsmeisjes aan mijn zijde. Inmiddels zijn we heel wat verhuizingen, verbouwingen en geboortes verder! Heel blij en dankbaar ben ik dat jullie beiden zo betrokken zijn in de voorbereiding van mijn promotie en ik ben super trots dat jij, Renée, mijn paranimf bent en op deze bijzondere dag naast mij staat!

Lieve Lidewij, wij leerden elkaar kennen op de afdeling Medische Psychologie binnen het VieCuri ziekenhuis in Venlo tijdens mijn opleiding tot GZ-psycholoog. Regelmatig bleef ik bij je overnachten in Nijmegen en het was altijd gezellig. Ik herinner me dat jij meer een avondmens was dan ik, waar ik ‘s ochtends vroeg al wat meer aanstond :). We zijn altijd vriendinnen gebleven en ik waardeer onze vriendschap enorm. Ik ben heel blij dat ook jij mijn paranimf bent vandaag!

Lieve Eefje, ook jou ontmoette ik tijdens de GZ-opleiding. Samen hebben we een mooie opleidingstijd beleefd en of we elkaar nu een tijd niet gesproken hebben, het zit altijd goed. Ik kan erg met je lachen en bewonder je enorme veerkracht!

Lieve Lisette, Justin en Josephine groeien samen op en zijn dikke maatjes. Of we straks schoonmoeders zullen zijn van onze beider kinderen zal de tijd uitwijzen, maar wij hebben het in ieder geval altijd gezellig samen! Ik waardeer je authenticiteit, betrokkenheid en onze vriendschap sterk.

Lieve Anna, we zien elkaar niet vaak, maar als ik je zie word ik altijd vrolijk. Ik waardeer je oprechte interesse in het wetenschappelijk onderzoek en cultuur en onze gesprekken zijn altijd dynamisch. Op naar nog veel leuke ontmoetingen!

Lieve Henk en Hélène, ontzettend bedankt voor de talloze zondagen dat Willem met onze kinderen bij jullie mocht zijn, zodat ik rustig kon schrijven. Ik waardeer jullie warmte, rust en relativerende levensinstelling. Na vandaag komen we weer vaker met zijn vijven, beloofd!

Lieve pap en mam, ik ben jullie ontzettend dankbaar voor alle kansen die jullie mij hebben gegeven en voor jullie steun in het volgen van mijn dromen. Het was super fijn om met Willem naar Porto te kunnen gaan voor het Global Neuropsychology Congress in de wetenschap dat jullie bij ons thuis alles draaiende hielden. Daarnaast zijn onze vakanties als we jullie kwamen opzoeken in Normandië altijd een welkome bron van rust en ontspanning geweest tijdens dit promotietraject. Op naar nog veel mooie momenten samen!

Lieve Jasper en Joanne, inmiddels zijn we niet alleen broer en zussen, maar zijn we gezamenlijk ook verantwoordelijk voor negen kleinkinderen binnen de familie :)! Het dagelijks leven slokt ons allemaal regelmatig op, maar laten we vooral met elkaar in verbinding blijven!

Lieve Willem, jij bent er altijd voor me. Ik ben je ontzettend dankbaar voor jouw liefde, warmte, onvoorwaardelijke steun en jouw vermogen om de zaken te relativeren. Ik bewonder jouw discipline, je constante toewijding aan je werk en ons gezin en hoe je me aan het lachen kunt maken. Ik hou van je en kijk uit naar ons verdere leven samen, dat nooit saai is!

De laatste woorden van dit dankwoord zijn voor onze kinderen, Josephine, Rosemarijn en Lennart. Door jullie besef ik hoe kostbaar het leven is, hoe niet vanzelfsprekend gezondheid is, hoe belangrijk het is om precies jezelf te zijn, te leven bij de dag en elke dag dankbaar te zijn voor alles wat je hebt. Jullie zijn mijn belangrijkste leerschool, ik heb jullie met heel mijn hart lief, tot aan de maan en weer terug 'en dan nog veel verder'!

Donders Graduate School

For a successful research Institute, it is vital to train the next generation of scientists. To achieve this goal, the Donders Institute for Brain, Cognition and Behaviour established the Donders Graduate School in 2009. The mission of the Donders Graduate School is to guide our graduates to become skilled academics who are equipped for a wide range of professions. To achieve this, we do our utmost to ensure that our PhD candidates receive support and supervision of the highest quality.

Since 2009, the Donders Graduate School has grown into a vibrant community of highly talented national and international PhD candidates, with over 500 PhD candidates enrolled. Their backgrounds cover a wide range of disciplines, from physics to psychology, medicine to psycholinguistics, and biology to artificial intelligence. Similarly, their interdisciplinary research covers genetic, molecular, and cellular processes at one end and computational, system-level neuroscience with cognitive and behavioural analysis at the other end. We ask all PhD candidates within the Donders Graduate School to publish their PhD thesis in de Donders Thesis Series. This series currently includes over 600 PhD theses from our PhD graduates and thereby provides a comprehensive overview of the diverse types of research performed at the Donders Institute. A complete overview of the Donders Thesis Series can be found on our website: https://www.ru.nl/donders/donders-series

The Donders Graduate School tracks the careers of our PhD graduates carefully. In general, the PhD graduates end up at high-quality positions in different sectors, for a complete overview see https://www.ru.nl/donders/destination-our-former-phd. A large proportion of our PhD alumni continue in academia (>50%). Most of them first work as a postdoc before growing into more senior research positions. They work at top institutes worldwide, such as University of Oxford, University of Cambridge, Stanford University, Princeton University, UCL London, MPI Leipzig, Karolinska Institute, UC Berkeley, EPFL Lausanne, and many others. In addition, a large group of PhD graduates continue in clinical positions, sometimes combining it with academic research. Clinical positions can be divided into medical doctors, for instance, in genetics, geriatrics, psychiatry, or neurology, and in psychologists, for instance as healthcare psychologist, clinical neuropsychologist, or clinical psychologist. Furthermore, there are PhD graduates who continue to work as researchers outside academia, for instance at non-profit or government organizations, or in pharmaceutical companies. There are also PhD graduates who work in education, such as teachers in high school, or as lecturers in higher education. Others continue in a wide range of positions, such as policy advisors, project managers, consultants, data scientists, web- or software developers, business owners, regulatory affairs specialists, engineers, managers, or IT architects. As such, the career paths of Donders PhD graduates span a broad range of sectors and professions, but the common factor is that they almost all have become successful professionals.

For more information on the Donders Graduate School, as well as past and upcoming defences please visit: http://www.ru.nl/donders/graduate-school/phd/

9 789465 152196 >

DONDERS
INSTITUTE

Radboud University

Radboudumc