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Effects of Musical Mnemonics on Working Memory Performance in Cognitively Unimpaired Young and Older Adults

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ABSTRACT

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

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Cognitive aging refers to cognitive change due to nonpathological aging, 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 aging, whereas for example conceptual reasoning and processing speed show a gradual decline over time (see for an overview Eikelboom, Bertens, & Kessels, 2020). Furthermore, there is considerable heterogeneity among older adults in the rate of decline (Harada, Natelson Love, & Triebel, 2013). Overall, aging-related decline in memory function is consistently reported (Nyberg, Lövden, Riklund, Lindenberger, & Bäckman, 2012). Notably, the ability to maintain and manipulate information for a brief period of time (i.e., working memory [WM]

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The auditory stimuli (mp4 sound files) used in this experiment are available upon request from the corresponding author.

capacity) declines with age (Nyberg et al., 2012) as does everyday memory function (episodic memory [EM]; Nyberg et al., 2012; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005).

The use of memory strategies – mnemonics – may ameliorate aging-associated memory decline that negatively influences wellbeing, quality of life and social participation (Fu, Kessels, & Maes, 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, Dixon, & Bäckman, 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, Fasotti, Kessels, & Oosterman, 2018).

With increasing age, a decreased repertoire of strategies is frequently reported (cf., Lemaire, 2016). However, Chevalère, Lemaire, and Camos (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, Madsen, & Michel, 1975) has often been applied for teaching social and academic skills (e.g., Jellison, 1976; Jellison & Miller, 1982; Ludke, Ferreira, & Overy, 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 Derks-Dijkman, Schaefer, & Kessels, 2021).

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 Derks-Dijkman et al., 2021).

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 Derks-Dijkman et al., 2021). 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 (Derks-Dijkman et al., 2021), 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, Samson, Miller, & Chalmers, 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, Gingras, Musil, & Stewart, 2014) to systematically assess the degree of musical expertise of our participants.

In line with the findings of Ratovohery, Baudouin, Gachet, Pallison, and Narme (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 aging and rhythmic presentation may reduce the need to rely on limited executive resources (e.g., Hester, Kinsella, & Ong, 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, Jakobson, & Cuddy, 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, Mulder, van Limbeek, Donders, & Schoonderwaldt, 1998). Descriptive statistics of the YA and OA groups are described in Table 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, Bakker, Saan, & Louman, 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 behavior 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 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 1. 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 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 analyzed 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 Table A1 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

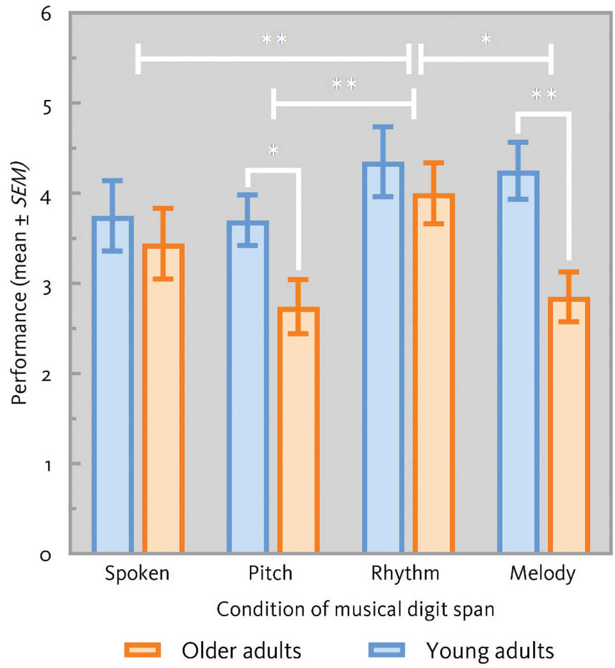

Figure 2. Mean number correctly reproduced digit sequences (± SEM) in the four task conditions for the young and older adults, showing the differences between the groups and between task conditions. * $p < .05$, ** $p < .01$ (one-tailed).

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.

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 2 shows the performance on all 4 conditions in the YA and OA (See also Table A2 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 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") (Derks-Dijkman et al., 2021). 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 aging (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, Bressi, Della Sala, Logie, & Spinnler, 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 (Derks-Dijkman et al., 2021) 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 aging, 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) (Derks-Dijkman et al., 2021).

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Appendices

Table A1. Administration orders of the experimental digit span task

Grid showing all possible administration orders with different combinations of the four conditions (i.e., spoken, rhythm, pitch, 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

Table A2. 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