Music deteriorates source memory, evidence from normal aging

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Previous research shows that music exposure can impair a wide variety of cognitive and behavioral performance. We investigated whether this is the case for source memory. Forty-one younger adults and thirty-five healthy elderly were required to retain the location in which pictures of colored objects were displayed. On a subsequent recognition test they were required to decide whether the objects were displayed in the same location as before or not. Encoding took place 1) in silence, 2) while listening to street noise, or 3) while listening to Vivaldi's "Four seasons". Recognition always took place during silence. A significant reduction in source memory was observed following music exposure, a reduction that was more pronounced for older adults than for younger adults. This pattern was significantly correlated with performance on an executive binding task. The exposure to music appeared to interfere with binding in working memory, worsening source recall.

Keywords: binding, executive function, music, source memory

Source memory may be defined as "the episodic source from which a specific item was acquired (e.g., from a person, a book, or a television show)" (Schacter, Kaszniak, Kihlstrom, & Valdiserri, 1991, p. 559). It can also be expanded to include any aspects of spatiotemporal or affective contextual features that were present during the encoding of an event (Johnson, Hashtroudi, & Lindsay, 1993). Source memory contributes to the phenomenological experience characterizing episodic reliving (El Haj & Allain, 2012a), illustrating its importance for episodic recollection. It is also found to be particularly sensitive to aging. Indeed, a substantive body of literature suggests that source memory is more affected by aging than is item memory (for a review, see, Raz, 2000). Older adults may have no difficulty remembering that a particular event occurred but they may be less likely to recollect the source, such as where or when the event took place or how they acquired their knowledge of the event (Glisky, Rubin, & Davidson, 2001). Crucially, the literature tends to suggest that this age-related source memory deterioration may be attributed to executive dysfunction.

The latter notion finds its origins in observations that patients with focal frontal lesions show great difficulties in source attribution (Johnson, O'Connor, & Cantor, 1997). In a related vein, studies in normal aging have shown greater impairments in source memory than in item memory. This decline is generally found to be associated with poor performance on frontal lobe dependent, executive function tests (Craik, Morris, Morris, & Loewen 1990; Glisky & Kong, 2008; Parkin, Walter, & Hunkin, 1995). The relationship between age-related source memory deterioration and executive dysfunction has been demonstrated in a literature review (El Haj & Allain, 2012b), which describes seven published papers reporting reliable correlations between source errors and executive dysfunction in older adults. One common feature characterizing these seven studies, as pointed out by El Haj and Allain (2012b), was the use of complex executive measures that prevented the specification of the nature of executive processes that may underlie source memory decline in older adults. This observation led the authors (El Haj & Allain, 2012b) to suggest the importance of assessing specific executive functions (e.g., binding, inhibition, updating, flexibility) when investigating source memory decline in clinical populations. We take this approach in the present work, as we aim to specify executive processes that my underlie a music exposure effect on source memory in older adults.

One prominent executive account of the origins of source memory variation after music exposure is binding. According to Mitchell and colleagues (Mitchell, Johnson, Raye, & D'Esposito, 2000), during encoding, source memory engages a feature-binding process that associates contextual features to the central event. The establishment of such associations is presumably carried out by a binding process in working memory that associates and integrates different characteristics of an event into one coherent episode (Mitchell et al., 2000). The maintenance and manipulation of information in working memory mediates the binding of the individual features of an experience together. The working memory aspect of binding is worth consideration. Baddeley's (2000) model defines several core components of working memory including a phonological loop and an executive control system. Because background music is an auditory stimulus, it is likely to activate the phonological loop, leaving fewer resources for other working memory components such as the executive control system. This may, in turn, worsen cognitive and behavioral performance. Our assumption fits a body of experimental literature which shows that music interferes with a wide variety of cognitive and behavioral tasks. For instance, music exposure was found to interfere with item recognition (Liu, Huang, Wang, & Wu, 2012) and to impair efficiency in surgeons learning a new procedure in the presence of background music (Miskovic et al., 2008). Music exposure has also been shown to negatively influence such activities as driving (Brodsky & Slor, 2013) and cycling (Terzano, 2013).

To summarize, music, as an auditory stimulus, is likely to activate the phonological loop, leaving fewer resources for the central executive system, which is responsible for mediating the binding of source features. Hence, we hypothesize that music exposure would deteriorate source recall in older adults and that this decline might be significantly correlated with perturbation in their binding ability.

Method

Participants

A cohort of 41 younger adults (23 women and 18 men; *M* age = 23.32 years, *SD* = 4.38), and 35 older adults (20 women and 15 men; *M* age = 67.94 years, *SD* = 9.49), voluntarily took part in the study. The younger adults were undergraduate and graduate students at the University of Lille 3. The older adults were following courses in humanities at the University of Lille 3 or came from the local community. They were non-institutionalized and managed their own households. Their episodic performance, referring to the sum of free recall on the Grober and Buschke's task (1987), showed normal ability (see, Table 1). Although the older adults had a significantly lower number of years of education than the younger adults ((*M* older adults = 10.17, *SD* = 3.11, *M* younger adults = 13.24, *SD* = 3.74, $t(74) = 3.85$, $p < .001$)), no differences in verbal ability were found between both age groups on the Mill Hill vocabulary test (French translation by Deltour, 1993) ((*M* older adults = 35.17, *SD* = 6.68, *M* younger adults = 32.73, *SD* = 8.29, *t*(74) = 1.39, *p* > .10)).

All participants were native French speakers and reported corrected-to normal vision and hearing. Exclusion criteria were history of neurological, psychiatric, or learning disorders. Participants with extensive musical training (> 2 years during childhood) were excluded since they may perceive and respond to music differently than do novices. Thirty nine older adults were originally recruited but 2 were eliminated from the analyses as they had difficulties with the French language and 2 left the study due to time constraints. Informed consent was obtained from all participants in accordance with the principles of the Helsinki Declaration.

Materials

Executive evaluation.

With regard to multidimensional executive models (e.g., Miyake et al., 2000), El Haj and Allain (2012b) recommended evaluation of specific executive processes when dealing with the relationship between source memory and executive function. In line with this suggestion, we evaluated four executive processes: inhibition, updating, shifting (as defined by the model of Miyake et al., 2000), and binding. Description of the four executive tasks can be found elsewhere (El Haj, Clément, Fasotti, & Allain, 2013; El Haj, Fasotti, & Allain, 2012a, El Haj, Fasotti, & Allain, 2012c) and so we provide only a brief description of them here, apart from for the binding evaluation, due to its critical importance in the present work. Binding and executive performances for each age group are depicted in Table 1.

- Inhibition**.** The score on the Stroop task was the completion time in the interference condition minus the average completion time in the word reading and color naming conditions.

- Updating**.** The score here was the number of erroneous responses on the 2-back task.

- Shifting**.** The score on the Plus-Minus task was the difference between the completion time for list three (alternating between adding and subtracting) minus the average completion time for lists one (adding) and two (subtracting).

- Binding. The task, consisting of 20 trials, was designed using the software package Psychopy (Peirce, 2007). In each trial, four (3 x 3) grids and one retention support were exposed on a 15-inch screen. In the first three grids, exposed for 1-sec each, a different letter was shown in each cell, and subjects had to retain their location. After a retention support was exposed for 8-sec, the subjects had to remember whether the letter in the fourth grid appeared in the same cell as before or not. The order of presentation of the 20 trials was randomized for each participant. However, in half of the trials, the letter in the fourth grid was exposed in the same cell as before, while in the other half, it was not. The performance was calculated as the number of "yes" and "no" correct responses (the same method of recognition scoring may be seen in previous binding tasks, see, Parra et al., 2010).

[INSERT TABLE 1 APPROXIMATELY HERE]

Source memory task.

As illustrated in Figure 1, the task was divided into an encoding and a recognition phase. In the encoding phase, twelve (2 x 2 cells) grids were displayed in the center of a 15-inch screen. In each grid, a colored picture of an everyday life object was displayed in a cell and participants were instructed that they had to retain the location of the object. Each grid was exposed for 3-sec. After the 12 grids were displayed, the participants proceeded to the recognition phase. Here, the same 12 grids were re-exposed, however, in half the grids, the objects were displayed in a different cell as compared to the encoding phase. Each grid was displayed until the participants decided whether the object was encountered in the same cell as before or not. Similarly to the binding task, the performance was calculated as the number of "yes" and "no" correct responses. Note that this task was also designed with Psychopy software, randomizing the order of presentation of the 12 grids in the encoding and recognition phases.

Participants performed the recognition phase during silence. The encoding phase was however performed in three conditions: 1) in silence, 2) while listening to street noise, and 3) while listening to music. The two auditory backgrounds were presented at the same volume. The sounds were presented with a speaker behind the display and no headphones were worn by the participants. The noise background (60±1 decibel) was a recording taken by us of a downtown street, with distant traffic and pedestrian noise as can be heard in everyday urban life. The music was the Vivaldi's ''Spring'' movement from the ''Four Seasons'', an opus widely used when assessing memory performance in older adults (El Haj et al., 2013, 2012a, 2012b; Irish et al., 2011). The order of presentation of the three conditions was counterbalanced across participants. In each condition, a different set of objects was used, so that participants never encountered the same object more than once.

[INSERT FIGURE 1 APPROXIMATELY HERE]

Results

In this section we investigated differences between performance on the three source memory tasks by submitting scores to ANOVA analyses, after checking for normal distribution with Kolmogorov-Smirnov tests. We then evaluated correlations between source memory performance and executive scores for each age group with Pearson correlation analysis. Finally, we carried out regression analyses to determine the executive factors that mainly predict source recall.

Poor source recall after music exposure in older adults.

The performance of each age group in the three source memory conditions is depicted in Figure 2. Scores were submitted to a repeated measures analysis of variance (ANOVA), with group (younger adults, older adults) as the between-participants factor and condition (silence, noise, music) as the repeated measures. Analysis revealed a significant group effect, $F(1, 74) = 71.49$, $p < .001$, $\eta^2 = .49$. The older adults showed poorer source memory than the younger adults, with a mean of 8.66 (*SD* = 1.71) and 10.57 (*SD* = 1.42), respectively. The condition effect was significant, $F(2, 148) = 22.94$, $p < .001$, $\eta^2 = .24$. Post-hoc Bonferroni-corrected pairwise comparisons showed that source memory was poorer after music exposure than after noise exposure, and the latter performance was poorer than after silence exposure, with a mean of 8.87 (*SD* = 2.08), 9.80 (*SD* = 1.77), and 10.42 (*SD* = 1.65), respectively. The interaction effect between group and condition was also significant, $F(2, 148) = 5.02$, $p < .01$, $\eta^2 = .06$. Post-hoc pair-wise comparisons revealed poorer source recall after music exposure than after noise exposure in the younger adults, $t(40) = 2.56$, $p < .05$, however, no significant difference was observed between source recall after noise exposure and after silence exposure, $t(40) = 1.23$, $p > .1$. With regard to the older adults, poorer source recall was detected after music exposure than after noise exposure, *t*(34) = 3.41, $p < .01$, and the latter performance was poorer than after silence exposure, *t*(34) = 2.35, $p < .05$.

[INSERT FIGURE 2 APPROXIMATELY HERE]

Significant correlation between binding and source memory deterioration in older adults.

Correlations between source recall (after silence, noise, and music exposure) and performances on the four executive measures (inhibition, updating, shifting, and binding) were computed for each age group after controlling for the potential confounding effects of age and educational level. Given the number of factors, we used a Bonferroni correction: thus considering only correlations reaching a threshold of $p < .007$ as significant. This level was obtained by dividing the alpha level by the number of comparisons (0.05/7). When applying these criteria, a significant correlation was detected between source memory after music exposure and binding in younger adults, $r = .45$, $p = .004$, and older adults, $r = .60$, $p < .001$. All remaining correlations between source memory and executive measures were found to be non significant.

As the latter results suggest, a significant correlation was found between source memory after music exposure and binding. We sought to examine whether binding would also be correlated with the deterioration of source recall across conditions. To this end, the previous correlational analyses were repeated with the dependent variable being the difference between scores after music and silence exposure. Once again, only source deterioration was significantly correlated with binding in younger adults, $r = .46$, $p = .003$, and older adults, $r = .53$, $p = .002$. All remaining correlations between source memory and executive measures were found to be non significant.

Finally, in order to detect whether the correlation between binding and source memory deterioration after music exposure was mediated by external factors (e.g., age) rather than binding per se, a forward stepwise regression analysis was performed. The dependent variable was the difference between scores after music and silence exposure while predictor variables were age, educational level, vocabulary level, episodic performance, and the executive scores. This analysis yielded one model in which binding was the main and sole factor predicting source memory deterioration after music exposure, predicting 30.2% ($p < .001$) of its variance.

To summarize, among the different executive measures assessed, binding was the sole factor correlating with and predicting source memory deterioration after music exposure. This correlation was found to be more significant for older adults than for younger adults.

Discussion

As we had predicted, music exposure impaired source memory in both younger and older adults. However the latter group of participants suffered a greater disadvantage of music exposure than the former, a deterioration that was significantly predicted by binding performance.

In line with the literature (Craik et al., 1990; Glisky & Kong, 2008; Parkin et al., 1995), our data also showed source memory deterioration in older adults relative to younger adults. The observed decline may be related to difficulty in binding contextual features into a coherent memory representation (Mitchell et al., 2000). Source memory requires relating contextual features to a central event and, integrating individual contextual characteristics into one coherent episode. Binding plays a pivotal role in source memory. Here, binding was found to correlate with source performance only after music exposure, and music-related source memory deterioration was significantly predicted by binding performance. Thus our results suggest that music exposure may affect binding resources more than silence or noise exposure.

The relationship between music exposure and binding can be seen in the working memory account. Binding is considered a core function of the working memory executive control system (Baddeley, 2000). Because working memory has a limited capacity and can only handle small amounts of information at any one time, it is relatively prone to interference (Baddeley, 2000). Following this view, music and noise, auditory stimuli activating the phonological loop, are likely to affect other working memory processes, and leave fewer cognitive resources for binding source information. This hypotheses is in line with our data, which show performance on a working memory binding task to be the main factor correlating and predicting source memory deterioration after music exposure. Further support for the auditory interference account comes from the consideration that when multiple tasks are performed simultaneously they overtax available cognitive resources, leading to interference (Norman & Bobrow, 1975). Armstrong and Greenberg (1990) found that exposure to the sound of a television deteriorates performance on a range of cognitive tasks. Such findings fit with the experimental literature showing that music exposure interfere with cognitive and behavioral efficiency (Brodsky & Slor, 2013; Liu et al., 2012; Miskovic et al., 2008; Terzano, 2013). Because sounds like music are processed obligatorily (i.e., we can close our eyes but not our ears), they can easily interfere with other working-memory processes (for a similar view, see, Schellenberg & Weiss, 2013), leaving fewer resources for binding source information.

Our results showed inferior source recall after music exposure relative to after noise exposure and we suggest that this can be interpreted in light of a classical work by Salamé and Baddeley (1989). The authors varied the type of sounds presented during a working memory digit-recall task and reported a poorer recall with instrumental music than with noise (i.e., amplitude varied in a speechlike way). The authors (Salamé & Baddeley, 1989) argued that, unlike music, noise is not processed in the phonological loop, and suggested that for this reason, it does not interfere with working memory performance. In line with this possibility, subsequent research has found that visual serial recall is attenuated by exposure to varying tones but not when the tones are simply repeated (Jones & Macken, 1993). Taken together, these findings suggest that the amount of acoustic change matters, with changing tones (i.e., music) using more of the capacity of the phonological loop than continuous noise.

With regard to older adults, correlation between source memory decline after music exposure and binding was higher than in younger adults. In other words, older adults seem to be more sensitive to music interference than younger adults. Needless to say, working memory is negatively affected by aging and interference may play a major role in this decline (Lustig, May, & Hahser, 2001). What is of interest here is that our older participants, showing binding deterioration, demonstrated greater source memory decline after music exposure than the younger participants. Music exposure is likely to interfere with binding in older adults, worsening their source recall. This hypothesis fits with our data showing a significant correlation between binding and source recall in older adults only after music exposure.

One may argue that our data simply reflect a distractibility effect, that is, music exposure may distract attention away from source memory processing. Indeed, this hypothesis can be supported by literature showing a decline of attentional resources with age (e.g., Craik & Salthouse, 2000; Luo & Craik, 2008; Salthouse & Fristoe, 1995). However, our results are not in line with such an account since no significant correlations in older adults were detected between source recognition after music exposure and "resistance to distraction" ability, the latter ability being evaluated with the plus-minus task. It is worthy of note that the plus-minus task has been put forward as a reliable task for assessing "attention switching" processes (Miyake et al., 2000). Another element pledging against the distractibility account is the lack of significant correlations in older adults between source recognition after music exposure and resistance to interference, the latter ability being argued to be reliably evaluated by the Stroop task (Miyake et al., 2000). Taken together, our results do not provide empirical evidence that music exposure affects source memory in older adults due to distractibility

Putting aside the executive account, our data can be paralleled with studies showing that music serves as an efficient retrieval cue for item memory. For instance, Smith (1985) presented subjects with words in silence or while listening to jazz or classical music. Two days later, the participants had to retrieve the words in three conditions: a) while listening to the same music, b) while listening to a different music selection, or c) in silence. Results showed superior recall when the same music was reinstated, suggesting a facilitative effect of matching encoding and retrieval musical contexts. These findings were replicated by Balch and Lewis (1996) who observed better recall when reinstated music was played at the same tempo than when it was played at another tempo. Mead and Ball (2007) also reported better word recall when reinstated music was played with the same key (minor–minor, major-major) than with a different key (minor-major, major-minor). Taken together, these results suggest better memory for words while listening to the same music that was played during encoding. These findings reflect the encoding specificity principle (Thomson & Tulving, 1970), which postulates that encoding and retrieval conditions must be coordinated to maximally enhance memory. In light of this principle one may argue that similarity between the contexts of our encoding condition and the silence condition during retrieval may have had a beneficial effect on source performance relative to the other retrieval conditions (i.e., noise or silence), which mismatched the encoding context. Although prominent, this suggestion must be considered with caution since our experimental design did not include a control condition (i.e., music during encoding and retrieval).

Another possible explanation for our results is that the source memory decline occurred because older adults tend to manifest strong emotional reactions to music. Such an account is worth considering since research has consistently shown that music evokes positive emotion in older adults (for a review, see, Creech, Hallam, McQueen, & Varvarigou, 2013). More precisely, studies suggest that music listening is an important leisure activity for promoting emotional well-being, evoking feelings of pleasure and relaxation in older adults, as well as enhancing identity, belonging, and agency (Laukka, 2007). These results, showing how music exposure can modulate emotions in older adults, mean that we cannot rule out the possibility that the deterioration in source memory is due to stronger musical emotions in older adults.

While the main focus of our work is normal aging, the performance of our younger participants is worth some consideration. Like the older adults, younger adults showed poorer source recognition after music exposure than after noise exposure. Performance of the younger adults was also significantly correlated with binding. Like the older adults, music exposure seems to interfere with binding in younger adults, worsening their source memory. Noise exposure, however, does not seem to interfere with binding in the latter participants since no significant correlations were detected between the two performances. Preserved binding ability, as observed in our younger participants' performance, seemed to reduce interference from noise exposure, at least as emitted in the present experiment. These outcomes are highly interesting in supporting the tendency to prohibit loud noise and music in working environments (e.g., library). With regard to the older adults, the current results are interesting in showing that although music exposure may enhance their well-being (Laukka, 2007), it may also negatively impact their cognitive functioning. Our data suggest that music exposure decreases cognitive performance in older subjects, a finding of particular interest for everyday activities such as driving. Listening to music whilst driving is a common activity, but the current results suggest that such exposure may decrease information processing in older adults, and consequently, negatively influence their driving performance and safety. This assumption is in line with a study showing that, when listening to music, older drivers required a louder external warning sound (e.g., car horn or police siren) relative to younger adults (Slawinsk & MacNeil, 2002). Other work shows associations between possession of `no claims' on motor insurance and a preference for silence over music in older drivers (Dibben & Williamson, 2007). Taken together, these findings are in line with our results, showing that music exposure may decrease cognitive performance in older adults. Thus, it is worth recommending that, for the sake of safety, such subjects are encouraged to reduce the volume level should they choose to listen to music whilst driving.

One could argue that the correlation between the binding and source tasks should be attributed to their similarity as, both tasks required association between items and their spatial locations. Although sharing common features, however, the two tasks differ significantly from one another since the binding task required working memory (responses were required after exposure of each grid), whereas the source task required long term memory (responses were required after exposure of the 12 grids). Furthermore, if the both tasks were so similar, significant correlations would be expected between binding and the three auditory modalities (i.e., silence, noise, and music), which was not the case. However, to eliminate any such concerns, future replications should use a wide variety of binding modalities, such as auditory binding. Another issue to be investigated by future replications is the use of a broader range of music, especially unfamiliar pieces. This to avoid the possibility that the older group might be distracted by the familiar “Four seasons” opus.

Finally, while we controlled for the participants’ musical training, we did not control for their familiarity with Vivaldi’s music. Knowledge about music might interfere with its processing, with, for instance, participants being tempted to sing Vivaldi’s music during the recognition phase. The music might also cue previous exposure. As older adults are likely to have more musical knowledge about classic music than younger adults, future replications should control for this bias by collecting information about such previous knowledge, which can then regressed out during analyses.

To summarize, studies show that music can impair performance in a wide variety of cognitive and behavioral tasks (Armstrong & Greenberg, 1990; Brodsky& Slor, 2013; Liu et al., 2012; Miskovic et al., 2008; Terzano, 2013). Our study extends these earlier findings to source memory in older adults. Our data also highlight binding as a mechanism that is likely to be particularly sensitive to the interference effect. Another implication of our findings is the observation that, in contrast to previous research showing beneficial effects of music exposure on autobiographical recall in older adults (El Haj et al., 2012a, 2012b, 2013; Irish et al., 2011)., music exposure has a negative impact on their source memory. It would appear that music exposure can have opposing effects on different types of memory, from a positive influence on self processing (El Haj et al., 2012b) to a negative influence on the source of a piece of remembered information.

References

Armstrong, G. B., & Greenberg, B. S. (1990). Background television as an inhibitor of cognitive processing. Human Communication Research, 16, 355-386.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417–423.

Balch, W. R., & Lewis, B. S. (1996). Music-dependent memory: The roles of tempo change and mood mediation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1354-1363.

Brodsky, W., & Slor, Z. (2013). Background music as a risk factor for distraction among young-novice drivers. *Accident Analysis & Prevention, 59*, 382-393.

Craik, F. I. M., Morris, L. W., Morris, R. G., & Loewen, E. R. (1990). Relations between source amnesia and frontal lobe functioning in older adults. *Psychology and Aging, 5*, 148–151.

Craik, F. I. M. & Salthouse, T. A. (Eds.). (2000). *Handbook of Aging and Cognition*. (2nd ed.). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Creech, A., Hallam, S., McQueen, H., & Varvarigou, M. (2013). The power of music in the lives of older adults. *Research Studies in Music Education, 35*(1), 87-102.

Deltour, J. J. (1993). *Echelle de vocabulaire de Mill Hill de J. C. Raven. Adaptation française et normes européennes du Mill Hill et du Standard Progressive Matrices de Raven (PM38*). Braine-le-Chateau: Editions l'application des techniques modernes.

Dibben, N., & Williamson, V. J. (2007). An exploratory survey of in-vehicle music listening. *Psychology of Music, 35*(4), 571-589.

El Haj, M., & Allain, P. (2012a). Relationship between source monitoring in episodic memory and executive function in normal aging. *Gériatrie et Psychologie Neuropsychiatrie du Vieillissement, 10*(2), 197-205.

El Haj, M., & Allain, P. (2012b). What do we know about the relationship between source monitoring deficits and executive dysfunction? *Neuropsychological Rehabilitation, 22*(3), 449-472.

El Haj, M., Clément, S., Fasotti, L., & Allain, P. (2013). Effects of music on autobiographical verbal narration in Alzheimer's Disease. *Journal of Neurolinguistics, 26*(6), 691-700.

El Haj, M., Fasotti, L., & Allain, P. (2012a). The involuntary nature of music-evoked autobiographical memories in Alzheimer's disease. *Consciousness and Cognition, 21*(1), 238-246.

El Haj, M., Fasotti, L., & Allain, P. (2012c). Source monitoring in Alzheimer's disease. *Brain and Cognition, 80*(2), 185-191.

El Haj, M., Postal, V., & Allain, P. (2012b). Music Enhances Autobiographical Memory in Mild Alzheimer's Disease. *Educational Gerontology, 38*(1), 30-41.

El Haj, M., Postal, V., & Allain, P. (2013). Destination memory in Alzheimer's Disease: When I imagine telling Ronald Reagan about Paris. *Cortex, 49*(1), 82-89.

Glisky, E. L., & Kong, L. L. (2008). Do young and older adults rely on different processes in source memory tasks? A neuropsychological study. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 809–822.

Glisky, E. L., Rubin, S. R., & Davidson, P. S. R. (2001). Source memory in older adults: An encoding or retrieval problem? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*(5), 1131-1146.

Grober, E., & Buschke, H. (1987). Genuine memory deficits in dementia. *Developmental Neuropsychology, 3*, 13–36.

Gunning-Dixon, F. M., & Raz, N. (2000). The cognitive correlates of white matter abnormalities in normal aging: a quantitative review. *Neuropsychology, 14*(2), 224-232.

Irish, M., Cunningham, C. J., Walsh, J. B., Coakly, D., Lawlor, A. B., Robertson, I. H., et al (2006). Investigating the enhancing effect of music on autobiographical memory in mild Alzheimer's disease. *Dementia and Geriatric Cognitive Disorders, 22*, 108–120.

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 369-381.

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin, 114*, 3–28.

Johnson, M. K., O'Connor, M., & Cantor, J. (1997). Confabulation, memory deficits, and frontal dysfunction. *Brain and Cognition, 34*,189-206.

Liu, B., Huang, Y., Wang, Z., & Wu, G. (2012). The influence of background music on recognition processes of Chinese characters: An ERP study. *Neuroscience Letters, 518*(2), 80-85.

Laukka, P. (2007). Uses of music and psychological well-being among the elderly. *Journal of Happiness Studies, 8*(2), 215-241.

Luo, L., & Craik, F. I. (2008). Aging and memory: a cognitive approach. Canadian Journal of Psychiatry. *Revue Canadienne de Psychiatrie, 53*(6), 346-353.

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General, 130*(2), 199-207.

Mead, K. M., & Ball, L. J. (2007). Music tonality and context-dependent recall: The influence of key change and mood mediation. *European Journal of Cognitive Psychology, 19*(1), 59-79.

Miskovic, D., Rosenthal, R., Zingg, U., Oertli, D., Metzger, U., & Jancke, L. (2008). Randomized controlled trial investigating the effect of music on the virtual reality laparoscopic learning performance of novice surgeons. *Surgical Endoscopy, 22*, 2416-2420.

Mitchell, K. J., Johnson, M. K., Raye, C. L., & D'Esposito, M. (2000). fMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Cognitive Brain Research, 10,* 197–206.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contribution to complex 'frontal lobe' tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology, 7*, 44-64.

Parkin, A. J., Walter, B. M., & Hunkin, N. M. (1995). Relationships between normal aging, frontal lobe function, and memory for temporal and spatial information. *Neuropsychology, 9,* 304–312.

Parra, M. A., Abrahams, S., Logie, R. H., Mendez, L. G., Lopera, F., & Della Sala, S. (2010). Visual short-term memory binding deficits in familial Alzheimer's disease. *Brain, 133*(9), 2702-2713.

Peirce, J. W. (2007). PsychoPy--Psychophysics software in Python. *Journal of Neuroscience Methods, 162*(1-2), 8-13.

Raz, N. (2000). Ageing of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of ageing and cognition.* Second edition. Hillsdale, NJ: Lawrence Erlbaum Associates.

Salamé, P., & Baddeley, A. (1989). Effects of background music on phonological short-term memory. *Quarterly Journal of Experimental Psychology, 41*A, 107-122.

Salthouse, T. A., & Fristoe, N. M. (1995). Process analysis of adult age effects on a computer-administered Trail Making Test. *Neuropsychology, 9*(4), 518-528.

Schacter, D. L., Kaszniak, A. W., Kihlstrom, J. F., & Valdiserri, M. (1991). The relation between source memory and aging. *Psychology and Aging, 6*, 559-568.

Schellenberg, E. G., & Weiss, M. W. (2013). Music and cognitive abilities. In D. Deutsch (Ed.), *The psychology of music* (3rd ed., pp. 499-550). Amsterdam: Elsevier.

Slawinski, E. B., & MacNeil, J. F. (2002). Age, Music, and Driving Performance: Detection of External Warning Sounds in Vehicles. *Psychomusicology: Music, Mind and Brain, 18*(1-2), 123-131.

Smith, S. M. (1985). Background music and context-dependent memory. *American Journal of Psychology, 98,* 591-603.

Terzano, K. (2013). Bicycling safety and distracted behavior in The Hague, the Netherlands. *Accident analysis and prevention, 57*, 87-90.

Tulving, E., & Thomson, D. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychalogical Review, 80*, 352-373.

Table 1. *Scores obtained on the neuropsychological battery.*

[redacted]		
Episodic memory (Grober & Buschkle's)	14.05 (2.79)***	10.74 (3.13)
Inhibition (Stroop)	12.80 (3.34)***	36.14 (10.88)
Updating (2-back)	4.05 (1.81)**	6.46 (3.93)
Shifting (Plus-Minus)	3.59 (2.52)***	6.66 (4.19)
Binding (binding task)	10.56 (1.36)***	9.17 (1.88)

Note. In except for the binding task, high numbers mean low performance; standard deviations are given between brackets; differences were significant at: ** $p < .01$, *** $p < .001$; comparisons were made using *t*-tests for independent samples

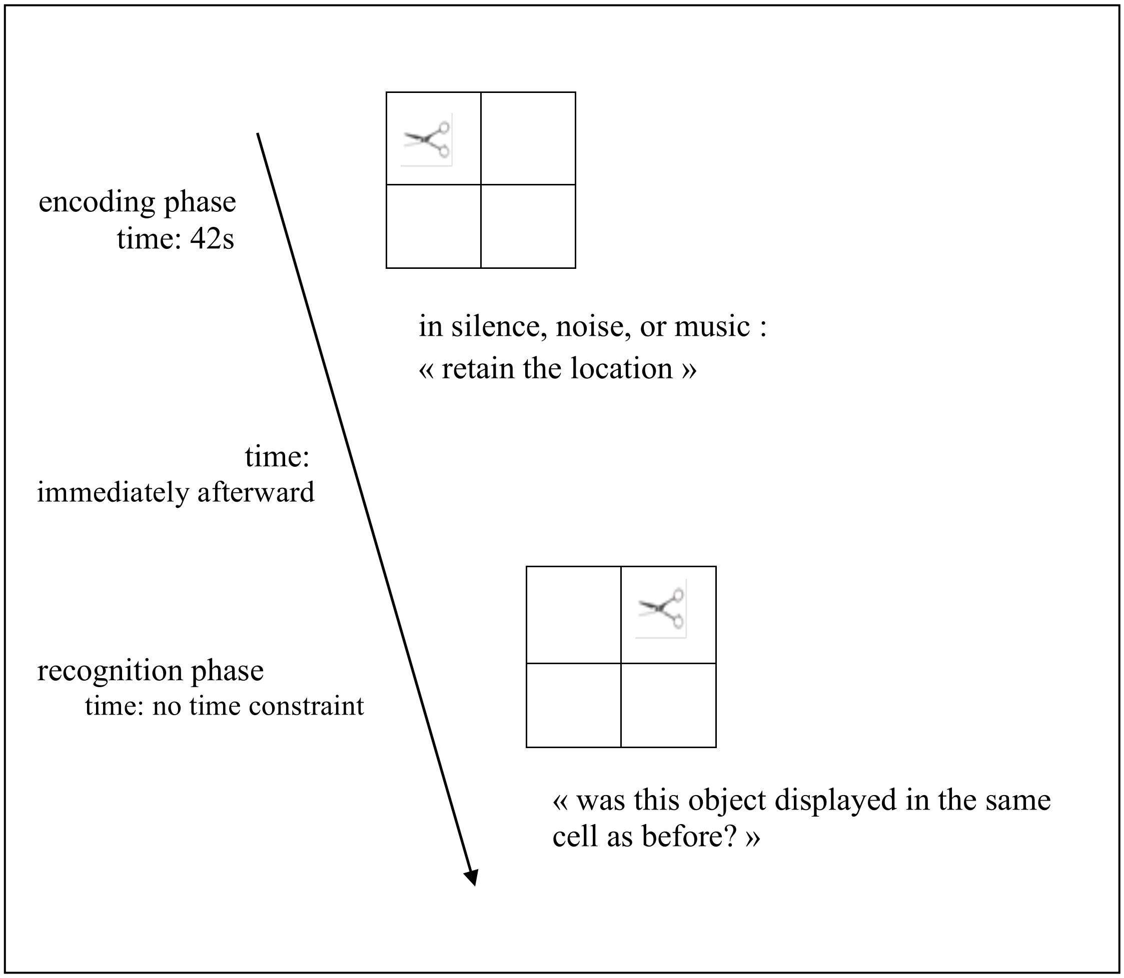

Figure 1. *In the source memory task, participants had to retain the location of 12 objects (in silence, noise, or music exposure). On a subsequent recognition task they had to decide (in silence) whether the objects were displayed in the same cell as before or not.*

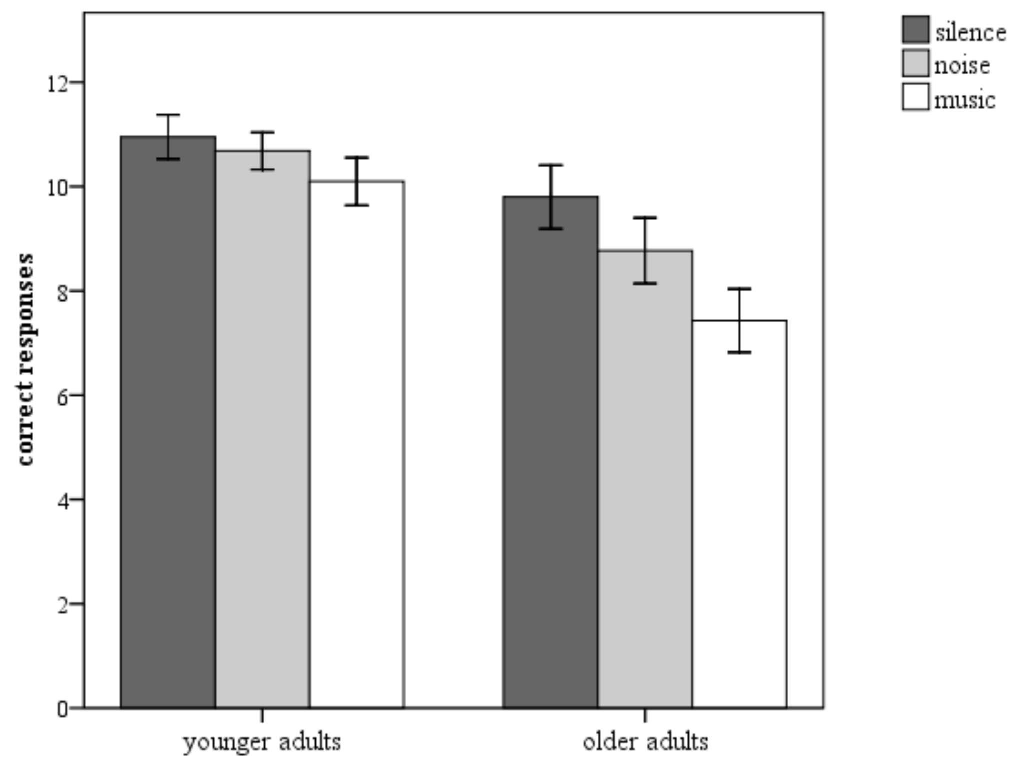

Figure 2. *Source recall after silence, noise, and music exposure. Error bars are 95% within-subjects confidence intervals.*