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Do Temporal Regularities during Maintenance Benefit Short-term Memory in the Elderly? Inhibition Capacities Matter

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ABSTRACT

Background/Study context: Recent research has shown a benefit of temporally regular structure presented during the maintenance period in short-term memory for young adults. Because maintenance is impaired in aging, we investigated whether older adults can also benefit from the temporal regularities for maintenance and how their cognitive capacities might affect this potential benefit.
Methods: Healthy older adults (range: 63–90 years old) had to memorize visually presented letters and maintain them in short-term memory for 6 s until recall. The six-second retention interval was either filled with an isochronous rhythmic sound sequence that provided a temporally regular structure or silent.
Results: The effect of the isochronous rhythm on recall performance was modulated by inhibition capacities of older adults: as compared to silence, improved recall performance thanks to the rhythm emerged with increased inhibitory capacity of the participants.
Conclusion: Even though maintenance of older adults benefits less from the presence of temporal regularities than does the maintenance of younger ones, our findings provide evidence for improved maintenance in short-term memory for older adults in the presence of a temporally regular structure, probably due to enhanced attentional refreshing. It further provides perspectives for training and rehabilitation of age-related working memory deficits.

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Music cognition research has provided evidence for a benefit of temporally regular structures on various processes, such as perception (Schwartze, Rothermich, Schmidt-Kassow, & Kotz, 2011), learning (Hoch, Tyler, & Tillmann, 2013; Selchenkova, Jones, & Tillmann, 2014) and, more recently, in episodic memory (Hickey, Merseal, Patel, & Race, 2020; Johndro, Jacobs, Patel, & Race, 2019), working memory and short-term memory (Fanuel, Portrat, Tillmann, & Plancher, 2018a; Plancher et al., 2018). Previous research has suggested that maintenance in working memory relies on two distinct mechanisms: verbal rehearsal and attentional refreshing (Camos & Barrouillet, 2014). While verbal rehearsal allows for

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maintenance of verbal information via the phonological loop described in Baddeley's model (Baddeley & Hitch, 1974; Baddeley, Lewis, & Vallar, 1984), attentional refreshing is viewed as a domain-general mechanism relying on attention (Camos et al., 2018). Attentional refreshing (also referred to as *refreshing*) can be described as a brief thought to an item that is no longer perceptually present (Johnson, 1992). Recent results have provided evidence that attentional refreshing in young adults can benefit from a temporally regular structure (Plancher et al., 2018). An isochronous tone sequence presented during the retention interval benefited to memory performance (in comparison to a silent retention period), suggesting that temporal regularities benefit maintenance in memory. As the benefit was not observed with a non-isochronous rhythm but persisted under concurrent articulation impeding verbal maintenance mechanism, temporal regularities were proposed to benefit attentional refreshing. There is consistent and compelling evidence that attentional refreshing is impaired in the elderly (Fanuel, Plancher, Monsaingeon, Tillmann, & Portrat, 2018b; Hoareau, Lemaire, Portrat, & Plancher, 2016; Jarjat, Portrat, & Hot, 2019; Johnson, Reeder, Raye, & Mitchell, 2002; Loaiza & McCabe, 2013; Plancher, Boyer, Lemaire, & Portrat, 2017). Our study investigated whether older adults can also benefit from an auditory temporally regular structure presented during maintenance and whether their cognitive capacities can affect the potential benefit of temporal regularities on maintenance in short-term memory.

Over the last decades, different hypotheses have been proposed for the cognitive mechanisms underlying age-related decline in working memory (Logie & Morris, 2014; Luo & Craik, 2008). The *slowing-down* theory proposes that in general the speed of cognitive processes (including working memory) declines with age (Salthouse, 1992). More specifically, the *attentional resource* theory makes the hypothesis that the amount of attentional resources available for cognitive processing declines with age (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Rabinowitz, Craik, & Ackerman, 1982), resulting in increased difficulties to perform highly demanding cognitive tasks, such as working memory tasks. Another account, the *inhibition* framework, proposes that older adults have less efficient inhibitory processes, leading to increased difficulties to deal with interference and block out irrelevant information from working memory (Borella, Carretti, & De Beni, 2008; Hasher & Zacks, 1988). Finally, a combination of the *attentional resources* and *inhibition* approaches was proposed by Jacoby and colleagues (Jacoby, 1991; Jennings & Jacoby, 1993), who hypothesized that older adults are specifically impaired in controlled processing, but not in automatic processing.

A growing body of evidence has shown that age-related deficits in working memory could be due to impaired attentional refreshing. The first studies investigating a deficit of refreshing in aging have focused on explicitly instructed refreshing of just-presented information and its impact on long-term memory (e.g., Higgins & Johnson, 2009; Johnson et al., 2002). In Johnson et al. (2002), for example, words were presented sequentially, and they were either presented once, repeated or followed by a dot that instructed participants to think about the preceding word (i.e., to refresh it). Each time a new word (or dot) was presented, participants read the new word aloud, or recalled the previous word aloud in the refreshing condition; response times were recorded. While older participants responded globally more slowly than did young adults, response times of both young and older adults benefited to the same extent from word repetition. In comparison to word repetition, response times in the refreshing condition increased for both young and older adults. Response times in the refreshing condition were slower for older adults than for young adults, highlighting a slowing down of refreshing in aging. Computational modeling of working memory performance in young and older adults (Hoareau et al., 2016; Plancher et al., 2017) also supported the hypothesis of slowed-down refreshing in aging. Memory performance of older adults was best fitted by a model in which refreshing times for older adults are five times longer than for young adults. Impaired refreshing could further explain why older adults benefit less from refreshing opportunities than do younger ones (Jarjat et al., 2019).

However, other studies provided evidence for a preservation of attentional refreshing in aging. In Johnson et al. (2002), memory performance was assessed after the presentation of the word list in a recognition task. Both age groups performed better for repeated words than for words that were presented once, and memory performance was better in the refreshing condition than in the other conditions, suggesting that both groups benefited from the refreshing opportunity. In line with this finding, other empirical evidence suggests that the attentional refreshing mechanism is still efficient in aging. In a retro-cue paradigm, older and young adults benefited to the same extent from a cue presented during the retention interval that indicated which item will be subsequently tested (Souza, 2016). Attentional refreshing involves both initiation of refreshing and refreshing *per se* (Johnson, McCarthy, Muller, Brudner, & Johnson, 2015). Because attentional refreshing is prompted by the cue, initiation is not necessary. This could explain the preserved benefit of older adults from refreshing in the presence of the retro-cue. Indicating the spatial location of the item that will be tested might guide attention toward this location and thus facilitate the initiation of refreshing of this specific item. Providing guidance for attention could thus be a mean to improve refreshing in aging and overcome the impaired initiation of refreshing.

The Dynamic Attending Theory (DAT, Jones, 1976; Jones & Boltz, 1989; Large & Snyder, 2009), a theoretical framework initially proposed in music cognition research, suggests that attentional resources are not distributed continuously over time, but develop over cycles (implemented via neurocognitive oscillations, e.g., Fujioka, Trainor, Large, & Ross, 2012, 2009; Nozaradan, Peretz, Missal, & Mouraux, 2011; Nozaradan, Zerouali, Peretz, & Mouraux, 2015). The presence of temporally regular structures in the environment provides predictable cues which synchronize attentional cycles (i.e., via entrainment). Successful synchronization allows predicting the occurrence of future events (see Arnal & Giraud, 2012 for a review), thus improving the allocation of attentional resources at the expected time points. For example and among other empirical findings, Cutanda, Correa, and Sanabria (2015) presented sequences of seven tones during the retention interval of a Sternberg-like paradigm. The six first tones of the sequence were at a low pitch and presented either isochronously (with a sound onset asynchrony of 800 ms), non-isochronously or only the first and seventh tones were presented. The last tone of the sequence, shorter and with a higher pitch, constituted the target tone, and participants were instructed to press a key as soon as they detected this tone. Detection times were faster when the target tone was preceded by the isochronous sequence than when preceded by the non-isochronous sequence or no sequence. The regular temporal structure provided by the isochronous sequences allowed perceivers to implicitly use the regularity for developing temporal expectations about the occurrence of the last tone, resulting in an enhanced perceptual processing (see also, Geiser, Notter, & Gabrieli, 2012 for converging data with an intensity discrimination task).

Recent research investigating short-term memory has revealed that a temporally regular structure can also improve maintenance of to-be-remembered information, in particular, attentional refreshing (Plancher et al., 2018). Yet, up to now, the beneficial effect of temporal regularities on maintenance was only investigated in young adults (Fanuel et al., 2018a; Plancher et al., 2018). In the present study, we investigated whether the beneficial effect of a temporally regular structure on maintenance in short-term memory extends also to older adults. To this end, the same experimental paradigm as in Plancher et al. (2018, Experiment 1) was used. Participants were instructed to memorize series of letters, maintain them over a retention interval of 6 s, and recall them. The retention interval was either silent or filled with an isochronous auditory rhythm. Previous research has suggested that spontaneous preferred tapping tempo might change over life span (McAuley, Jones, Holub, Johnston, & Miller, 2006). While the reported tempi increased from childhood to young adulthood, they were quite similar (around 630 ms) for young adults and the elderly (60–74 years old; see McAuley et al., 2006). Thus, we here used the same isochronous sequence with 1-s sound onset asynchrony as did Plancher et al. (2018). As the benefit of the isochronous sequence during the retention interval in young adults was due to the temporal regularities rather than the mere presence of tones, we here focused directly on this comparison. If the temporal regularities improve the efficiency of refreshing even in aging, memory performance should be greater in the rhythm condition (i.e., with the isochronous sequence) than in the silence condition.

Based on the hypothesis that rhythm perception skills are likely to influence the processing of temporal regularity, interindividual variation in rhythm perception was evaluated with tasks of the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA; Dalla Bella et al., 2017). If rhythm perception is mediating the memory benefit from the regular sequence, then these abilities should modulate the effect of the isochronous rhythm on memory performance.

Moreover, because aging has been associated with various cognitive changes, in particular in executive functions (Valdois, Joanette, Poissant, Ska, & Dehaut, 1990; Ylikoski et al., 1999), we investigated whether the cognitive capacities of older adults might mediate the potential benefit of the temporal regularities (if any) on maintenance in short-term memory. In particular, the effect of a temporally regular structure on maintenance in short-term memory might be modulated by the sensitivity to irrelevant information. For each participant, we evaluated general cognition, executive functions including inhibition, short-term memory, and working memory. If one (or more) cognitive function(s) mediate(s) the benefit from the regular structure, then the performance in the associated neuropsychological evaluation should predict the potential benefit in the rhythm condition compared to silence. Because the presence of the tones can be considered as irrelevant information regarding the memory task (Page & Norris, 2003), inhibition capacities can be expected to mediate the benefit of temporal regularities. We further investigated whether older adults benefited from the presence of a temporally regular structure to the same extent as younger adults. To do so, we contrasted the rhythm effect on memory performance for older and younger adults. We expected that the age-related deficit in inhibition processes might led to a smaller benefit of temporal regularities on maintenance in working memory for older adults than for younger ones.

Method

Participants

Forty participants (25 women) aged between 63 and 90 years (M = 72.13, SD = 6.57) voluntarily participated in the study. Sample size was determined based on our previous study (Plancher et al., 2018) investigating the effect of temporal regularities on maintenance in working memory with 20 young adults. Because of higher variability in cognitive profiles in the elderly as compared to younger adults (Lindenberger & von Oertzen, 2006), we doubled the amount of participants for the present study. They were recruited either in a retirement home or through social networks and were not selected relative to musical training. Participants did not report any sensory, cognitive, psychological or neurological disorders. The study was conducted in Lyon 2 university, which does not have an Institutional Review Board. Even though the study was not approved by an ethics committee, it was conducted in line with recommendations from Helsinki declaration, and participants gave written informed consent prior to the experiment.

Neuropsychological Evaluation

Each participant completed several neuropsychological tests. A general measure of cognition was obtained with the Mini Mental State Evaluation (MMSE, Folstein, Folstein, & McHugh, 1975; Kalafat, Hugonot-Diener, & Poitrenaud, 2003 for the French version used in the present study). The MMSE scores confirmed that none of the participants was cognitively impaired (cutoff score of 27): M = 28.85 ± 1.10; range = 27–30). For a more detailed cognitive profile of the participants, memory and executive functions were also assessed. Short-term memory and working memory were measured with the forward and backward span tasks of the Wechsler Adult Intelligence Scale (WAIS, Wechsler, 2014), respectively. Speed processing and flexibility measures were provided by the Trail Making Test (TMT, Lezak, Howieson, Loring, & Fischer, 2004), by calculating response times to perform the TMT-A and calculating the difference between response times in the TMT-A and TMT-B (furthered referred to as TMT B-A). Finally, the Stroop Victoria Test (Stroop, 1935; Davidson, Zacks, & Williams, 2003; Bayard, Erkes, & Moroni, 2011 for the French version) provided a measure of inhibitory capacities distinguishing the inhibition of a dominant, highly interfering, response (i.e., the classical Stroop task comparing the naming of the color of dots versus naming the color of the ink of words of color) and the inhibition of an information that is producing weak interference (i.e., comparing the naming of the ink of dots versus neutral words, which do not refer to colors; Bayard et al., 2011). Both measures of inhibition correspond to a ratio between the task involving inhibition (i.e., naming of words) and the control condition (i.e., naming of the color of the dots): the higher the score, the lower the inhibition capacities. The Hospital Anxiety and Depression Scale (HADS, Zigmond & Snaith, 1983; Untas et al., 2009 for the French version) provided a general measure of anxiety and depression and the Geriatric Depression Scale (GDS, Yesavage et al., 1982; Clement, Nassif, Leger, & Marchan, 1997 for the French version) allowed for an elderly-specific assessment of depression. To ensure that participants did not suffer from depressive or anxiety symptoms that could interfere with working memory functioning (Christopher & MacDonald, 2005), inclusion criteria were to score below 8 to the HADS and below 10 at the GDS (Mykletun, Stordal, & Dahl, 2001; Yesavage, Brink, Rose, & Adey, 1983).

Rhythm Perception

After the neuropsychological evaluation, two sub-tests of the BAASTA (Dalla Bella et al., 2017) were used to evaluate participants' rhythm perception (with isochronous sequences and with music; stimulus inter-onset interval and inter-beat interval = 600 ms). Data were collected with a tablet LG G Pad 8.0. Participants first performed the Anisochrony Detection task with tones and then the Beat Alignment Test (BAT). The Anisochrony Detection task with tones consisted in the presentation of sequences of five tones that were either isochronous or not, depending on the inter-onset interval (IOI) between the penultimate and the last tone. Participants were asked to decide whether the sequence was regular or irregular. The threshold for detecting anisochrony was calculated using an adaptive method (see Dalla Bella et al., 2017 for more details). In the BAT, short musical excerpts were presented with an isochronous sequence of tones superimposed onto the music. The sequence of tones was either aligned to the musical beat or not. Participants were instructed to decide whether the isochronous sequence was aligned with the beat of the musical excerpt or not. Correct responses and false alarms were calculated and resulted in a sensitivity measure of beat alignment (i.e., d').

Experimental Task

Material

Material and procedure were as described in Plancher et al. (2018), except that the number of training trials was doubled to ensure correct understanding of instructions by the elderly participants. The experiment was programmed with OpenSesame 3.0 (Mathôt, Schreij, & Theeuwes, 2012).

Twenty-four sequences of six letters were created from a subset of letters including only bi-syllabic consonants (i.e., all consonants except the "W" which is trisyllabic in French) and constituted the to-be-memorized material. A given letter was only presented once in a sequence. Acronyms and alphabetically ordered string were avoided. Each letter was equally presented over the entire experiment and at each serial position.

An isochronous rhythm was created using a woodblock tone of 58-ms duration. The tone was repeated six times with a sound-onset asynchrony (SOA) of 1000 ms.

Procedure

(Figure 1). Each trial began with a black fixation cross displayed in the center of the white screen during 500 ms. Letters from a given sequence were then sequentially presented in black in a 60-pixels mono font in the center of a white screen. Each letter remained on the screen for 800 ms followed by 200 ms of blank. Participants were instructed to read the letters aloud when they appeared on the screen and to memorize them as best as they can. After the letters' presentation, the screen remained blank for 6000 ms, constituting the retention interval. This retention interval was filled with the auditory isochronous rhythm (Rhythm condition) in half of the experimental trials and remained without sound in the other half of the experimental trials (Silence condition). As in previous studies (Fanuel,

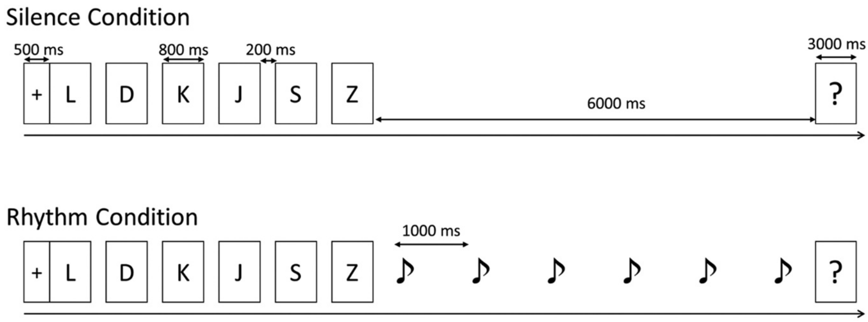

Figure 1. Schematic representation of the experimental design. Each trial started with a fixation cross displayed during 500 ms. Then, six letters were sequentially presented on the screen for 800 ms followed by 200 ms of blank. After the letters' presentation, the screen remained blank for 6000 ms, constituting the retention interval. Retention interval was silent (Silence condition) in half of the trials or filled with the auditory isochronous rhythm (Rhythm condition) in the other half. A question mark appeared after the retention interval, inviting participants to start recalling the letters.

Portrat, et al., 2018a; Plancher et al., 2018), participants were asked to recall the letters aloud in their order of appearance after the retention interval. The experimenter wrote down the recalled sequence and asked participants for more details on the serial position if any doubt remained for the experimenter (i.e., if the participant recalled less than six letters, he/she was asked to explicit the position of the letters). A given letter in a sequence was considered as correctly recalled when it was recalled at the correct serial position. One point was attributed to each letter that was correctly recalled, leading to a serial recall score with a maximum of six points for each sequence.

Experimental conditions (Rhythm, Silence) were blocked and the order of presentation as well as the letter sequences assigned to each condition were counterbalanced across participants following a Latin square. Each experimental condition began with four training trials followed by 12 experimental trials.

Statistical Analyses

Statistical analyses were computed using JASP 0.11.1 (JASP Team, 2019) with the default settings. In addition to classical frequentist statistics, Bayesian statistics were computed. The Bayesian factor (BF) associated with an effect is the resulting statistics of the comparison between all the models including this particular effect and all the models *not* including this effect (Etz & Wagenmakers, 2017). Thus, it reflects the probability of the inclusion of this effect averaged across all candidate models. When applicable, we reported the Bayesian factor associated with an effect (BF), as well as the most probable model (i.e., the model that fits best the data) and its associated Bayesian factor (BF_M). Importantly, a Bayesian factor can give evidence toward the alternative hypothesis (H1) or toward the null hypothesis (H0). Following Lee and Wagenmakers (2014), a BF between 3 and 10 is considered as moderate support for the alternative hypothesis and BF above 10 are considered as a strong support for the alternative hypothesis. BF_{10} values between 1/3 and 1/10 and below 1/10 are considered as moderate support and strong support for null hypothesis, respectively. BF_{10} values between 1/3 and 3 are considered as ambiguous information (Etz, Gronau, Dablander, Edelsbrunner, & Baribault, 2017; Lee & Wagenmakers, 2014; Wagenmakers, 2007).

Results

Neuropsychological Measurements

Results of all neuropsychological tests are reported in Table 1. Importantly, no indication of cognitive disorders was observed in our pool of participants (all MMSE scores were above or equal to 27), and none of the participants had anxiety or depression-related symptoms (HADS < 8 for both anxiety and depression sub-tests; GDS < 10).

BAASTA Tasks

Concerning the BAASTA tasks, fewer data were acquired due to either participants who interrupted the task (N = 2 for the Beat Alignment Test, N = 6 for the Anisochrony Detection with Tones) or technical reasons (N = 13): data of 25 participants were analyzed for the Beat Alignment Test (mean d' = 1.81, SD = 1.33) and 21 for the Anisochrony Detection with Tones (mean threshold = 78 ms – i.e., 13% of the IOI -, SD = 27 ms). These results are consistent with previous data assessing rhythm perception in the elderly (Bégel,

Table 1. Overview of neuropsychological and perceptual evaluation and their correlation with the difference of memory performance between Rhythm and Silence condition. Descriptive statistics for the group of participants are reported for each score obtained by the participants in the neuropsychological and perceptual tests are reported (N = the number of participants whom completed each tests, M = Mean of the group, SD = standard deviation of the group, Min. = the minimum score, Max. = maximum score, cutoff = cutoff used to decide whether a score is pathological or not). Pearson's correlations between difference of memory performance between Rhythm and Silence condition and neuropsychological and perceptual evaluations are also reported (df = degree of freedom, r = Pearson's r, *p* = *p*-values, BF = Bayesian Factor). Significant correlations are flagged. **p <.01. NA stands for Not Applicable.

	Descriptive statistics						Correlation with Rhythm – Silence difference in memory performance			
Neuropsychological and perceptual tests	N	M	SD	Min.	Max.	Cutoff	df	r	p	BF
General cognition										
MMSE	40	28.25	1.10	27	30	27	38	−0.167	.303	0.33
Anxiety and Depression										
HADS – Anxiety	40	3.30	2.13	0	8	8	NA	NA	NA	NA
HADS – Depression	40	3.38	1.18	0	8	8	NA	NA	NA	NA
GDS	40	2.65	2.35	0	9	10	NA	NA	NA	NA
Memory										
Forward span	40	5.73	1.18	4	9	NA	38	0.184	.255	0.37
Backward span	40	4.58	1.15	2	8	NA	38	0.149	.360	0.30
Executive functions										
TMT A	40	43.03	26.96	17	163	NA	38	0.191	.238	0.39
TMT B-A	38	55.87	38	8	225	NA	36	−0.153	.359	0.30
Stroop – highly interfering response inhibition	40	2.24	0.63	1.17	4.58	NA	38	−0.147	.366	0.29
Stroop – weakly interfering information inhibition	40	1.38	0.33	0.93	2.3	NA	38	−0.443**	.004	10.02
Rhythm perception										
Beat Alignment Test – d'	25	1.81	1.33	−0.25	4.37	NA	23	−0.074	.726	0.30
Anisochrony Detection with Tones – Threshold	21	78	27	40.8	135	NA	19	0.047	.838	0.63

Verga, Benoit, Kotz, & Dalla Bella, 2018, mean age = 62.95, SD = 5.92, ranged between 50 and 76 years-of-age) with the Anisochrony Detection task with tones (first session: mean threshold = 13.67%, SD = 3.27, second session: mean threshold = 12.92%, SD = 2.86) and the Beat Alignment Test (first session: mean d' = 1.67, SD = 1.36; second session: mean d' = 1.82, SD = 1.49). Rhythm perception of the elderly did not seem to differ from young adults performance (mean age = 23.9 ± 4.1, mean threshold for anisochrony detection with tones about 10% and mean d' for Beat Alignment Test about 2.10, Dalla Bella et al., 2017).

Serial Recall

A one-way ANCOVA was performed on serial recall performance with experimental condition (Silence vs. Rhythm) as the within-participant factor and the MMSE score as a covariate to control for general cognition differences. The effect of condition was not significant ($F(1, 38) = 1.01$, $p = .32$) and Bayesian analyses showed moderate evidence for no effect of condition (BF = 0.32; M = 4.41, SD = 0.94 in the silence condition; M = 4.31, SD = 1.13 in the rhythm condition).[1]

To investigate whether cognitive processes or perception abilities could mediate a potential effect of rhythm on maintenance in memory, correlation and regression analyses were performed with the difference in serial recall performance between the two experimental conditions (i.e., Rhythm-Silence) as dependent variable and the neuropsychological measures (MMSE, forward span, backward span, response time for TMT A, TMT B-A, inhibition score for dominant response and inhibition score for weakly-interfering information) as well as the rhythm perception performance (d' of beat alignment and anisochrony detection threshold). Stepwise multiple regressions were then conducted for each of the dependent variables with all neuropsychological measures as potential predictors to be included in the regression equation.[2] In the stepwise regression, predictor variables were entered into the regression equation one at a time based upon statistical criteria (i.e., $p < .05$). At each step in the analysis, the predictor variable that contributes the most to the prediction equation in terms of increasing the multiple correlation, R, is entered into the regression equation. When no additional predictor variables added further statistically significant contribution to the regression equation, the analysis stops.

The difference in serial recall performance between the experimental conditions (i.e., rhythm-silence) was correlated only with the inhibition score for the weakly-interfering information (Pearson's $r(38) = -.44$, $p < .001$, BF = 10.02; note that the lower the score, the better the inhibition capacities). The other correlations were not significant (all $p > .23$) and were associated with either moderate evidence in favor of the null hypothesis (MMSE, Backward span, TMT B-A, Stroop score for highly interfering information, d-prime score for Beat Alignment Test) or with ambiguous information (Forward span, TMT A, threshold of anisochrony detection with tones; see Table 1). The regression analysis on the difference between memory performance in Rhythm and Silence conditions was performed to evaluate whether the inhibition score for irrelevant information was sufficient to predict the rhythm effect on memory performance or whether the inclusion of other neuropsychological measures could provide a better account. At step one of the analysis, the inhibition score for weakly-interfering information was entered into the regression equation, and it significantly predicted the rhythm effect on memory performance ($F(1,36) = 7.97$, $p = .008$).

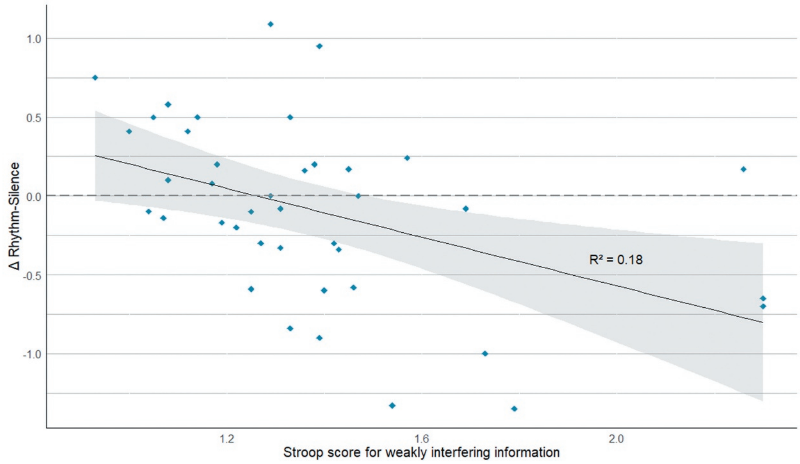

Figure 2. Memory performance difference between the two experimental conditions (ΔRhythm-Silence) are reported for each participant as a function of the Stroop score for weakly-interfering information. Black line represents the linear trend. Note that the relation between the two variables remained and became stronger (R^2 = .34) when the three extreme participants (i.e., with a Stroop score over 2) were removed from the analysis.

The contribution of the inhibition score for weakly-interfering information was significant (β = −0.77, t(36) = −2.82, *p* = .008) and accounted for about 18% of the variance of the memory performance difference Rhythm-Silence. As shown in Figure 2, the presence of the rhythm elicited a positive effect on recall performance as compared to silence for older adults who had a lower Stroop score (i.e., high inhibition capacities). On the contrary, the presence of the rhythm impaired recall performance of older adults with a higher Stroop score (i.e., lower inhibition capacities). For detailed individual performance in Rhythm condition presented as a function of performance in the Silence condition, see Figure S1 in Supplementary material. Data were best fitted by the model including only inhibition score for weakly-interfering information (BF_M = 6.99). No other measure entered into the equation at step two of the analysis, showing that the inhibition capacity for weakly-interfering information was the only significant predictor of the memory performance difference between rhythm and silence conditions.[3]

Comparison with Younger Adults

To better understand whether aging influenced the beneficial effect of temporal regularities on maintenance in working memory, we compared the data from the older adults of the present study with data of younger adults (data from Plancher et al., 2018, experiment 1). Experimental designs of Plancher et al. (2018, experiment 1) and the present study were identical, except for neuropsychological evaluation and rhythm perception measures, which were not collected for the younger adults.

The 20 young adults of Plancher et al.'s study were non-musician students from Lyon. Aiming for comparable educational background in the two populations and the largest N possible for both age groups, we selected a subset of older adults whose educational level matched the one of the young adults (i.e., 12 years of studies or more, corresponding to post-secondary education). Older adults were not selected based on their musical training but none of them were professional musician. This sub-sampling resulted in the following two participant groups: (1) 23 older adults (out of 40, i.e. 57.5% of the initial sample) aged between 64 and 83 years-old (M = 71.31, SD = 4.68) with an educational level ranging between 12 and 17 years of study (M = 14.56, SD = 1.92) and (2) 20 younger adults aged between 20 and 29 years-old (M = 24.55, SD = 2.50) with an educational level ranging between 13 and 19 years of study (M = 15.8, SD = 1.44).

A two-way analysis of variance (ANOVA) was performed with Condition (Rhythm, Silence) as within-participant factor and Age (Older, Younger) as between-participants factor. The main effect of Condition was significant and associated with a strong evidence for the effect ($F(1,32) = 36.07$, $p < .001$, η2p = .53, BF = 39,307), with better memory performance in the rhythm condition (M = 4.81, SD = 0.78) than in the silence condition (M = 4.41, SD = 0.90). The main effect of Age was not significant (F < 1; M = 4.71, SD = 0.83 for older adults, M = 4.51, SD = 0.67 for younger adults), but the inclusion of the Age factor in the model was highly probable (BF = 1,528). The interaction between Age and Condition was significant ($F(1, 41) = 30.33$, $p < .001$, η2p = .43, BF = 6,099, Figure 3). As expected, for younger adults, performance was significantly better in the rhythm condition (M = 4.96, SD = 0.55) than in the silence condition (M = 4.05, SD = 0.88; $p < .001$), but not for the older adults (M = 4.69, SD = 0.93 in the rhythm condition, M = 4.73, SD = 0.81 in the silence condition; $p = .769$). Bayesian analyses highlighted that the model including Condition and Age main effects in addition to their interaction best fitted the data (BF_M = 86,630). Comparison between younger and older adults confirmed that older adults benefited less than younger adults from the presence of temporal regularities during the retention interval.

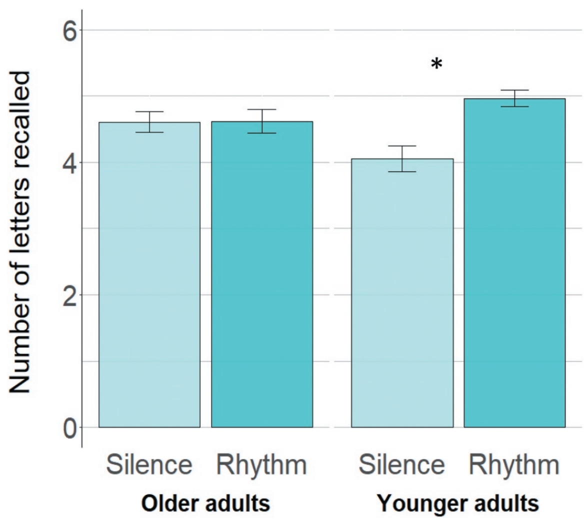

Figure 3. Recall performance (with a maximum of six letters) presented as a function of the experimental condition (rhythm vs. silence) and age (older vs. younger adults). Vertical bars represent standard error. Data of younger adults from Plancher et al. (2018). Significant simple effect of condition is flagged with an asterisk.

Discussion

The present study aimed to investigate whether older adults can benefit from temporal regularities during short-term memory maintenance as previously observed for young adults. Related to the previously reported attentional deficit in aging (Fanuel et al., 2018b; Hoareau et al., 2016; Jarjat et al., 2019; M. K. Johnson et al., 2002; Plancher et al., 2017), we hypothesized an enhancement of attentional refreshing in the presence of an isochronous rhythm during the retention interval and investigated whether the cognitive capacities of older adults can affect the potential benefit of temporal regularities on maintenance in short-term memory. To address these questions, we contrasted the presence of an isochronous rhythm during the retention period to a silent retention interval. Serial recall performance of letters was measured to assess memory performance.

The isochronous rhythm during the retention interval did not benefit memory performance at the group level. The absence of benefit of temporal regularities on maintenance in older adults as a group contrasted with the previously reported benefit of temporal regularities on maintenance in younger adults (Plancher et al., 2018). The benefit of temporal regularities on maintenance in younger adults might be due to some fine-tuned matching between refreshing rate and subdivisions of the isochronous rhythm (Plancher et al., 2018). As attentional refreshing is slowed down in aging (Hoareau et al., 2016; Plancher et al., 2017), the refreshing rate of older adults might not be as well tuned to the subdivision of the isochronous rhythm as it is the case for the young adults, thus decreasing the potential beneficial effect of temporal regularities on maintenance.

Our further investigations of the impact of an isochronous rhythm on memory performance by including the evaluation of cognitive functions and rhythm perception revealed an influence of participants' inhibitory capacities. More specifically, inhibitory capacities for weakly-interfering material predicted the difference in memory performance between the two conditions. Notably, memory performance of the participants with high inhibitory capacities for weakly-interfering material (as assessed by the Stroop Victoria subtest) seemed to benefit from the isochronous rhythm, while memory performance of the participants with lower inhibition capacities seemed impaired in the presence of the temporal regularities. No other measure of cognitive functions or rhythm perception was linked to a potential effect of rhythm on memory performance.

In line with previous findings in young adults (Plancher et al., 2018), the present study highlights that maintenance in short-term memory in older adults can be enhanced in the presence of temporal regularities, but this benefit depends on the inhibition profiles of the elderly participants. Based on the Irrelevant Sound Effect (Page & Norris, 2003), the auditory rhythm presented during the retention interval can be considered as an interfering stimulation, even though only with a low-level interference because the six tones were all identical and were presented in a predictable way. Older adults with good inhibition capacities might be more efficient in inhibiting the influence of sound occurrence per se, and thus be able to take advantage of the regular structure that guides attention over time and benefits to refreshing information. In contrast for older adults with lower inhibition capacities, the presence of tones might have thus constituted an irrelevant stimulation difficult to deal with and preventing them to benefit from temporal regularities.

In line with previous studies suggesting that short-term memory is not always altered in normal aging (e.g., Bopp & Verhaeghen, 2005; Connor, 2001; Peters et al., 2007; Sekuler, McLaughlin, Kahana, Wingfield, & Yotsumoto, 2006), memory performance of older adults was similar to the one of younger adults. Yet, temporal regularities benefited to older adults in a lesser extent than to young adults. As inhibition processes are proposed to be impaired in aging (Borella et al., 2008; Hasher & Zacks, 1988), inhibition capacities might have contributed to the age difference in the benefit from temporal regularities on maintenance. Future studies should empirically investigate how the reduced benefit of temporal regularities in older adults as compared to younger adults is related to an age-related deficit of inhibition capacities, and in particular to weakly interfering material.

It is worth pointing out that inhibition capacities assessment consisted in measuring the time ratio between the response time of naming of color ink with and without interference. A higher ratio thus indicates that more time is necessary to inhibit irrelevant information. Older adults with lower inhibition capacities for irrelevant information thus needed more time to inhibit irrelevant information (i.e., tones). Because time sharing of attentional resources is at the core of working memory functioning (Barrouillet, Bernardin, & Camos, 2004; Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Barrouillet, Portrat, & Camos, 2011), the findings suggest that if more time is used for the inhibition of irrelevant stimuli like the tones' occurrence, then less time is available for attentional maintenance. One could thus argue that older adults who needed more time to inhibit the tones have less time for maintenance, and also not enough available time to benefit from the temporal regularities. This would also be consistent with the smaller benefit of temporal regularities for older adults in comparison to the benefit observed for young adults (Plancher et al., 2018). Fewer attentional resources seem to be available to older adults than young adults (Naveh-Benjamin et al., 2004; Rabinowitz et al., 1982). If less attentional resources are available – either because they are used to process something else or because of an age-related reduction of the amount of attentional resources –, then synchronizing them to an externally regular structure might be more difficult, explaining why older adults benefit less from temporal regularities than do young adults and why older adults for whom inhibition takes more time do not benefit at all.

The DAT proposes that the presence of temporal regularities can facilitate and speed up cognitive processes, in particular for events occurring at the expected time points. As a temporally regular structure allows the perceiver to develop temporal expectations about the occurrence of future events, the allocation of increased attentional resources at expected points in time leads to faster processing of the event (Jones, Moynihan, MacKenzie, & Puente, 2002; Sanabria, Capizzi, & Correa, 2011). In light of the slowing down proposal to explain age-related deficit in working memory (Salthouse, 1992), the presence of a temporally regular structure may improve maintenance of older adults by speeding up the cognitive processes occurring at this moment. If refreshing one specific item requires less time, then more time is available for the refreshing of other items, resulting in improved memory performance.

The attentional refreshing mechanism can be separated into two distinct processes: the initiation of refreshing and the refreshing *per se* (Johnson, 1992; Johnson et al., 2015). While refreshing *per se* relies on perceptual cortical areas (e.g., fusiform area for faces, parahippocampal area for scenes, Johnson, Mitchell, Raye, D'esposito, & Johnson, 2007), the initiation of refreshing relies on frontal lobes that are known to be involved in executive functions (Miyake et al., 2000) and more generally in attentional processes (Foster, Eskes, & Stuss, 1994). Numerous studies have provided evidences for a deficit of attentional refreshing in aging (Hoareau et al., 2016; Jarjat et al., 2019; M. K. Johnson et al., 2002; Plancher et al., 2017), and specifically hypothesized a deficit in the initiation of refreshing (Fanuel, Plancher, et al., 2018b). It has been shown that external information in the memory environment can contribute to compensate impaired self-initiated processes (Craik, 1983, 1986; Luo & Craik, 2008). In our present study, the auditory rhythm could have provided the environmental support for the initiation of attentional refreshing and thus benefit to maintenance.

Aging has also been related to changes in the use of cognitive strategies. Young and older adults do not use the same strategies (e.g., Dunlosky & Hertzog, 2001; Duverne & Lemaire, 2004). Older adults also make poorer choices amongst available strategies and are less efficient in executing the selected strategy (Lemaire, 2010). In our study, the presence of temporal regularities might have benefited to short-term memory by helping older adults in the use of (maintenance) strategies. Using a retro-cue paradigm, Souza (2016) showed preserved attentional refreshing in aging when participants were explicitly instructed to use the retro-cue as a refreshing indication. With explicit instruction, older adults would use the same maintenance strategy as younger (i.e., refreshing) because they have an environmental support. In our study, no explicit instructions were given, neither about potential maintenance mechanism to use nor how to "use" the tones. Nevertheless, the auditory rhythm seems to have provided some form of environmental support for maintenance processes, which might have remained on an implicit level.

The hypotheses of an enhanced initiation of refreshing and a speeding up of refreshing thanks to temporal regularities are not mutually exclusive. Studies investigating the time needed for refreshing in aging (Hoareau et al., 2016; Johnson et al., 2002; Plancher et al., 2017) did not distinguish the time necessary to initiate refreshing and the time required for refreshing *per se*. Providing external guidance for the allocation of attentional resources with temporal regularities can facilitate and fasten the initiation of attentional refreshing, which would result in more time available for refreshing *per se* and thus in improved memory performance. To test this hypothesis, further studies providing a time measurement of refreshing, distinguishing the initiation of refreshing and the refreshing *per se*, are necessary. This would allow us to distinguish whether the presence of a temporally regular structure prompts the initiation of refreshing or speeds up the refreshing *per se* in the elderly.

Overall, the present study revealed that the maintenance in short-term memory of older adults can benefit from the presence of temporal regularities under some conditions. The findings suggest an improvement of attentional refreshing in the presence of a temporally regular structure, notably with attentional refreshing benefitting from guidance of attention over time. It might be argued that the presence of temporal regularities benefited verbal rehearsal as the to-be-memorized material was verbal and the phonological loop was available for maintenance. However, support for the influence of the temporally regular structure on attentional refreshing has been previously provided, notably the benefit of the rhythm persisted under concurrent articulation for young adults (Plancher et al., 2018, experience 2).

Working memory is at the core of the cognitive system and its impairment with aging is assumed to mediate the effect of aging on cognition (Salthouse, 1994). Enhancing working memory of older adults might thus contribute to reduce the decremental effect of aging on general cognition. The potential beneficial effects of music and music-like material on rehabilitation and cognitive stimulation has been previously shown in other cognitive domains (Bigand et al., 2015). Future studies should provide a better understanding of the cognitive processes involved in the improvement of maintenance in working memory thanks to temporal regularities. Beyond the here observed influence of inhibition capacities, the tempo embedded in the temporal regularities (i.e., here implemented with the sound onset asynchrony in the sequence) and the individual differences in general temporal processing capacities (e.g., rhythm and beat perception and production) as well as their potential changes in aging might impact the benefit of temporal regularities on maintenance in memory. Future studies should extend the present findings to concrete applications aiming to improve working memory of older adults using musical and rhythmic training activities. Indeed, previous research has provided evidence for the link between musical training and memory performance (see Talamini, Altoè, Carretti, & Grassi, 2017 for a review), even in the elderly (Hanna-Pladdy & MacKay, 2011). Because working memory deficits have also been reported for various pathologies, such as dementia (Kirova, Bays, & Lagalwar, 2015), strokes (Martin & Ayala, 2004) or schizophrenia (Starc et al., 2017), these applications could also be broadened to the clinical domain aiming at improving cognitive functions as well as the well-being of these populations.

Notes

1. To check for potential order effects, a two-way ANCOVA was performed with condition (Silence vs. Rhythm) as a within-participant factor, the order of block presentation (Silence-Rhythm vs. Rhythm-Silence) as between-participants factor, and the MMSE score as covariate. Neither main effects nor interaction were significant ($F < 1$ for both main effects of condition and order, $F(1, 37) = 1.835$, $p = .18$, Condition*Order interaction), and BF either favored null hypothesis (BF = 0.29 for Condition main effect, BF = 0.29 for the Condition*Order interaction) or were ambiguous (BF = 0.49 for Order main effect).
2. Rhythm perception measures were not included in the regression analyses because of the missing data which reduced the data set. For completion only, we conducted also the correlation and regression analyses including only participants for whom all data (neuropsychological and rhythm perception measures) were available ($N = 20$). The overall result pattern was confirmed, but with slight differences (see footnotes below) likely due to lower statistical power because of the drastic reduction of the sample size.
3. Analyses including only participants with data for the BAASTA showed that the correlation with the inhibition score for weakly-interfering information just failed to reach significance ($p = .07$), no other correlation was significant. No predictor factor entered into the regression equation (note that for inhibition score for weakly-interfering information, $\beta = -0.81$, $t(18) = -1.93$, $p = .07$).

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