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Reduced late positivity in younger adults, but not older adults, during short-term repetition

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Abstract

Although word repetition was generally associated with enhanced amplitude of late positive complex (LPC), it seemed to yield attenuated LPC when words were repeated over short enough lags. However, this issue and its corresponding age effects have not been examined directly. For this purpose, EEG was recorded when young and elderly participants were required to make animacy decision during an incidental word repetition paradigm with words repeated after 1, 6, or 9 intervening words. The results revealed that with one intervening word lag LPC decreased for nonliving words which supposed to be related to higher semantic activation levels reflected by larger N400, unchanged for living words associated with lower semantic incongruity activation levels, and increased in relatively longer lags (with 6 or 9 intervening words) in the young group. Whereas, enhanced LPC was observed in the elderly in all conditions. Furthermore, significant age-related LPC repetition differences were revealed only with one intervening word lag for nonliving words. The results suggested that (1) how LPC changes after repetition is influenced by the initial incongruity activation levels of items and their thereafter maintenance in short-term memory; (2) the age-related differences result from the declining of short-term memory maintenance rather than from initial lower incongruity activations among elderly adults.

Keywords

word repetition; aging; lag; LPC; N400

1 Introduction

Incidental repetition has generally been used to investigate implicit memory by not requiring participants to discriminate between words presented for the first and second time (Rugg et al., 1988.). Across a variety of tasks to which the repetition of words was incidental (e.g. lexical judgment, semantic categorization), repetition effects are associated with more accurate, faster responses and generally positive-going ERP shifts relative to initial ERP waveforms 300–900ms after stimulus onset (Bentin and Peled, 1990; Friedman et al., 1992; Mecklinger, 2000; Nagy and Rugg, 1989; Rugg, 1995). This ERP repetition effect is often interpreted as a modulation of an early component (an attenuated N400) and a later component (an enhanced “late positive complex”-LPC).

As an indirect manifestation of memory, word repetition effects sparked enormous interest and have become one of the most thoroughly studied topics since the 1990s. The literature has suggested that the N400 attenuation repetition effect was consistently established across a broad range of studies using pure word lists for semantic categorization tasks (Besson et al., 1992; Friedman et al. 1993; Friedman, et al., 1992; Hamberger & Friedman, 1992; Karayanidis, et al., 1993; Matsumoto et al., 2001; Misra & Holcomb, 2003; Rugg et al., 1994; Rugg, et al., 1997; Swick & Knight, 1997). In these experiments, repetition related LPC increment was generally reported. But on careful inspection of these data, it seemed that if the repetition lag was short enough (0, 1), a decreased LPC (and/or unchanged LPC) could occur. For example, an obvious LPC attenuation trend with immediate repetition (lag=0) could be seen in the younger participants in Swick and Knight et al. (1997), but the authors neglected this phenomenon and concluded that the younger participants generated repetition effects only in the 300–500 ms interval (attenuated N400). Rugg et al. (1997) also reported that a trend toward decreased LPC in response to words repeated over short lag (lag=1) could be seen only in their younger participants. Additionally, unchanged LPC was observed in younger adults with immediate masked repetition (Misra & Holcomb, 2003). These data implied that in contrast with the general trend of LPC increment found in longer delay repetitions, LPC decrement was observed in short-term repetitions (lag= 0,1).

We found the functional significance of LPC proposed by Van Petten et al. (1991) was best to explain the opposite LPC repetition effect on shorter and longer lags. Van Petten et al. (1991) proposed that LPC indexes the demand on retrieving information from long-term memory to update working memory. According to this proposal, if the word is still held temporarily in an active form in working memory when it is repeated, less retrieval will be directed at their current occurrences giving rise to a reduced LPC. Otherwise, an increased LPC will be produced. According to this proposal, the initial word activation level and the repetition lag together would determine the direction of LPC repetition effect (increase/decrease). In other words, if the initial words were repeated with a short-enough lag for the initial presentation of the words to maintain in working memory, the probability of retrieval

from long term memory upon subsequent presentations being necessary will be decreased resulting in a reduced LPC.

Furthermore, the long-standing view of word repetition has suggested that the incidental repetition is an implicit task, which is intact in older adults. This view was supported by several studies using relatively longer lags, which revealed that the repetition-induced LPC increase observed in longer lags did not differ between younger and older participants, though LPC latency was prolonged in the elderly (Frienman et al., 1992; Karayanidis et al., 1993). However, the LPC repetition effect over short enough lags differed between older and younger participants. Swick and Knight (1997) found an increased LPC in their older counterparts when LPC attenuation was observed in younger participants (lag=0). The trend toward decreased LPC in response to words repeated over short lag (lag=1) in Rugg et al (1997) was also only seen in their younger participants. These data implied that the age effects on LPC repetition effect were also likely to differ depending on lag.

Although implied, the existence of LPC decrement and corresponding age effects have not been reported directly in word repetition studies using pure word list. In the present study, we adopted nonliving/living animacy judgment task and expected repetition-induced LPC decrement to occur on nonliving words, since nonliving words were usually associated with greater N400 in ERPs implying greater activation level than living words. Therefore, the present study was designed to address two questions regarding LPC repetition effects and any corresponding age effects by varying lag (1, 6, 9): to confirm whether word repetition yielded opposite LPC effects at longer lag versus shorter lag and explore whether animacy affected the LPC effects in younger adults, and to evaluate whether older adults would manifest LPC repetition effects differently than younger adults in short lag repetition.

2 Results

2.1 Behavioral results

The performance of the participants was shown in Table 1. Accuracy and reaction time were analyzed by means of repeated-measures ANOVA with repetition (first presentation, repetition), lag (1, 6, 9), and congruity (congruous/living, incongruous/nonliving) as within-group factors and age group (young, old) as a between-group factor. η_p^2 indicated partial eta-squared effect size.

The ANOVAs on accuracy only revealed a significant repetition $\times$ lag interaction [$F(2,56) = 4.628, p < .05, \eta_p^2 = 0.142$], reflecting improved accuracy with repetition given lag 9 [$F(1,29) = 8.44, p < .01$]. The ANOVAs on RT showed a significant main effect of Age on RTs [$F(1, 28) = 5.821, p < .05, \eta_p^2 = 0.172$], significant interactions of lag $\times$ congruity [$F(2,56) = 7.119, p < .01, \eta_p^2 = 0.203$] and repetition $\times$ congruity [$F(1,28) = 4.259, p < .05, \eta_p^2 = 0.132$] and main effects of repetition [$F(1,28) = 39.468, p < .001, \eta_p^2 = 0.585$] and congruity [$F(1,28) = 56.235, p < .001, \eta_p^2 = 0.668$]. For the lag $\times$ congruity interaction, simple effect analyses revealed that RTs for nonliving words exceeded those for living words in each lag condition (all $ps < .001$). The difference between RTs of nonliving words and living words was reliably greater

in the lag 1 condition than in the lag 6 ($p < .05$) or lag 9 condition ($p < .01$) as indicated by *Post hoc* Tukey tests. For the repetition $\times$ congruity interaction, simple effect analyses showed that RTs for both living and nonliving words were faster after repetition [living: $F(1,29) = 26.38$, $p < .001$; nonliving: $F(1,29) = 27.85$, $p < .001$], and the repetition-induced RT decrement was greater for nonliving words ($t = 2.10$, $p < .05$). The absence of any significant effects involving repetition $\times$ age suggested that although the older adults had slower RTs on animacy judgment task, they had normal repetition effect compared to the young adults, either on accuracy or RTs.

In sum, nonliving words were associated with slower responses and the RT difference between nonliving and living words was largest for lag1. Repetition effect, which was considered as RT decrement after repetition, was larger for nonliving than living words, suggesting that the repetition effect was affected by the congruity nature of semantic representation.

2.2 ERP results

Grand average waveforms and topographic maps of each group are shown for the lag1 repetition of nonliving words in Figure 1 and for that of living words in Figure 2. Grand average waveforms for lag 6 and lag 9 repetitions are shown in Figure 3. Visual inspection showed that, for repetitions across all condition, the overall pattern of change with repetition was similar in the two groups: a prominent, positive-going shift associated with repeated words appeared approximately 300 to 900 ms after stimulus onset. However, a different pattern was observed in the 550–900ms interval only for nonliving word repetition at lag 1 (Figure 1); the younger adults generated smaller positive responses to repeated words in this latency region (a reduced LPC), whereas the older adults continued to generate a larger positivity (an enhanced LPC).

The first presentation ERPs were across lag because lag was theoretically supposed to make no sense for the first presentations. To ensure this theoretical assumption, we analyzed whether ERPs associated with first presentations showed differential effects of lag. No such evidence was found, so the first presentation ERPs were collapsed across lags.

Since our initial hypothesis was specified that both the direction and the function relevance of LPC changes at shorter lag are different from those at longer lags, our main ERP analyses were structured as follows. First, an omnibus repeated-measures ANOVAs including three within-group factors of condition (first presentation, lag 1 repetition, lag 6 repetition, lag 9 repetition), animacy (living, nonliving), electrode site (18 sites), and between-group factor of age group (young, old), were performed for the mean amplitude within the two latency regions (300–550ms, 550–900ms). Second, any significant interactions involving condition were examined in detail by three repeated-measures ANOVAs across the three levels of lag (first presentation *vs.* lag1 repetition, first presentation *vs.* lag6 repetition, and first presentation *vs.* lag9 repetition). These analyses tested for the reliability of repetition effects at each corresponding lag (e.g. Henson et al., 2004).

Given the present interest in repetition effects, only significant effects including the factor of condition were reported in the absence of significant higher-order interactions.

For the 300–550 ms latency, the initial ANOVAs yielded a main effect of condition [$F(3,84) = 10.514, p < .001, \eta_p^2 = 0.273$] and a condition $\times$ electrode site interaction [$F(51,1428) = 1.982, p < .05, \eta_p^2 = 0.066, \varepsilon = 0.167$]. The subsequent ANOVAs on lag1 (first presentation vs. lag 1 repetition) showed reliable repetition effects [$F(1,28) = 23.067, p < .001, \eta_p^2 = 0.452$] and an interaction of the repetition $\times$ electrode site [$F(17,476) = 4.794, p < .001, \eta_p^2 = 0.146, \varepsilon = 0.343$]. The subsequent ANOVAs on lag6 (first presentation vs. lag 6 repetition) also showed a main effect of repetition [$F(1,28) = 28.498, p < .001, \eta_p^2 = 0.504$], an repetition $\times$ electrode site interaction [$F(17,476) = 3.500, p < .05, \eta_p^2 = 0.111, \varepsilon = 0.198$] and a marginally significant repetition $\times$ animacy interaction [$F(1,28) = 3.258, p = .082, \eta_p^2 = 0.104$]. The subsequent ANOVAs on lag9 (first presentation vs. lag 9 repetition) also showed main effects of repetition [$F(1,28) = 11.093, p < 0.01, \eta_p^2 = 0.284$] and a marginally significant repetition $\times$ animacy $\times$ electrode site interaction [$F(17,476) = 2.443, p = .056, \eta_p^2 = 0.080, \varepsilon = 0.216$]. Simple effect analyses indicated that the repetition effect was significant for both living and nonliving words with either lag6 or lag9 repetition. There were neither significant group effects nor group interaction effects on the ERP amplitude in this time region. Therefore, the N400 evoked by repeated words was decreased in amplitude in each repetition condition, and this N400 repetition effect was comparable in the two groups in either magnitude or scalp distribution.

For the 550–900 ms latency, the initial ANOVAs yielded a main effect of condition [$F(3,84) = 4.628, p < .01, \eta_p^2 = 0.142$] and interactions of condition $\times$ animacy [$F(3,84) = 3.863, p < .05, \eta_p^2 = 0.121$], condition $\times$ electrode site [$F(51,1428) = 1.997, p < .05, \eta_p^2 = 0.067, \varepsilon = 0.194$]. The subsequent ANOVAs on lag1 gave rise to interactions of repetition $\times$ group [$F(1,28) = 4.919, p < .05, \eta_p^2 = 0.149$], repetition $\times$ animacy [$F(1,28) = 4.843, p < .05, \eta^2 = 0.147$], repetition $\times$ electrode site [$F(17, 476) = 4.071, p < .001, \eta_p^2 = 0.127, \varepsilon = 0.307$], and repetition $\times$ electrode site $\times$ group [$F(17,476) = 2.65, p < .05, \eta_p^2 = 0.086, \varepsilon = 0.307$]. Simple effects analyses broken down by congruity only found a marginally significant effect of repetition for living words [$F(1,28) = 3.00, p = .095$] with the repeated living words showing a trend toward relatively larger LPC. The repetition $\times$ age group interaction was not significant for living words [$F(1,28) = 0.71, p > .05$]. The significant repetition $\times$ age group interaction obtained on nonliving words [$F(1,28) = 5.11, p < .05$] highlighted the fact that the LPC repetition effect on nonliving words differed between groups in terms of direction as observed in Fig 1. T test contrasting the two groups' mean amplitude of LPC repetition effect averaged across all electrode sites showed age differences only for the nonliving words repetition ($t = -2.261, p < .05$) (Figure 4).

When conducting separate ANOVAs within each group to test the reliability of repetition effects at lag1, the younger group exhibited significant repetition effects [$F(1,14) = 5.068, p < .05, \eta_p^2 = 0.020$] and repetition $\times$ animacy interaction effects [$F(1,14) = 6.994, p < .05, \eta_p^2 = 0.333$] reflecting the LPC attenuation only for nonliving words ($F(1,14) = 13.512, p < .01$). Only the repetition $\times$ electrode site interaction was found to be significant in the older

group [$F(1,14) = 4.891, p < .01, \eta_p^2 = 0.259$]. These results reflected that an increased LPC was consistently produced by repetition of either living words or nonliving words in the older group, whereas only a decreased LPC was produced by repetition of nonliving words in the young group. Visual inspection also showed latency shift for the nonliving words from the first presentation to the repeated presentation at lag1. To examine this, the peak latencies detected between 550ms and 900ms from all 18 electrode sites were submitted to repeated-measures ANOVAs with repetition, animacy, electrode site and group, which gave rise to significant interactions of repetition $\times$ animacy [$F(1, 28) = 4.993, p < .05, \eta_p^2 = 0.151$] and repetition $\times$ animacy $\times$ electrode site [$F(17, 476) = 2.680, p < .05, \eta_p^2 = 0.087$]. Simple effects analysis found significant effect of Repetition only on nonliving words [$F(1, 28) = 4.51, p < .05$], in keeping with the observation that LPC latency of nonliving words was reliable larger for the first presentation than the repeated presentation at lag1. The absence of any significant effect of group suggested no age effect.

The subsequent ANOVAs on lag6 only showed a main effect of condition [$F(1,28) = 10.037, p < .01, \eta_p^2 = 0.264$] and an interaction of condition $\times$ electrode site [$F(17,476) = 3.761, p < .01, \epsilon = 0.247, \eta_p^2 = 0.118$]. The subsequent ANOVAs on lag9 also showed a condition $\times$ electrode site interaction [$F(17,476) = 2.522, p < .05, \eta_p^2 = 0.083, \epsilon = 0.264$]. Neither case provided any evidence of reliable group or animacy effects (all $ps > .05$).

3 Discussion

3.1 Repetition effect

In line with previous findings and our prediction, the direction of repetition-induced LPC changes in the younger participants was influenced by lag; LPC was decreased with repetition on nonliving words in lag 1, unchanged on the living words in lag 1, and increased in all other lags. Note that, in addition to lag, we also found the animacy to affect the change direction of LPC. The reason for this was that, word initial activation level was a crucial factor to the direction of repetition-induced LPC changes, and nonliving words were associated with greater initial activation level than living words. The following evidence supported the greater activation level of nonliving words. First, according to the logogentype model, faster responses associated with the repeated words were due to the activation of the initial presentation of words (Morton, 1969). Thus, the larger RT repetition effect for nonliving than for living words in our behavior data implied higher activation of nonliving words relative to living words. Second, Figure 5 suggested living/nonliving differences for the non-repeated words and showed that the nonliving words elicited larger semantic incongruity-related N400 [$F(1,28) = 9.207, p < .01$] and a slower decision-related P300 [$F(1,28) = 16.871, p < .001$]. Our task instruction might be responsible for this difference imposed on nonliving words. Unlike instructions like “Whether this word describe a living object or a nonliving object?” we used such instructions as “Does this word describe a living object? If it is true, press Yes; if not, press No.”, which essentially created “non_targets” status for nonliving words. The subjects were supposed to pay more attention on living features and would respond as “no” after when they sought for living features on nonliving items. The slower RT and slower decision-related P300 of nonliving words led support to

the non-target status of the nonliving words compared with the living words. This manipulation also imposing partial expectations and/or attentions in advance on the living features would create a kind of ‘conflict/incongruity’ in seeing a nonliving item, because the nonliving item was incongruous in this instruction context, which would produce larger semantic incongruity-related N400.

Our hypothesis that higher word activation could be critical for repetition-induced LPC attenuation was confirmed by a line of context-based repetition studies. In these studies, semantic context was usually used to increase word activation and repetition-induced LPC decrement was found even at longer lags. For example, Van Petten et al. (1991) had participants read short texts for comprehension, recorded the consequences of the repetition, and compared the ERP responses to new versus repeated words. Olichney et al. (2000, 2002, 2006, 2007) adopted semantic context plus a target noun complex (e.g. ‘a kind of red fruit – apple’) and required participants to read the category statement aloud, say the target word, and indicate whether it was an exemplar of the defined category. Both these context-based studies found LPC decrement in longer lags (e.g. lags of 10–13 items) because of the higher word activation level.

Our results led support to the proposal that LPC indexes the updating of working memory with information retrieved from long-term memory (LTM). According to the account, if the words were still activated in working memory when they recurred, the LPC would be attenuated as no additional retrieval would be required. In other word, if word activation level upon its second presentation was high enough, a LPC magnitude decrement may be observed. The word activation upon its second presentation is determined by both the activation level of its initial presentation (e.g. words’ activation levels) and the maintenance (e.g. the rate of memory decay increased with repetition lag). Therefore, if the initial words had higher activation level or were repeated with a short-enough lag, the probability of retrieval from long term memory upon their subsequent presentations being necessary will be decreased and hence a reduced LPC would be observed. This reduced LPC observed might reflect the automatic activation and maintenance of previous episode in short-term working memory system (WM). Meanwhile, an increased LPC occurred in lower activation conditions (e.g. lag1 living; lag6; lag9) might reflect implicit retrieval from long-term episodic memory system (LTM), since additional retrieval would be required. This was confirmed by one main finding of the present study that both lag and word activation level influenced the direction of repetition-induced LPC changes.

3.2 Age effect

It has been suggested that both the N400 and LPC repetition effects were generally insensitive to increasing age in incidental repetition paradigms (Frienman et al., 1992; Karayanidis et al., 1993). In marked contrast to prior studies, we observed age effects on repetition in two distinct but complementary ways. One approach involved comparing individual differences in different age groups; the other compared the magnitude of repetition effect in each age group.

First, while the direction of LPC repetition effect (decrease or increase) changed as a combined function of lag and word activation in a successive manner in younger adults, the

direction of LPC repetition effect remained invariable in the older adults and resembled younger adults' longer lag condition. Furthermore, significant age-related LPC repetition differences were revealed only with one intervening word lag for nonliving words. In this condition (lag=1, nonliving), the LPC repetition effect differed between the two groups in three aspects. First, its change direction was opposite in that for older adults repeated words produced an increased LPC, but for younger adults a decreased LPC was observed. For the younger adults, the semantic representation activated by the first occurrence of a nonliving word was still activated at the reoccurrence only after one intervening word, and therefore lower retrieval demand was required. For the older adults, the reason for the older adults still elicited enhanced LPC might be that, the ability of keeping the word representation activated for even a short time (lag=1) were disrupted and additional retrieval was necessary to perform at a level comparable to the younger adults.

Both semantic activation and short-term maintenance determined the ability of keeping the word representation activated for a relatively short time. Thus, possible sources for the observed age-related difference include changes in activation and short-term maintenance. To test whether the word activation was intact in the older adults, we examined the semantic N400 effect in both groups and found that nonliving words elicited a larger N400 than living words in the absence of age differences. This result suggested that the semantic N400 effect was unaffected in the older adults. Because this preserved semantic processing may imply a lack of qualitative mental encoding change, we suggest that the age-related LPC repetition effect difference might be more likely to result from faster memory trace decay in older adults. In other words, the age-related LPC repetition effect difference reflected declining short-term memory maintenance rather than declining activation among elderly adults.

Second, there was a reliable latency shift such that the ERP to repeated words peaked earlier relative to their first presentation only in the younger adults. For this group, the automatic activation and maintenance of mental representation occurred earlier than retrieval, resulting in shorter latency in the condition (lag=1, nonliving) in which the retrieval demand was minimized relative to other conditions where retrieval normally occurred. However, the lack of lag $\times$ animacy $\times$ repetition RT interaction from the behavioral data made it difficult to entirely support this hypothesis. The RT difference between nonliving words and living words being largest at lag1 suggested qualitative differences in nonliving and living word repetition at lag 1.

According to our proposal, the processes engaged in repetition under high word activation conditions and low word activation conditions differ in the degree to which they rely on WM (short-term activation and maintenance) and LTM (implicit retrieval). Because implicit retrieval was usually thought preserved in older adults whereas working memory was more affected by aging than other cognitive function, qualitative differences were observed in the case where working memory was most responsible for the phenomenon observed (i.e. lag1 nonliving). For the young adults, the semantic representation activated by the first occurrence of nonliving was still activated at the reoccurrence only after one intervening word, and no additional implicit retrieval was required. It was probable that for the old adults, this short-term maintenance in WM was affected and additional implicit retrieval was

involved as a kind of compensation to gain comparable behavioral performance with the young adults.

We observed decreased LPC for only one condition (lag=1, nonliving) and only for the younger adults. However, Olichney et al. (2000, 2002, 2006, 2007) reported decreased LPC with repetition at all lags (lags of 0–3 items, 10–13 items) in older adults. In such studies, category statements were read aloud followed by a visually-represented target word. Participants were instructed to indicate whether or not it was an exemplar of the defined category by saying “yes” or “no”. Repeated targets appeared with the same category statement as on first presentation. The existence of LPC decrement repetition effects was associated with high word activation level. In their studies, the preceding category statement was also repeated when the target word was repeated, and the repeated predictive context would ensure that the target word was still highly activated at the second presentation. We believe these differences made the activation of targets more salient and less likely to decay in their older participants even after the longer lags used in their study such that a decreased LPC similar to that observed in our younger adults under the highest activating condition (lag=1, nonliving) was observed at all lags in their studies. In addition, their LPC repetition effect was evident primarily on congruous targets which were the right category exemplars of the prior semantic context, much like our nonliving words, both of which were supposed to be highly activated either by using semantically-predictive context or by creating target incongruity.

Note that, two facts would undermine our conclusions and restrict further inference. First, besides nontarget/target status, there were also other subtle differences between nonliving and living words. For example, the living words were more semantically related to each other than the nonliving words and were more likely to have within-list semantic priming, which could confound with the word activation level and weaken the link between word activation level and LPC repetition effect. In addition, the older adults had significant greater RT of nonliving words for the first presentation at lag 1 than other lags, meaning this condition was more difficult for the older adults. This factor of difficulty might confound with the observed repetition effect patterns and corresponding age effects.

4 Methods and materials

4.1 Participants

Fifteen right-handed younger volunteers (mean age 22.9 years, range 20–25, six females) and 15 right-handed elderly volunteers (mean age 67.9 years, range 63–73, seven females) participated. None had prior experience with the task. All participants had normal or corrected-to-normal vision and all reported themselves to be in good physical and mental health and free from psychiatric disorders or medications known to affect the central nervous system. The study was approved by the ethics committees of the Institute of Psychology, Chinese Academy of Sciences. All participants were paid at a rate of RMB 50 CNY/h and gave informed consent before the study. The elderly participants were first given the Mini-Mental State Examination (MMSE) as a screening measure, and a minimum score of 25 was required for inclusion in the study (Folstein et al., 2000). All Participants completed a battery of standardized neuropsychological tests in a separate 1.5-h session

targeting certain cognitive functions involving intelligence, memory, language, visuospatial, and executive function. The groups were matched on years of full-time education, gender, and on WAIS IQ as estimated from the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale (WAIS-R) (Wechsler, 1981). The elderly participants scored significantly lower than the young participants on many measures of neuropsychological function, especially on memory measures such as word-pair recall (immediate, delayed) from Wechsler memory scale (WMS-R) (Wechsler, 1987) and short-story recall (immediate, delayed) from the Clinical Memory Scale (Xu & Wu, 1986) and on executive function measures including the Digital Span subtest of the WAIS-R and Trail Making. Such information is summarized in Table 2.

4.2 Stimuli

The stimuli consisted of 216 concrete two-character Chinese nouns with usage degree ranking (which is calculated based on times of occurrence, distribution in category, and distribution in paragraph) ranging 590–634 and frequency of occurrence (which is the ratio of the occurrence of each word and the total occurrences of all words) ranging 8–59 occurrences per million according to a Chinese language database (Chinese Frequency Dictionary). Half of the words represented living things (e.g. hunter, farmer, peacock, sea gull) and half non-living things (e.g. luggage, plate, gun, cushion). Two word lists of 108 randomly ordered words (54 living and 54 nonliving) were formed with the constraint that the usage degree ranking and frequency of occurrence for both living and nonliving words were balanced between lists. These lists would serve as the ‘repeated’ and ‘non-repeated’ lists during experimentation. From the ‘repeated’ list, three subsets of 36 words were repeated after 1, 6, or 9 intervening word lags. The ‘repeated’ lists and their repetitions were mixed with ‘non-repeated’ list to generate a list of total 324 words. The stimuli were counterbalanced across each condition. In addition, a practice block was constructed using 10 old words and 10 new words (which were used only for practice and did not overlap with the experimental block stimuli) prior to the experiment to ensure that the participants had been prepared for the experiment. Which list served as the old or new list was balanced across participants.

4.3 Procedures

We employed a semantic judgment (i.e., animacy decision) task to which the repetition of words was incidental. Specifically, the instruction was presented as “Does this word describe a living object? If it is true, press Yes; if not, press No ”.

After informed consent was provided, participants were fitted with an electrode cap and seated 1.0 M from a stimulus presentation monitor. All stimuli were presented in black colors on a white background and subtended maximum vertical visual angles of 0.3 degree. Participants were required to respond “Yes” with the index finger of the left hand, if they decided that the word described a living object; if they thought that the word did not describe a living object, they were required to respond “No” with the index finger of the right hand. Assignment of hands to responses was counterbalanced across participants. Each trial began with an asterisk being presented (500ms) followed by a word (maximum duration 5sec). Task timing was self-paced; trials advanced when the participant made a valid

response. If the subject failed to respond within 5sec, the next trial would be triggered automatically. The participants were instructed to respond as quickly and accurately as possible and to fixate throughout. Each participant completed three blocks of the semantic task and took a 1min break between blocks.

4.4 Electrophysiological recording

EEG activity was recorded using a 64-channel amplifier and data acquisition software (Neuroscan 4.3) with centered Ag/AgCl electrodes embedded in an elastic cap from 62 scalp sites in accordance with the international 10–20 system, a 0.05–100Hz bandpass, and 500Hz sampling rate. Vertical eye movement was monitored with electrodes placed above and below the left eye, and horizontal eye movement was monitored with electrodes placed at the outer canthus of each eye. Electrode impedance was kept below 5k Ω . All scalp electrodes with the right mastoid electrode together were referenced on-line to the left mastoid, then re-referenced off-line to an average of the left and the right mastoids.

4.5 EEG data analyses

EEG data were epoched from –100 to 900 ms and baseline-corrected relative to the 100 ms pre-stimulus period. Ocular artifact correction was applied and the EEG epochs were lowpass-filtered at 30 Hz (zero-phase shift filter; 24dB/octave). ERPs were averaged for each subject and each condition. Epochs containing amplitudes exceeding ± 80 μ V on any channel and epochs with incorrect responses were excluded from the averaging. ERPs recorded from 18 electrode sites (Fz, F3, F4, F5, F6, Cz, C3, C4, C5, C6, Pz, P3, P4, P5, P6, POz, PO3, PO4) were submitted to further statistical analysis. The latency regions were 300–550 ms (N400), and 550–900 ms (LPC). All 18 electrodes were included in a single variable (electrode site) in the analysis because our focus was on the changes direction rather than the scalp distribution of the LPC repetition effect, such that we did not make precise inferences about anterior/central/posterior dimension or inferior/mid-lateral/superior dimension.

The Greenhouse-Geisser correction was applied where necessary and Epsilon value (ϵ) for correcting degree of freedom was reported (Greenhouse and Geisser, 1959). The Tukey test was used when a *post hoc* test was required. Two-tailed $P < 0.05$ was considered significant for all analyses.

5 Conclusion

In conclusion, we demonstrated both word activation level of its initial presentation and repetition lag were critical for the direction of repetition-induced LPC changes. These findings support the account of LPC indexing the demands on retrieval from LTM to update working memory. The fact that the older adults failed to manifest LPC decrement repetition effect but preserved their semantic N400 effect reflected that the older adults had difficulties in maintenance rather than initial word activation.

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Figure 1. Grand average waveforms for the nonliving words shown separately for the first presentation and lag 1 repetition from the young and older participants.

Figure 2.
Grand average waveforms for the living words shown separately for the first presentation and lag 1 repetition from the young and older participants.

Figure 3.
Grand average waveforms from Cz electrode of the first presentation, lag 6 repetition and lag 9 repetition from the young and older participants.

Figure 4.

The mean subtraction amplitude by subtracting the ERPs of the nonliving words for the first presentation from those for lag 1 repetition averaged across all (18) electrode sites.

Figure 5. Grand average waveforms from the CPz electrode for the non-repeated words (presented once) shown separately for nonliving and living words from the young and older participants.

Table 1

Mean percentage correct responses and mean reaction time (RT) as a function of presentation for the two age groups (N:nonliving words, Y: living words).

			once		lag=1				lag=6						lag=9			
					first		second		first		second		Y	N	Y	N	Y	N
			N	Y	N	Y	N	Y	N	Y	N	Y	Y	N	Y	N	Y	Y
Accuracy																		
	young	Mean	0.97	0.96	0.96	0.95	0.97	0.97	0.97	0.95	0.97	0.97	0.95	0.97	0.95	0.96	0.94	0.98
		SD	0.03	0.03	0.04	0.06	0.06	0.05	0.04	0.06	0.04	0.04	0.06	0.04	0.07	0.05	0.08	0.03
	old	Mean	0.96	0.96	0.97	0.99	0.95	0.96	0.96	0.96	0.94	0.94	0.96	0.94	0.97	0.97	0.96	0.97
		SD	0.04	0.04	0.05	0.03	0.06	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.04	0.05	0.03	0.04
RTs (ms)																		
	young	Mean	749	688	779	663	705	627	753	685	703	644	756	682	702	653	702	653
		SD	148.5	129.3	150.4	108.6	142.5	92.4	143.4	130	130.7	93.1	129.1	106	116.3	105.6	106	105.6
	old	Mean	930	825	980	819	881	773	934	821	880	807	915	847	891	807	847	807
		SD	290.9	221.8	341.7	235.3	227.2	202.9	272.2	214.1	259.3	230.4	295	217.4	291.1	219.0	217.4	219.0

Table 2

Demographic and neuropsychological test measures for the two groups.

Measure	Young(N=15) M±SD	Old(N=15) M±SD	p ^a	
Age (years)		22.9±1.7	67.9±3.1	***
Gender (% female)		6/15	7/15	
Education (years)	14.7±2.4	14.7±1.4		
Global	MMSE	na	28.6±1.3	
Intelligence	WAIS vocabulary	67.5±6.0	63.2±6.4	
	WAIS block design	45.8±2.7	33.6±7.0	*
	WAIS verbal IQ	113.7±5.4	118.9±5.5	*
	WAIS performance IQ	119.1±3.7	112.0±8.8	*
	WAIS IQ	114.2±7.1	117.1±6.1	
Memory	Word pairs immediate recall	5.9±1.2	4.1±1.3	**
	Word pairs delay recall	5.6±1.4	3.6±1.3	**
	Story immediate recall	14.4±5.0	10.0±3.7	
	Story delay recall	12.7±5.0	8.1±3.0	
Language	Write fluency	23.5±6.4	14.6±3.1	***
	Category fluency	50.5±12.4	50.9±15.6	
Visuospatial	Trail making A	27.9±6.8	52.7±19.7	***
Executive Function	Trail making B-A	10.0±5.0	27.6±17.0	**
	WAIS digital span	16.3±2.8	12.7±1.1	***

Note.

 $p < 0.001$,**
 $p < 0.01$,*
 $p < 0.05$;

na= not administered. Writing fluency score was the total number of characters with specific radical components (讠, 讠) the subjects could produce in 120 s.⁵ Category fluency score was the total number of words in 60 seconds for each category (food, animal) subjects could produce.

^aIndependent samples t test.