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Testing a Distinctiveness Explanation of the Primacy Effect in Free Recall Using Event-Related Potentials

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Abstract

The primacy effect in free recall is commonly attributed to more frequent rehearsals for stimuli in the first few serial positions. Using event-related potentials (ERPs), we investigated whether the first list position also provides a distinctive feature to the stimulus, which enhances its encoding and aids retrieval on a recall test. The amplitude of the *P300* elicited by stimuli that deviate physically or semantically from their context has previously been shown to correlate with the probability of later recall when participants use rote rehearsal. We reasoned that if the temporal distinctiveness of the first item in a list contributes to its enhanced recall, such a P300 subsequent memory effect should be present for this item as well. Participants studied and immediately recalled lists of 15 words including one physically deviant "isolate" while their EEG was recorded. We quantified P300 amplitude by a principal component analysis, and applied a correction for inter-trial latency jitter. The first words in a list and isolates were better recalled than regular words in the middle list positions, and the P300 elicited by these words was correlated with subsequent recall. Regular words in the middle list positions, as well as words in the second list position, did not show such a P300 subsequent memory effect. These results support a distinctiveness-based explanation of the primacy effect in free recall.

Keywords: Primacy effect; event-related potentials; free recall; P300; subsequent memory effect.

Introduction

We tested the hypothesis that items in the first serial position of a study list are distinctive, which accounts for the primacy effect in free recall. We used the P300 event-related potential (ERP) as an index of distinctiveness. Prior studies have shown that under rote rehearsal the amplitude of the P300 elicited by physically or semantically deviant study items is correlated with later recall success (Fabiani & Donchin, 1995; Fabiani, Karis & Donchin, 1990; Karis, Fabiani & Donchin, 1984). We investigated whether this same effect is also observed for the first list item, which would support a distinctiveness-based explanation of the primacy effect in free recall.

The term "primacy effect" refers to the increased probability of free recall of the first few, compared to the middle items within a study list. The most influential explanation for this effect attributes it to more frequent rehearsals of primacy items (e.g., Rundus, 1971). However, some data indicate that part of the recall enhancement for the first item (at least when it is also the first item retrieved) cannot be explained by rehearsal frequency (e.g., Howard & Kahana, 2002). The first item is also at a unique list position that may make this item stand out. Therefore, the distinctiveness of the first item may contribute to its greater probability of recall success (e.g., Brown, Neath & Chater, 2007).

One difficulty in testing distinctiveness-based explanations of behavioral phenomena lies in the fact that "distinctiveness" refers to a subjective experience rather than a physical property of an object (Hunt, 2006). Therefore, it is essential to find a measure of distinctiveness that is independent of the enhanced recall. To this end, a neural index of perceived distinctiveness is the P300 component of the ERP (Sutton, Braren, Zubrin & John, 1965), which peaks between 300 and 700 ms after the presentation of stimuli that are rare, unexpected, as well as task-relevant (for a review see Donchin, 1981). The *context updating model* (Donchin, 1981; Donchin & Coles, 1988) associates P300 amplitude with the degree to which novel information conflicts with expectations derived from a mental schema; information thus registered as unexpected, or distinctive, is then incorporated to update the schema. Since this process occurs interactively with information in long-term memory, this theory closely relates the P300 to memory processes.

To the extent that P300 indexes distinctiveness, the results of Ritter, Vaughan and Costa (1968) support the idea that stimuli at the beginning of a sequence are distinctive when their onset is unpredictable. They showed that, in addition to physically deviant stimuli, only the first stimulus in a monotonous sequence elicited a P300. By contrast, the second stimulus and all subsequent stimuli that did not stand out from the sequence, did not elicit a P300.

Items that stand out from their study list are more likely to be recalled than non-distinctive items (Von Restorff, 1933). Several studies have shown that when participants use rote rehearsal, physically distinctive words that elicit larger P300 amplitudes are more likely to be recalled on a later free recall test (Fabiani & Donchin, 1995; Fabiani et al. 1990; Karis et al. 1984; Otten & Donchin, 2000). Since the variance in P300 amplitude and the variance in recall probability are correlated, the enhancing effects of distinctiveness on recall can be indexed by this correlation.

The design used in these studies, as well as in the present study, is known as the *subsequent memory paradigm*. Participants view several study items while their brain activity is recorded and later complete a memory test. Then, their brain activity is sorted according to the degree to which items were subsequently remembered (the *subsequent memory effect*, for a review see Paller & Wagner, 2002).

Previous studies examining primacy subsequent memory effects using the P300 have yielded inconsistent results. Azizian and Polich (2007) reported that P300 amplitude elicited by words in the initial list positions was correlated with recall; however the authors collapsed ERPs across the first three list positions – a disadvantage from the standpoint of our hypothesis that P300 amplitude will be correlated with recall only for position 1. By contrast, Wiswede, Ruesseler and Muente (2007) reported that although the first word elicited a P300, there was a P300 subsequent memory effect only for the *final* study words. A problem with this study is that only 11 out of 18 participants showed a primacy effect; a subsequent memory effect may have been obtained if the behavioral effect was more reliable. A third study found only a small primacy effect and no P300 subsequent memory effects for either primacy or recency positions (Rushby, Barry & Johnstone, 2002). This study, however, averaged over 5 consecutive list positions, again preventing conclusions about the first item only.

All three studies ignored the possibility that P300 latency may have varied between trials and participants - as their broad ERP waveforms suggest. Since such *latency jitter* can reduce average ERP amplitudes, a correction allows for more meaningful comparisons between conditions (e.g., Spencer, Abad, & Donchin, 2000). A further shortcoming is that all studies used mean- or peak amplitude measures to quantify the P300, which are not able to disentangle overlapping ERP components. Finally, no study included a manipulation known to elicit a P300, such as the isolation of a word by its font size; such a manipulation would allow for a direct comparison of subsequent memory effects for the first list position and isolates.

Some support for the idea that primacy items may show a P300 subsequent memory effect comes from an fMRI study in which the first list items elicited stronger activity in brain areas known to generate the P300 (the temporoparietal junction) when these words were later successfully retrieved in an associative recall test (Sommer, et al., 2006). However, fMRI has a lower temporal resolution than ERPs and the design differed from typical free recall studies, so our distinctiveness hypothesis remains to be tested.

We addressed the shortcomings of the prior ERP studies by including a physical "isolate" in each list, by applying a principal component analysis (PCA), and by correcting for latency jitter. We hypothesized that, similar to the isolates, words in list position 1 are distinctive and therefore elicit a P300, which will be larger for those words that are later successfully recalled, compared to forgotten items.

Methods

For this study we combined data from two experiments, each employing 20 critical lists (i.e., lists of interest for the present analysis) randomly interspersed with other list types. Each list was presented as part of a study-recall sequence. Critical lists consisted of 15 words, including one physically deviant word (see below). In one study, lists that varied in word frequency (n=23) were randomly interspersed with the critical lists; in the other study, word lists of varied emotional content were employed (n=22). Here, we only report data from the critical list type. A comparison of the recall- and ERP data ensured that there were no differences between the samples.

Participants. Fourty five college students participated in exchange for course credit (n=33) or $7 per hour (n=12). The data from 14 participants were excluded from the analysis due to excessive artifacts in their EEG[1], and one participant was excluded due to non-compliance with the instructions. The remaining 22 female and 8 male participants were between 18 and 45 years old (M=22.57). All participants gave written informed consent, and all procedures were approved by the institutional review board.

Stimuli. Each study list contained 15 words, presented one at a time in white 16 pt font of Arial Unicode style, on a black screen. Stimuli included emotionally neutral nouns, verbs and adjectives with a word frequency of 11-50 per million according to Francis & Kucera (1982), and were between 3 and 8 letters long. The composition of each list and the order of words within a list were randomized, and no word was presented to the same participant twice. Words were presented for 250ms, followed by a fixation cross for 2s. Each critical list contained an "isolate" in a larger font size (24 pt), which was randomly placed between serial positions 6 and 10. After the last word of each list, a grey triangle appeared indicating the start of the recall phase.

Procedure. The experiment consisted of two sessions, each up to 2 1/2 hours long. Over the course of the two sessions, participants studied a total of 70 (exp 1) or 80 (exp 2) word lists, including 20 critical lists. The first session also contained 2 practice lists. After the preparations for the EEG recording, participants were seated at a distance of 60cm from the computer screen and instructed to memorize the words using rote rehearsal. After each list, participants wrote down every word they remembered in any order. Recall lasted at least 45s, but participants were allowed to write down words for as long as they wished. Participants initiated the start of the next list with a button press and breaks were allowed after sets of 4 lists. After the second session participants were debriefed about their encoding strategies.

[1] The high number of participants excluded due to artifacts was due to frequent movement artifacts at the beginning of the lists, possibly because participants were still getting comfortable.

EEG Recording and Analysis. The EEG was recorded with a 128 channel Electrical Geodesics, Inc. (EGI) system, digitized with a sampling rate of 250 Hz and referenced to electrode Cz. For all off-line analysis we used NetStation (EGI) software, the EEGlab toolbox (Delorme & Makeig, 2004), J. Dien's EP toolkit (Dien, 2010), as well as self-written MATLAB scripts. The data were low-pass filtered at 20 Hz and segmented into epochs of 400 ms before to 2000 ms after word onset. Segments were corrected for eye blink artifacts using independent component analysis. Segments still containing artifacts were excluded and the data were mathematically re-referenced to linked mastoids and baseline corrected for a time window of 400 ms before the stimulus. We computed ERPs separately for regular words in serial positions 6-10 (henceforth referred to as "standards"), words in a larger font size ("isolates"), and for words in serial positions 1, 2, and 3.

Principal Component Analysis (PCA). To quantify ERP amplitudes, we conducted a spatio-temporal PCA (Spencer, Dien & Donchin, 1999). This approach has been widely used as temporal PCA (Donchin, 1966; Donchin & Heffley, 1978) in the analysis of ERP data. With the advent of dense electrode array EEG recordings, spatial PCA was developed to identify ERP component's spatial distributions (Spencer, Dien & Donchin, 1999); this is then followed by a temporal PCA to identify time courses. The PCA approach allows parsing of the ERP into components and yields measures of component amplitudes (factor scores) that can be used for testing hypotheses.

Submitted to the PCA were the ERP averages of isolates, standards (list positions 6-10), and words in positions 1, 2, and 3. We rotated 15 factors, as identified by a scree test (Cattell, 1966), using the Promax rotation method (e.g., Dien, Beal & Berg, 2005). The factor score coefficients of the PCA factor corresponding to the P300 were then applied to each EEG trial to calculate "virtual ERPs" (factor scores plotted across the time points; Spencer et al., 1999).

Since the broad peaks of the virtual ERPs indicated that P300 latency varied between trials, they were corrected for latency-jitter using a cross-correlation technique (see Gratton, Kramer, Coles & Donchin, 1989, for a review of this and other jitter correction techniques). The grand average P300 virtual ERP was used as a template, which was cross-correlated with every trial. The point of maximal cross correlation was then used to determine a lag to shift this trial, with the restriction that the P300 peak had to lie within 450 and 750ms after word onset. Each trial was baseline corrected again for 200ms, and the average over the latency corrected trials was computed for each word type and recalled and not recalled words. Since isolates and words in positions 1-2 had low trial numbers and since the number of trials included in an ERP average can affect ERP amplitudes, we matched the recalled and not recalled categories for trial number by randomly selecting the same number of trials. This resulted in an average of 5 trials contributing to the recalled- and the not recalled isolates, and an average of 4.8 and 4.6 trials for the recalled- and not recalled words in positions 1 and 2, respectively.

Finally, we quantified P300 amplitude by applying a temporal PCA on the jitter-corrected virtual ERPs to obtain a single factor score for each participant, word type, and for recalled and not recalled words. In the temporal PCA we rotated 15 factors with the Promax technique.

Statistical Analysis. Since the data violated the assumption of sphericity necessary for repeated measures ANOVA, we conducted a MANOVA on the recall rates for words in position 1, standards and isolates; as well as a 2x4 MANOVA on the P300 amplitudes (as quantified by the factor scores) testing for differences between word types (isolates, standards, position 1 and position 2), and recalled and not recalled words. Words from position 3 were not included in the statistical analysis since the ERPs showed the same pattern as position 2, and since one participant had no artifact-free trials for the "position 3/recalled" category.

Results

Behavioral Data. The debriefing confirmed that most participants had used a rote memorization strategy. This was supported by the serial position curve (figure 1),which showed the typical shape, with a primacy effect for the first three to four serial positions and a recency effect over the last five serial positions.

Recall rates differed between words at serial position 1, isolates, and standards [Wilk's Lambda=.14, $F(2,28)=87.07$, $p<.01$]. Paired samples t-tests showed that recall for words in list position 1 was superior to recall for both standards, $t(29)=8.46$, $p<.01$, and isolates, $t(29)=2.41$, $p<.05$, while isolates were recalled with a higher probability than standards, $t(29)=8.18$, $p<.01$. All but 4 participants showed superior recall for words in position 1 and all but 3 participants (a different set then the aforementioned 4) showed superior recall for isolates, compared to standards.

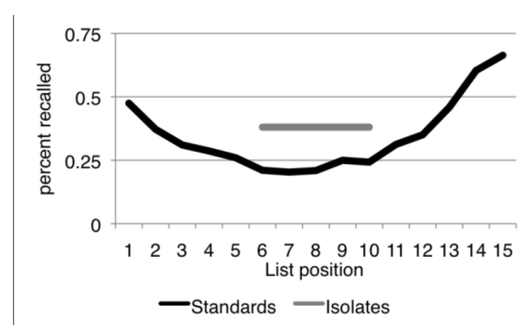

Figure 1. Serial position curve for regular-sized words ("standards"), and isolates. Note: percent recalled for isolates is averaged across positions 6-10.

Event-Related Potentials. The spatial PCA solution accounted for a total of 85% of the variance in the data. Based on its parietal distribution, the fourth spatial factor was identified as the P300. Figure 2a displays the loadings of this factor, which accounted for 7% of the total variance.

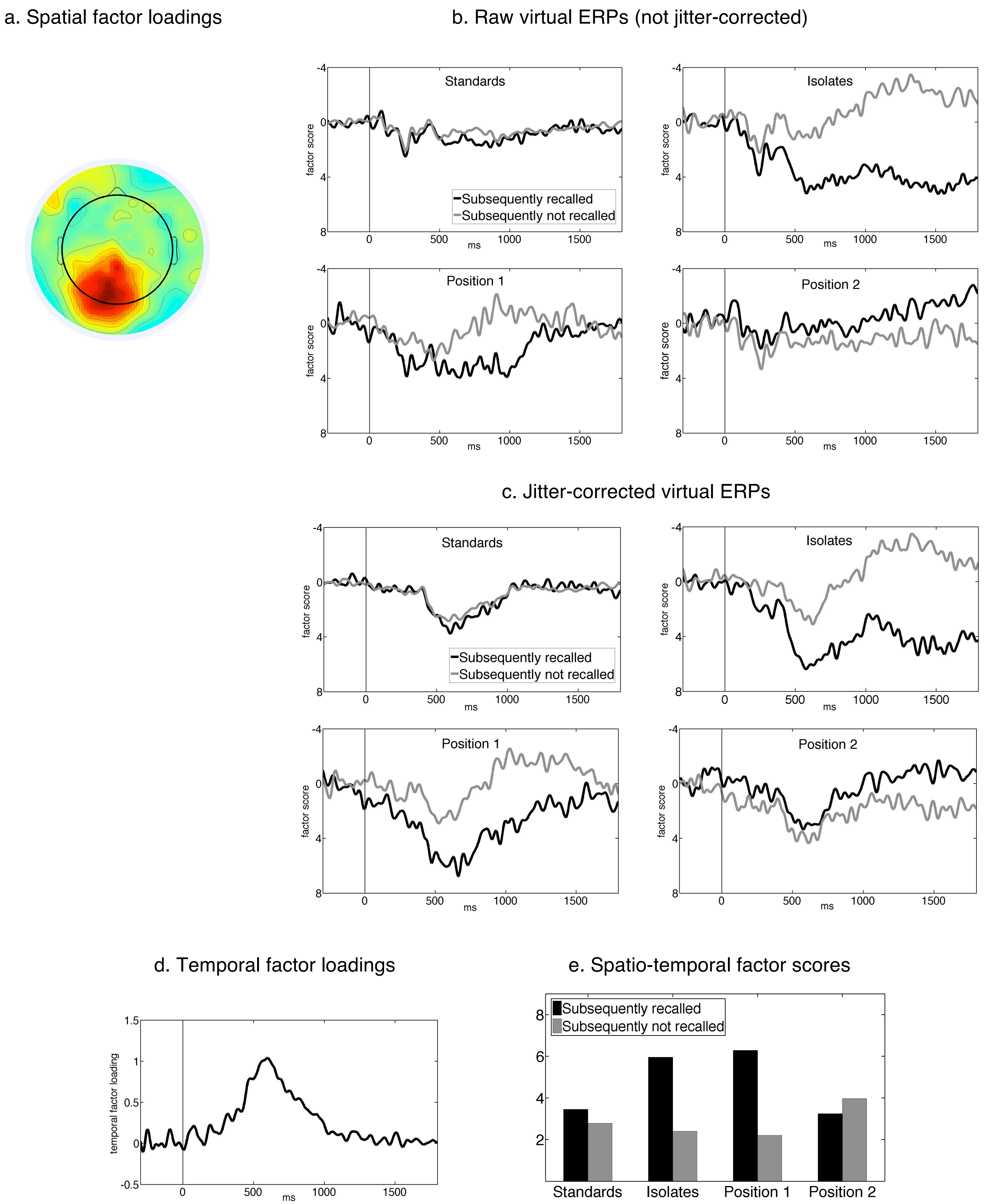

Figure 2. P300 PCA factor. a. Spatial factor 4; loadings over all 128 electrodes. b. Virtual ERPs for standards, isolates, and words in serial position 1 and 2 by subsequent recall. c. Latency-jitter corrected virtual ERPs. d. Temporal factor 2; loadings over all time points. e. Factor scores, indexing P300 amplitude, by word type and subsequent recall.

Figure 2b shows the raw virtual ERPs of the P300 factor by word type and subsequent recall. The P300 peaked between 500 and 700 ms after word onset. The broad peaks for isolates and words in position 1 strongly suggest the presence of latency jitter. The latency jitter corrected virtual ERPs are displayed in figure 2c. A comparison of figures 2b and 2c indicates that the jitter correction was successful, producing narrower peaks and higher amplitudes. Note that it is not unusual that even standards and words in position 2 now exhibit a small positivity, since the algorithm picks the point of maximal cross-correlation, and thus tends to bias the jitter-corrected average towards the template. It is also important to note that the direction of the difference between recalled and not recalled words was not changed by the jitter correction for any word type.

The second temporal factor, which accounted for 14% of the variance of the P300 virtual ERPs, lined up with the P300 peak and was therefore identified as the temporal P300 factor. Temporal factor loadings are displayed in figure 2c. Figure 2d shows the mean spatio-temporal factor scores, as a measure of P300 amplitude, for the four word types and for recalled and not recalled words.

The 2x4 MANOVA revealed that P300 amplitude differed between later recalled and not recalled items, Wilk's Lambda=.66, $F(1,29)=14.77$, $p<.01$, which was qualified by an interaction between word type and recall success, Wilk's Lambda=.64, $F(3,27)=4.98$, $p<.01$. There was no main effect for word type, Wilk's Lambda=.93, $F(3,27)=63$, *ns.* Critically, subsequent paired samples t-tests revealed a significant difference in P300 amplitude between recalled and not recalled words for isolates, $t(29)=2.28$, $p<.05$, and words in position 1, $t(29)=3.09$, $p<.01$, but not for standards, $t(29)=1.21$, *ns*, or words in position 2, $t(29)=-.8$, *ns*.[1]

To test whether overall, isolates and words in position 1 elicited a larger P300 than the other word types, we conducted planned comparisons between the combined P300 amplitude values of isolates and position 1; and the combination of standards and position 2, separately for recalled and not recalled words. Although for both recalled and not recalled words, isolates and words in position 1 elicited larger P300 amplitudes than the other word types, the difference only reached significance for the recalled words, $t(29)=2.7$, $p<.05$.

Discussion

We found a correlation of P300 amplitude with subsequent recall for isolates, replicating prior studies (e.g., Karis et al., 1984). Critically, the analogous subsequent memory effect was evident for items in the first list position. Words in the middle- and the second list positions, by contrast, did not show this pattern. Since the P300 subsequent memory effect indexes the enhancing effects of item distinctiveness on recall, our results support the hypothesis that the first serial position provides a distinctive feature to the stimulus, thus enhancing encoding and aiding later retrieval.

Although Azizian and Polich (2007) reported a P300 subsequent memory effect for the first list positions, our study provides stronger support for the distinctiveness hypothesis of the primacy effect. First, our data indicate that the P300 subsequent memory effect is only present for the first word, suggesting that temporal distinctiveness does not extend to later serial positions. Second, by using PCA we were able to disentangle the P300 from other overlapping components. Furthermore, our latency-jitter correction insured that (1) differences between item types were not due to differences in P300 latency variability and (2) any true differences were not obscured by latency jitter, as may have been true in Wiswede et al. (2007) and Rushby et al. (2002). Finally, we were able to directly compare the subsequent memory effects for physical isolates and words in position 1, and these showed remarkable similarities (figure 2c).

Our distinctiveness explanation does not contradict the well-supported idea that rehearsal frequency accounts for the primacy effect (e.g., Rundus, 1971). Indeed, items at the first list position showed higher recall than the isolates, suggesting that item distinctiveness may not be the only factor enhancing recall of the first item. Recall was also enhanced for positions 2 and 3 (figure 1), which did not show a P300 subsequent memory effect. Therefore, we suggest that the temporal distinctiveness of the first item *adds* to the recall advantage by enhancing encoding and/or providing a distinctive retrieval cue. Further studies are necessary to investigate whether the effects of rehearsal frequency and distinctiveness are additive or synergistic.

Note that the P300 only indexes distinctiveness to the extent that the participant registers the distinctive feature at the time of stimulus encounter. It cannot index other conceptualizations of distinctiveness, such as distinctiveness of the first item due to the relatively early output position during recall (cf., Brown et al., 2007).

We did not have enough trials in the "position 15/not recalled" category to conduct a subsequent memory analysis for the recency positions. However, the last list item may also be perceived as distinctive, and therefore future studies should focus on such an analysis. Finally, an analysis of the relationship between individual differences in P300 amplitude and the behavioral effects was beyond the scope of this paper, but will be investigated in the future.

In conclusion, our study provides psychophysiological evidence for the hypothesis that the primacy effect in free recall is in part due to the enhancing effect of the first item's distinctiveness on recall. Our analysis focused only on the P300, but future studies will also be focused on the interaction of serial position effects with frontal slow wave subsequent memory effects, which are thought to index

[1] A supplementary analysis on the mean amplitudes of the raw ERPs between 500 to 700 ms at two parietal electrodes revealed the same patterns of results, with the exception that the subsequent memory effect for position 1 only approached significance ($p=.11$). This may be due a decreased power for this comparison due to latency jitter.

working memory processes that support between-item elaborative encoding (e.g., Fabiani & Donchin, 1995).

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References

Azizian, A., & Polich, J. (2007). Evidence for Attentional Gradient in the Serial Position Memory Curve from Event-Related Potentials. *Journal of Cognitive Neuroscience, 19*(12), 2071-2081.

Brown, G. D., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. *Psychological Review, 114*(3), 539-576.

Cattell, R. B. (1966). The Scree Test for the number of factors. *Multivariate Behavioral Research, 1*(2), 245-276.

Delorme, A., & Makeig, S. (2004). EEGlab: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134,* 9-21.

Dien, J. (2010). The ERP PCA toolkit: An open source program for advanced statistical analysis of event-related potential data. *Journal of Neuroscience Methods, 187*(1), 138-145.

Dien, J., Beal, D. J., & Berg, P. (2005). Optimizing principal component analysis of event-related potentials: Matrix type, factor loading weighting, extraction and rotations. *Clinical Neurophysiology, 166,* 1808-1825.

Donchin, E. (1966). A multivariate approach to the analysis of average evoked potentials. *IEEE Transactions on Bio-Medical Engineering*, *BME-13*, 131-139.

Donchin, E. (1981). Surprise! ... Surprise? *Psychophysiology, 18*(5), 493-513.

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral Brain Science, 11,* 357-374.

Donchin, E., & Heffley, E. (1978). Multivariate analysis of event-related potential data: A tutorial review. In D. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (555-572). Washington, D.C.: U.S. Government Printing Office.

Fabiani, M., & Donchin, E. (1995). Encoding processes and memory organization: a model of the von Restorff effect. *J Exp Psychol Learn Mem Cogn, 21*(1), 224 - 240.

Fabiani, M., Karis, D., & Donchin, E. (1990). Effects of mnemonic strategy manipulation in a Von Restorff paradigm. *Electroencephalogr Clin Neurophysiol, 75*(2), 22 - 35.

Francis, W., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar.* Boston, MA: Houghton Mifflin.

Gratton, G., Kramer, A. F., Coles, M. G. H., & Donchin (1989). Simulation studies of latency measures of the event-related brain potential. *Psychophysiology, 26*(2), 233-248.

Howard, M. W., & Kahana, M. J. (2002). A distributed representation of temporal context. *Journal of Mathematical Psychology, 46*(3), 269-299.

Hunt, R. R. (2006). The concept of distinctiveness in memory research. In: R. R. Hunt, & J. B. Worthen (Eds.), *Distinctiveness and memory* (pp. 3-26). New York: Oxford University Press

Karis, D., Fabiani, M., & Donchin, E. (1984). "P300" and memory: Individual differences in the von Restorff effect. *Cognitive Psychology, 16*(2), 177 - 216.

Otten, L. J., & Donchin, E. (2000). Relationship between P300 amplitude and subsequent recall for distinctive events: Dependence on type of distinctiveness attribute. *Psychophysiology, 37*, 644-661.

Paller, K. A., & Wagner, A. D. (2002). Observing the transformation of experience into memory. *TRENDS in Cognitive Sciences, 6*(2), 93-102.

Ritter, W., Vaughan, H. G., & Costa, L. D. (1968). Orienting and habituation to auditory stimuli: A study of short term changes in average evoked responses. *Electroencephalography and clinical Neurophysiology, 25,* 550-556.

Rundus, D. (1971). Analysis of rehearsal procedures in free recall. *Journal of Experimental Psychology, 89*(1), 63-77.

Rushby, J. A., Barry, R. J., & Johnstone, S. J. (2002). Event-related potential correlates of serial-position effects during an elaborative memory test. *International Journal of Psychophysiology, 46*(1), 13-27.

Sommer, T., Rose, M., & Buechel, C. (2006). Dissociable parietal systems for primacy and subsequent memory effects. *Neurobiology of Learning and Memory, 85*(3), 243-251.

Spencer, K. M., Abad, E. V., & Donchin, E. (2000). On the search for the neurophysiological manifestation of recollective experience. *Psychophysiology, 37,* 494-506.

Spencer, K. M., Dien, J., & Donchin, E. (1999). A componential analysis of the ERP elicited by novel events using a dense electrode array. *Psychophysiology, 36,* 409-414.

Squires, K., Wickens, C., Squires, N., & Donchin, E. (1976). The effect of stimulus sequence on the waveform of the cortical event-related potential. *Science, 193*(4258), 1142-1146. doi: 10.1126/science.959831

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-Potential Correlates of Stimulus Uncertainty. *Science, 150*(3700), 1187-1188.

Von Restorff, H. (1933). Über die Wirkung von Bereichsbildungen im Spurenfeld. *Psychologische Forschung, 18*, 299-342.

Wickens, C., Kramer, A., Vanasse, L., & Donchin (1083). Performance of concurrent tasks: A psychophysiological analysis of the reciprocity of information-processing resources. *Science, 221*(4615), 1080-1082.

Wiswede, D., Rüsseler, J., & Münte, T. F. (2007). Serial position effects in free memory recall -- an ERP study. *Biological Psychology, 75*, 185-193.