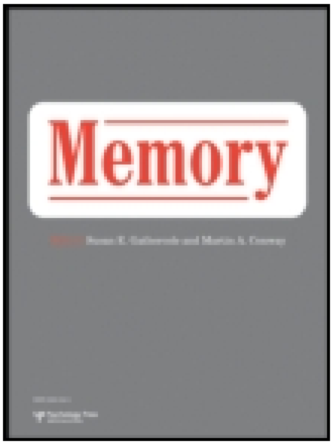

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Inter- and intra-individual variation in immediate free recall: An examination of serial position functions and recall initiation strategies

Nash Unsworth [a], Gene A. Brewer [a] & Gregory J. Spillers [a]
[a] Department of Psychology, University of Georgia, Athens, GA, USA
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Inter- and intra-individual variation in immediate free recall: An examination of serial position functions and recall initiation strategies

Nash Unsworth, Gene A. Brewer, and Gregory J. Spillers

Department of Psychology, University of Georgia, Athens, GA, USA

Serial position functions in immediate free recall have been historically noted for their bowed shape, where items presented at the beginning (primacy) and end (recency) of a list are better remembered than those presented in the middle. While extensive work has examined these effects, researchers typically ignore the systematic differences among individuals that likely contribute, but are lost when using an aggregate function. In the current study, inter- and intra-individual differences in serial position functions and differences in recall strategies were examined. Participants performed a free recall task on multiple lists. Three groups of participants were derived based on the relative profiles in their serial position functions. These groups differed in the extent that they output mainly primacy items, recency items, or both primacy and recency items. Performance on immediate free recall and on cognitive ability tasks was compared between these three groups. Systematic inter- and intra-individual variation in recall strategies led to differential profiles of performance in immediate free recall, which was also related to the additional cognitive ability measures. Performance on a task can be due to the utilisation of a variety of control processes that emphasise various components of that task over other components.

Keywords: Serial position functions; Individual differences.

In immediate free recall participants are given a list of to-be-remembered (TBR) items and immediately after the presentation of the last item are required to recall the items in any order they wish. Typically participants recall items presented at the beginning of the list better than items presented in the middle of the list (primacy effect). Additionally, items presented at the end of the list tend to be recalled better than mid-list items (recency effect). Thus the serial position of items presented in a list has some effect on the probability of recalling a given item. Largely beginning with the work of Deese and Kaufman (1957) and Murdock (1962), serial position functions in immediate free recall have been studied extensively and are one of the cornerstone findings that models of memory must account for. In the current study we examined both inter-individual and intra-individual differences in serial position functions and differences in recall strategies.

SERIAL POSITION EFFECTS IN IMMEDIATE FREE RECALL

Perhaps the most popular explanation of serial position functions in immediate free recall is based on a dual-store/dual-component model of memory where items are either maintained in primary memory/short-term store/short-term memory or are retrieved from secondary memory/long-term store/long-term memory (e.g., Atkinson &

Address correspondence to: Nash Unsworth, Department of Psychology, University of Georgia, Athens, GA 30602-3013, USA. E-mail: nunswor@uga.edu

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Shiffrin, 1968; Glanzer, 1972; Waugh & Norman, 1965). In these models primacy effects are explained by the fact that the first few items presented are maintained and rehearsed in primary memory and then are transferred to secondary memory. Theoretically the more rehearsals an item receives the more likely it will be recalled later on (Rundus & Atkinson, 1970). Thus the primacy effect occurs because the first few items presented receive the most rehearsals or perhaps the most attention, which leads to a highly accessible representation that can be easily retrieved from secondary memory during recall. Recency effects, on the other hand, are due to the fact that items presented at the end of the list are still being maintained in primary memory during recall, and thus these items are simply unloaded leading to a high probability of recall. Although other models of memory can explain primacy and recency effects in immediate free recall without postulating two components or two stores (e.g., Brown, Neath, & Charter, 2007), the dual-component model has long been considered the classic explanation.

Evidence consistent with the notion that primacy and recency effects are due to two different components comes from various studies that have found experimental and group dissociations between the two. For instance, word frequency (Raymond, 1969), presentation rate (Glanzer & Cunitz, 1966), list length (Murdock, 1962), and proactive interference (Craik & Birtwistle, 1971) have all been shown to affect pre-recency items but not recency items. Recency effects, however, are diminished if the task changes from immediate free recall to delayed free recall where a distracting task is placed in between item presentation and recall (Glanzer & Cunitz, 1966). Additionally, amnesic patients (Baddeley & Warrington, 1970; Brown et al., 1995; Carlesimo, Marfia, Loasses, & Caltagirone, 1996) and individuals with low working memory capacities (Unsworth & Engle, 2007) tend to have recall deficits associated with pre-recency items compared to controls or individuals with high working memory capacities, while recall of recency items is roughly the same. However, differences between older adults and younger adults tend to occur at all serial positions (Kahana, Howard, Zaromb, & Wingfield, 2002). Thus some variables affect primacy but not recency, while other variables affect recency but not primacy consistent with a dual-component conception of memory.

To account for these systematic effects a number of detailed dual-component models have been developed (e.g., Atkinson & Shiffrin, 1968; Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Raaijmakers & Shiffrin, 1980). For instance, in Atkinson and Shiffrin's model (1968, 1971) it was assumed that some small proportion of information could be actively maintained in the short-term store/primary memory, whereas other information would have to be retrieved from the long-term store/secondary memory and brought into the capacity limited region. Furthermore, Atkinson and Shiffrin (1968, 1971) suggested that the flow of information was under the direct control of the individual and that participants relied on control processes such as rehearsal, coding decisions, and retrieval strategies in order to remember information. Thus memory performance in tasks like immediate free recall resulted from the joint contribution of the two memory components and the control processes that acted on information within the components. Subsequent dual-component models have generally maintained the basic notions outlined by Atkinson and Shiffrin (1968, 1971) and have elaborated on various components of the model including capacity limitations and attentional maintenance in the short-term store (Craik & Levy, 1976; Cowan, 2001; Shiffrin, 1976), activation dynamics and cognitive control in the short-term component (Davelaar et al., 2005), as well as search in the long-term store based on contextual and semantic-lexical information (Davelaar et al., 2005; Raaijmakers & Shiffrin, 1980; Sirotin, Kimball, & Kahana, 2005) to name a few. Nearly all of these models successfully account for serial position effects in immediate free recall by assuming that some items (recency items) are retrieved rapidly and nearly perfectly from the short-term store whereas other items (pre-recency items) are retrieved from the long-term store via a probabilistic search.

One problem with these models, however, is that they generally do not take into account intra- and inter-individual variation that might be due to differences in control processes. Specifically, in nearly all cases aggregate (aggregated across individuals and across lists within a task) serial position functions are simulated and there is little to no mention of differences in serial position functions across and/or within individuals. Aggregating across individuals can then lead to a typical pattern of performance that is in fact distorted from what each individual is doing. Indeed, Kosslyn et al. (2002, p. 341) noted:

> . . . people (or other animals) may differ not only in the efficacy of specific mechanisms but also in the frequency with which particular mechanisms are recruited (which in turn would make some more salient than others). If some people tend to rely on one 'strategy' (i.e., combination of processes), whereas others habitually rely on alternative strategies, pooling data from both groups may be uninformative at best and outright misleading at worst.

Thus, assuming that all individuals are essentially doing the same thing and simply vary with the ability to do it is likely incorrect. Rather, it is likely that individuals are doing a variety of things and thus a single score can be achieved by multiple people but for very different reasons. For instance, take a basic free recall task where participants are presented with a list of items and are asked to recall those items later. Two participants may both recall 80% of the items, suggesting that they have similar recall abilities, but how they reach that 80% may be vastly different. Participant A may rely on an elaborative rehearsal strategy at encoding that allows for easier retrieval later, while Participant B may rely on a maintenance rehearsal strategy where the last few items are continually rehearsed (e.g., Speer, Jacoby, & Braver, 2003). This in turn would lead to Participant A recalling many of the first items presented (i.e., a strong primacy effect), while Participant B would likely recall many of the last items presented (i.e., a strong recency effect). Thus, although the two participants had the same mean level of performance on the task, the strategic processes utilised were in fact quite different leading to different patterns of performance.

To account for serial position functions in immediate free recall, most dual-component models usually assume that items in the short-term store are immediately available for recall and participants always begin recall by outputting recency items first (e.g., Raaijmakers & Shiffrin, 1980). After all the items are recalled from the short-term store, items are recalled from the long-term store via a probabilistic search. Thus, in these types of models, it is assumed that individuals use a recency recall initiation strategy and assume (at least implicitly) that individuals do not differ in their recall initiation strategies. However, other work suggests that this is not always the case. For instance, Kimball, Smith, and Kahana (2007) found that they were unable to simulate serial position functions from immediate free recall from Kimball and Bjork (2002) with an extended version of the Search of Associative Memory model (SAM; Raaijmakers & Shiffrin, 1980) because participants did not always begin their recall with recency items in that study. Thus, Kimball et al. (2007) suggested that more work was needed to investigate recall initiation strategies and that such strategies should be incorporated into the SAM model.

This suggests the possibility that individuals differ in their recall initiation strategies, a form of control processes, and that differences in serial position functions should arise across individuals as a function of recall initiation strategy. For instance, participants who extensively rehearse primacy items and decide on a primacy recall initiation strategy should start recall with primacy items and probability correct should be high for primacy items, but relatively low for recency items. That is, with a primacy recall initiation strategy performance should resemble forward serial recall with strong primacy effects and reduced recency effects (at least with visual presentation of items; e.g., Madigan, 1971). Participants who devote rehearsals to maintaining recency items and decide on a recency recall initiation strategy should start recall with recency items, leading to a strong recency effect and a much smaller primacy effect consistent with research in which participants are explicitly instructed to begin their recall with the last items first (e.g., Bhatarah, Ward, & Tan, 2008; Craik & Birtwistle, 1971; Dalezman, 1976).

Evidence consistent with this hypothesis comes from a recent study by Gibson, Gondoli, Flies, Dobrzenski, and Unsworth (2010) that examined differences between children diagnosed with ADHD and age-matched controls in immediate free recall. Gibson et al. found that 54% of participants (both ADHD and controls) started recall with a recency item and demonstrated large recency effects in their serial position functions. Gibson et al. also found that 27% of participants started their recall with a primacy item and these participants demonstrated stronger primacy than recency effects in their serial position functions. Finally, Gibson et al. found that the remaining 19% of participants tended to start their recall equally between primacy and recency items across trials leading to serial position functions with roughly equal primacy and recency portions. Thus this preliminary evidence suggests that individuals differ in their recall initiation strategies, and this affects the shape of the serial position function differentially.

Not only is it likely that individuals will differ in their recall initiation strategies, it is also likely that these strategies will change within a task based on a number of variables. That is, participants may start out using one strategy and then switch to another strategy based on initial performance. Indeed, prior work has suggested that participants are likely to develop a recency recall initiation strategy after a few initial study-test trials (e.g., Dallett, 1963; Keppel & Mallory, 1969; Murdock & Okada, 1970). Indeed, Murdock (1974, p. 237), in discussing serial position curves, noted that:

> it is common knowledge among experimenters, though not very well documented in the literature, the curve is different for naïve subjects. On the very first trial, subjects typically show more primacy and less recency than practiced subjects. This effect is very transitory; by the second or third list, subjects have shifted over.

Thus, researchers have known for some time that serial position effects in immediate free recall can change as function of practice on the task.

More systematic investigations of the primacy to recency shift have suggested a number of interesting findings. For instance, Goodwin (1976) found that participants' serial position functions when instructed to output primacy items first closely resembled participants' serial position functions in a non-instructed group on the first few trials. On later trials, participants' serial position functions closely resembled serial position functions for participants who were instructed to output recency items first. Additionally, Goodwin (1976) found that primacy reduced as proactive interference (PI) increased and that a release of PI mainly led to an increase in the recall of primacy items. Thus Goodwin argued that the reductions in primacy as a function of trials within a task reflected susceptibility to PI (see also Craik & Birtwistle, 1971) and that increases in recency reflected a change in recall initiation strategies as a function of practice. Similarly, Huang (1986); see also Huang, Tomasini, & Nikl, 1977) suggested that the primacy–recency shift occurred because as PI accrued within a task participants changed to a recency strategy. That is, as PI accrued this primarily affected primacy items and as a consequence participants adopted a recency strategy in which the last items were actively maintained to prevent PI (Craik & Birtwistle, 1971) and were output first during the recall period. Thus the development of a recency strategy partially relies on the accrual of PI within a task.

THE PRESENT STUDY

In the present study, we examined inter- and intra-individual variation in serial position functions and recall initiation strategies in immediate free recall. Specifically, we examined whether subgroups of participants could be identified based on differential serial position curves and recall initiation strategies, and whether these groups' serial position curves changed as a function of practice within a task. As noted previously, it is likely that three groups of participants will be found in which some participants rely primarily on recency strategy, whereas others rely on a primacy strategy, and others show equivalent primacy and recency (e.g., Gibson et al., 2010). Furthermore, it is possible that these groups' serial position functions may change as a function of time on a task. That is, do participants who show a recency strategy demonstrate this even on early trials, or does this strategy develop as a function of time on the task as suggested by previous work (e.g. Goodwin, 1976; Huang, 1986)? Finally, if such groups can be identified, do these groups differ in performance on immediate free recall and do they differ on other measures of cognitive abilities? That is, are participants who adopt a recency strategy more susceptible to PI? Furthermore, do these groups differ on measures of working memory capacity and fluid intelligence? Recent work has suggested that performance on immediate free recall is correlated with performance on measures of working memory capacity and fluid intelligence (e.g., Unsworth & Engle, 2007; Unsworth, Spillers, & Brewer, 2010) and part of this relation may be due to differences in recall initiation strategies. Indeed, our prior work examined correlations between immediate free recall measures and measures of working memory capacity and fluid intelligence, but this work did not explicitly examine possible differences in recall initiation strategies, nor did this prior work examine possible intra-individual variation. Thus the current study extends prior individual differences studies of immediate free recall by examining both inter- and intra-individual differences in hopes of better elucidating the processes that are carried out in immediate free recall.

In order to examine these issues, we had participants perform an immediate free recall task with 10 separate lists. Participants were classified as using a primacy strategy, a recency strategy, or both based on their aggregate serial position functions. These groups were examined on various performance measures on the immediate free recall task to determine if differences in recall strategies resulted in differences in performance. Likewise, serial position effects early and late in the task were examined as a function of group to determine if the groups differed in the extent to which they demonstrated a primacy–recency shift. Finally the groups were compared on a number of cognitive ability measures in order to determine if they differed in other cognitive abilities. Specifically, measures of working memory capacity (WMC), fluid intelligence (gF), vocabulary knowledge, and susceptibility to proactive interference, were also collected in order to determine if group differences seen in immediate free recall were specific to that task, or whether these differences reflected more fundamental differences in cognitive abilities thereby providing external validity to the results. These measures were chosen because prior work has suggested a correlation between these measures and immediate free recall performance. Furthermore, these measures were chosen in order to provide external validation to the results by demonstrating that any inter- and intra-individual variation found on immediate free recall was not idiosyncratic to that task, but rather reflected more general differences in cognitive abilities.

METHOD

Participants

A total of 150 participants were recruited from the subject pool at the University of Georgia. Participants were between the ages of 18 and 35 and received course credit for their participation. Each participant was tested individually in a laboratory session lasting approximately 2 hours.

Materials and procedure

After signing informed consent, all participants completed the immediate free recall task, the Brown-Peterson task, Operation span (Ospan), Symmetry span (Symspan), Reading span (Rspan), a brief computerised version of the Raven progressive matrices (Raven, Raven, & Court, 1998), a brief paper/pencil verbal analogies test, a version of Thurstone's (1962) Number Series test, a brief paper/pencil synonym vocabulary test, and a brief paper/pencil antonym vocabulary test.

Immediate free recall task. In this task, participants were given 10 lists of 10 words each. All words were common nouns that were presented for 1 s each. After the presentation of the last word, participants saw ???, which indicated that they should write down as many words they remembered from that trial in any order they wished. Participants had 30 s for recall. Prior to the real lists, participants completed two practice lists with letters to familiarise them with the task.

Brown-Peterson task. In this task, participants were given 12 lists of five words each broken down into three blocks (four lists per block). All words in each block came from the same semantic category (e.g., fruits, animals, and professions). The first four lists allowed for proactive interference (PI) to accrue and the first list in the next block allowed for a "release from PI". Each word was presented onscreen for 1 s. Following the last word in a list, participants were required to count backwards by threes as quickly and accurately as possible from a three-digit number presented onscreen. Participants wrote their answers down until instructed to stop after 18 s. At the conclusion of the distracting task, participants had 15 s to recall as many words as possible from the current list in any order they wished (i.e., delayed free recall). Prior to the real lists, participants completed two practice lists with letters to familiarise them with the task.

Working memory capacity (WMC) tasks: Operation span. Participants solved a series of maths operations while trying to remember a set of unrelated letters that were presented for 1 s each. Immediately after the letter was presented the next operation was presented. Three trials of each list length (3–7) were presented, with the order of list length varying randomly. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. Participants received three sets (of list length 2) of practice. For all of the span measures, the score was the proportion of correct items in the correct position.

Symmetry span. In this task, participants were required to recall sequences of red squares within a matrix while performing a symmetry judgement task. In the symmetry judgement task participants were shown an 8×8 matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical half of the time. Immediately after determining whether the pattern was symmetrical, participants were presented with a 4×4 matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations in the preceding displays, in the order they appeared by clicking on the cells of an empty matrix. There were three trials of each list length with list length ranging from 2 to 5. The same scoring procedure as Ospan was used.

Reading span. Participants were required to read sentences while trying to remember the same set of unrelated letters as Ospan. For this task, participants read a sentence and determined whether the sentence made sense or not (e.g. "The prosecutor's dish was lost because it was not based on fact.?"). Half of the sentences made sense while the other half did not. Nonsense sentences were made by simply changing one word (e.g., to "dish" from "case") from an otherwise normal sentence. After participants indicated whether the sentence made sense or not, they were presented with a letter for 1 s. At recall, letters from the current set were recalled in the correct order by clicking on the appropriate letters. There were three trials of each list length with list length ranging from 3 to 7. The same scoring procedure as Ospan was used.

General fluid intelligence (gF) tasks: Raven Progressive Matrices. The Raven is a measure of abstract reasoning (Raven et al., 1998). This version of the Raven is a brief computer-administered version that consists of 12 items. Each item consists of a matrix of geometric patterns with the bottom right pattern missing. Participants are instructed to select, among either six or eight alternatives, the one that correctly completes the overall series of patterns. Each matrix item appeared separately on screen along with the response alternatives. Using the mouse, the participant simply clicked on the response that they thought completed the pattern. The mouse click registered the response and moved the program on to the next problem. Participants were allotted 5 minutes to complete the task. Items were presented in ascending order of difficulty (i.e., the easiest item is presented first and the hardest item is presented last). A participant's score was the total number of correct solutions. Participants received two practice problems.

Verbal analogies. In this task, participants read an incomplete analogy and were required to select the one word out of five possible words that best completed the analogy. After one practice item, participants had 5 minutes to complete 18 test items. These items were originally selected from the Air Force Officer Qualifying Test (AFOQT; Berger, Gupta, Berger, & Skinner, 1990), and we used the same subset of items used in Kane et al. (2004). A participant's score was the total number of items solved correctly.

Number series. In this task, participants saw a series of numbers and were required to determine what the next number in the series should be (Thurstone, 1962). That is, the series follows some unstated rule that participants are required to figure out in order to determine which the next number in the series should be. Participants selected their answer out of five possible numbers that were presented. Following five practice items, participants had 4.5 minutes to complete 15 test items. A participant's score was the total number of items solved correctly.

Vocabulary tasks: Synonym vocabulary. In this task, participants were given 10 vocabulary words and were required to select the best synonym (out of five possible choices) that best matched the target vocabulary word (Hambrick, Salthouse, & Meinz, 1999). Participants were given 2 minutes to complete the 10 items. A participant's score was the total number of items solved correctly.

Antonym vocabulary. In this task, participants were given 10 vocabulary words and were required to select the best antonym (out of five possible choices) that best matched the target vocabulary word (Hambrick et al., 1999). Participants were given 2 minutes to complete the 10 items. A participant's score was the total number of items solved correctly.

RESULTS AND DISCUSSION

Inter-individual variation

In order to examine possible differences in recall strategies, cluster analysis was used. Cluster analysis is a tool used to determine group membership by minimising within-group differences and maximising between-groups differences (Everitt, Landau, & Leese, 2001; Kaufman & Rousseeuw, 1990). Groups are formed where individuals in the group are very similar to one another but unlike individuals in other groups. It should be noted that these methods are largely atheoretical, and group membership is merely based on similarities within a cluster and differences across clusters.

To determine the groups, aggregate serial position functions for each individual were computed by averaging each serial position across the 10 lists. These aggregate serial position functions were then entered into a two-step cluster analysis (i.e., 10 variables were entered into the cluster analysis). The two-step cluster analysis was performed using SPSS version 16. In this analysis, cases were first grouped into pre-clusters at the first step by constructing a cluster feature tree (see Zhang, Ramakrishnan, & Livny, 1996). For each case, the algorithm determined if the case should be included with a previously formed pre-cluster or a new pre-cluster should be created based on the cluster feature tree. In the second stage, an agglomerative hierarchical clustering method was used on the pre-clusters and allowed for an exploration of different numbers of clusters. In this stage, clusters were recursively merged until the desired number of clusters was determined. In these analyses, distance between clusters was based on a log-likelihood measure whereby distance was related to the decrease in log-likelihood as the clusters were formed into a single cluster.

The cluster analysis suggested the presence of three groups in the data consisting of 68, 30, and 52 participants each. As can be seen in Figure 1,

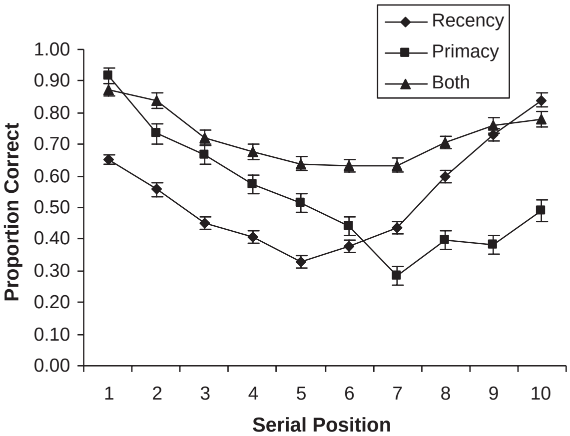

Figure 1. Proportion correct as a function of serial position and Group. Error bars represent one standard error of the mean.

these groups can be classified as a Recency group ($n = 68$), a Primacy group ($n = 30$), and a Both group ($n = 52$). As shown in Figure 1, there was a significant group × serial position interaction, $F(9,\ 1323) = 28.12$, $MSE = .02$, $p < .01$, $\eta_p^2 = .28$. Thus the groups differed in their overall serial position functions, with some participants in some groups emphasising primacy items whereas participants in other groups seemed to emphasise recency items.[1]

In order to examine this claim more thoroughly, we specifically examined only primacy (the first three items) and recency (the last three items) to see if it was indeed the case that the groups differed primarily in their recall of items from these positions. As shown in Figure 2, there was a clear interaction between primacy and recency components and the groups, $F(2,\ 147) = 107.49$, $MSE = .01$, $p < .01$, $\eta_p^2 = .59$, with the Recency group demonstrating stronger recency than primacy, with the Primacy group demonstrating stronger primacy than recency, and the Both group demonstrating both strong primacy and recency. Importantly, the Both group demonstrates the same amount of primacy as the Primacy group and the same amount of recency as the Recency group. Thus it seems that the major difference between the groups is the extent to which participants in a given group emphasise primacy or recency items.

Another way of examining primacy and recency effects is to plot the probability of first recall (e.g., Howard & Kahana, 1999). Probability of first recall is simply the number of times the first word recalled comes from a given serial position divided by the number of times the first recalled word could have come from that serial position. For instance, if a person begins recall with the last presented word nine out of ten times, then the probability of first recall for that serial position would be .90. Probability of first recall (PFR) was computed for each individual and each list. If participants in the Recency group are using a recency recall initiation strategy, then recency items should be the first recalled. Likewise, if the Primacy group is using a primacy recall initiation strategy then primacy items should be the first

[1] Note that we also classified participants based on whether they demonstrated more primacy than recency (i.e., at least a .10 difference between primacy and recency), more recency than primacy, or demonstrated equal primacy and recency similar to Gibson et al. (2010). This led to qualitatively identical results to those found with the cluster analysis.

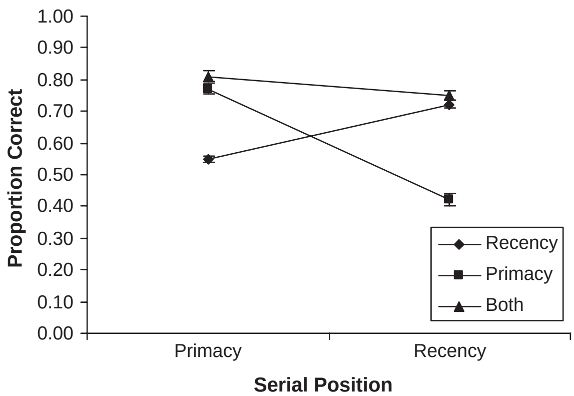

Figure 2. Proportion correct as a function of Primacy and Recency and Group. Error bars represent one standard error of the mean.

recalled items. Importantly, it should be noted that most studies that have examined PFR in immediate free recall have found that recency items have higher PFR than primacy items (e.g., Howard & Kahana, 1999; Unsworth & Engle, 2007), and thus evidence for strong primacy PFRs would be evidence in favour of a primacy recall initiation strategy. Shown in Figure 3 are the resulting PFR functions for all serial positions as a function of group. As can be seen, there was a interaction between serial position and group, $F(18, 1323) = 13.24$, $MSE = .01$, $p < .01$, $\eta_p^2 = .15$. Specifically, the Recency group tended to start recall primarily recency items (especially the last three items presented) although they also started recall with some primacy items. The Primacy group initiated recall primarily with primacy items (i.e., serial position 1 was the first recalled 64% of the time) and the Both group initiated recall with both primacy and recency items. Interestingly, as can be seen primacy effects were mostly restricted to the first serial position, whereas recency effects occurred for the last three serial positions (see also Unsworth & Engle, 2007).

In order to examine these PFR effects more thoroughly for the groups, we again examined only the primacy items (the first three serial positions) and the recency items (the last three serial positions). As can be seen in Figure 4 there was an interaction between serial position and group, $F(2, 147) = 22.18$, $MSE = .02$, $p < .01$, $\eta_p^2 = .23$. Specifically, the Recency group was the most likely to start recall with recency items and was the least likely to start recall with primacy items. The Primacy group demonstrated the opposite such that they were the most likely to start recall with primacy items and the least likely to start recall with recency items. The Both group started recall equally often with primacy and recency items. This provides important evidence that the group differences found in the serial position functions were due in part to differences in recall initiation strategies. Some participants emphasise recency items and these are the first items recalled. Other participants emphasise primacy items and these are the first recalled.

Finally we examined differences between the groups in terms of a number of internal variables on the immediate free recall task. For instance, differences in overall mean levels of performance, estimates of primary and secondary memory (Tulving & Colotla, 1970), intrusion errors, and repetition errors were examined. Shown in Table 1 are the results. As can be seen, the Both group recalled significantly more words than either the Recency or Primacy groups, and the latter two did not differ in the number of words recalled, $p > .83$. Additionally, as might be expected the Primacy

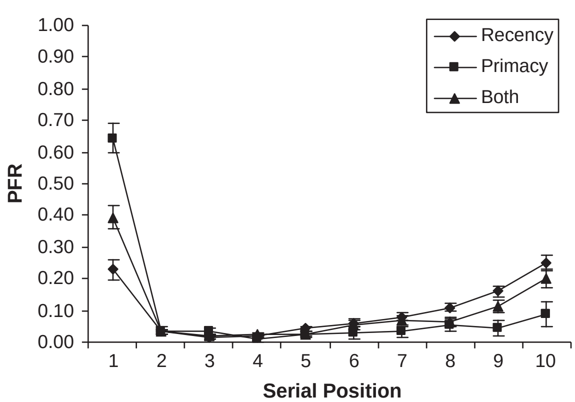

Figure 3. Probability of first recall (PFR) as a function of serial position and Group. Error bars represent one standard error of the mean.

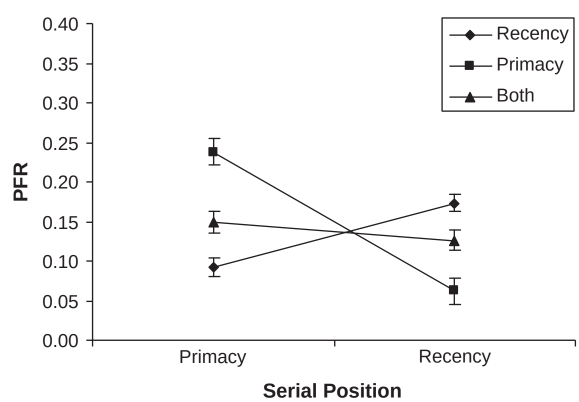

Figure 4. Probability of first recall (PFR) as a function of serial position (Primacy vs. Recency) and Group. Error bars represent one standard error of the mean.

TABLE 1
Descriptive statistics and omnibus ANOVA results for each group and overall performance on internal variables from immediate free recall

	Group					
Measure	*Recency*	*Primacy*	*Both*	*Overall*	*F*	η^2
# Correct	5.45 (0.65)	5.43 (0.66)	7.28 (0.69)	6.08 (1.10)	130.1	.64
PM	2.85 (0.47)	1.90 (0.68)	2.68 (0.91)	2.60 (0.78)	19.9	.21
SM	2.60 (0.66)	3.53 (0.88)	4.61 (1.20)	3.48 (1.28)	69.2	.49
PLI	0.14 (0.12)	0.11 (0.12)	0.07 (0.10)	0.11 (0.12)	5.4	.07
ELI	0.22 (0.23)	0.32 (0.30)	0.16 (0.15)	0.22 (0.23)	5.1	.07
Repeat	0.02 (0.04)	0.02 (0.04)	0.02 (0.04)	0.02 (0.04)	*0.3*	.00

Correct = average number correct; PM = estimate of primary memory; SM = estimate of secondary memory; PLI = average number of previous list intrusions; ELI = average number of extralist intrusions; Repeat = average number of repetition errors. Numbers in parentheses are standard deviations. Non-significant (i.e., $p > .05$) *F*-values are italicised.

group had lower estimates of primary memory (PM) than the other two groups, both ps $< .01$, but the Recency and Both groups did not differ, $p > .53$. All groups differed significantly from one another in their estimates of secondary memory (SM), all ps $< .01$. In terms of previous list intrusions (PLIs), the only significant group difference was a difference between the Recency group and the Both group, $p < .01$. In terms of extra-list intrusions (ELIs), the Primacy group made more ELIs than either the Recency or the Both group, both ps $< .05$, but the latter two groups did not differ, $p > .12$. Thus not only did the groups differ in their recall initiation strategies and in their resulting serial position functions, but there were also a number of differences in other performance measures extracted from immediate free recall. Perhaps most interesting was the finding that Recency and Primacy groups did not differ in overall levels of performance despite large differences in their recall initiation strategies and serial position functions.

Intra-individual variation

Our next set of analyses examined whether the groups' serial position functions would differ as function of time within a task. That is, would a primacy to recency shift be found in the current data and would this differ as a function of the underlying groups? In order to inspect this, we examined each groups' serial position functions for the first three lists vs the last three lists on the immediate free recall task. Submitting the data to an ANOVA suggested a significant interaction between beginning vs end of the task and serial position, $F(9, 1323) = 8.67$, $MSE = .08$, $p < .01$, $\eta_p^2 = .06$, such that primacy was stronger at the beginning of the task than at the end of the task, and recency was stronger at the end of the task than at the beginning of the task consistent with prior research (Goodwin, 1976; Huang, 1986; Huang et al., 1977). Importantly this also interacted with group, $F(18, 1323) = 1.87$, $MSE = .08$, $p < .05$, $\eta_p^2 = .03$. As can be seen in Figure 5, early in the task the Recency group demonstrated fairly strong primacy and recency effects. At the end of the task, however, the Recency group demonstrated much smaller primacy effects but the same recency effects. The Primacy group demonstrated large primacy effects both at the beginning and the end of the task, but also started to show some recency effects late in the task. Finally, the Both group demonstrated both primacy and recency early and late into the task, but seemed to increase the size of their recency effect slightly.

To get a better sense of how a within-task strategy shift effected primacy and recency, we next examined only primacy (the first three items) and recency (the last three items) components. Consistent with the overall analysis there was a significant three-way interaction, $F(2, 147) = 3.99$, $MSE = .04$, $p < .05$, $\eta_p^2 = .05$. As shown in Figure 6a, early in the task the Primacy and Both groups demonstrated more primacy than recency and the Recency group demonstrated slightly more recency than primacy. As shown in Figure 6b, however, late in the task the Both group demonstrated slightly more recency than primacy and the Recency group demonstrated much stronger recency than primacy effects. The Primacy group, however, still showed large primacy and much smaller recency effects. Thus not only was there a primacy–recency shift consistent with prior research (Goodwin, 1976; Huang, 1986; Huang et al., 1977), but this shift

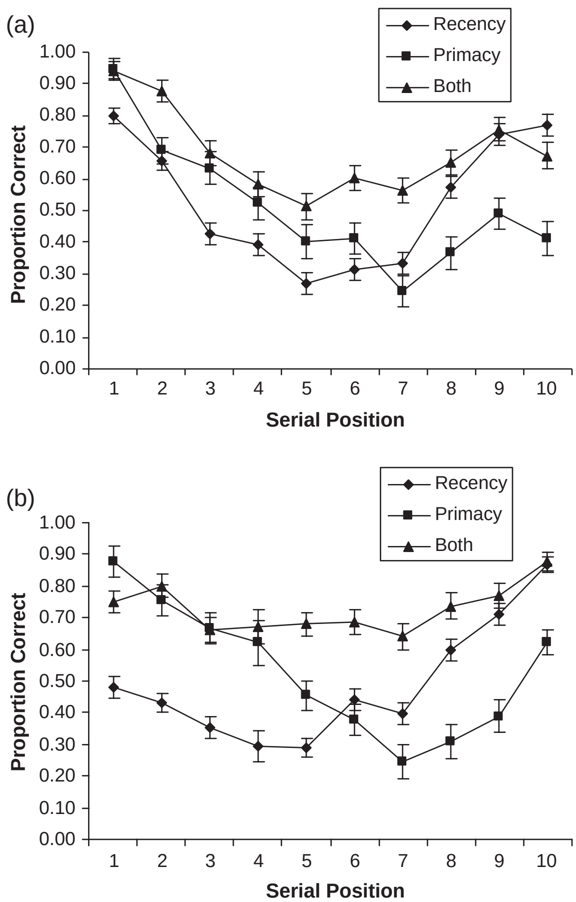

Figure 5. (a) Proportion correct as a function of serial position and Group for the first three lists. (b) Proportion correct as a function of serial position and Group for the last three lists. Error bars represent one standard error of the mean.

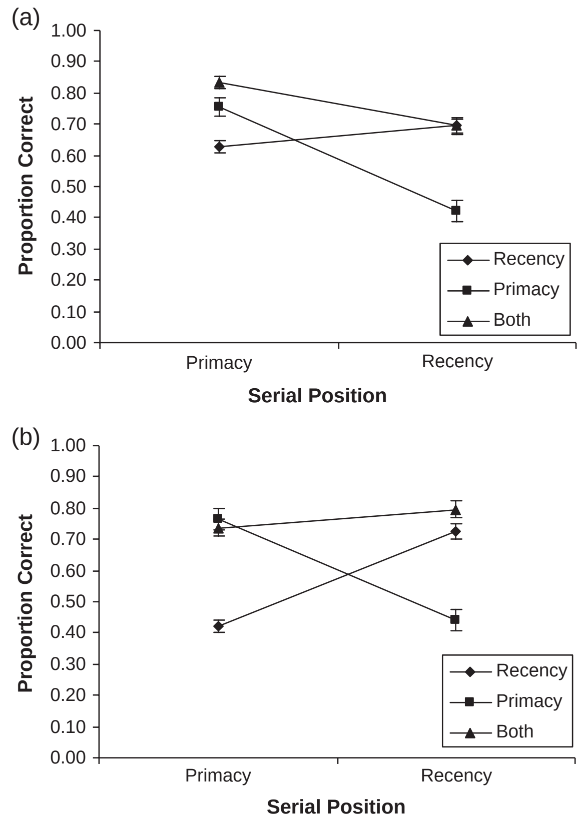

Figure 6. (a) Proportion correct as a function of Primacy and Recency and Group for the first three lists. (b) Proportion correct as a function of Primacy and Recency and Group for the last three lists. Error bars represent one standard error of the mean.

varied as a function of individual differences. Specifically, only some participants demonstrated the primacy–recency shift, whereas other participants continued to recall primarily primacy items.

Next, within-task effects were examined for probability of first recall (PFR). Specifically we examined whether participants would change which items they initiated recall with as a function of time on task and whether this would interact with group. As shown in Figure 7, and consistent with prior research (Goodwin, 1976; Huang, 1986; Huang et al., 1977), PFR changed as function of task, $F(9, 1323) = 13.21$, $MSE = .03$, $p < .01$, $\eta_p^2 = .08$, such that early in the task participants were more likely to start with primacy items, but as the task progressed participants started to also initiate recall with recency items. However, this did not interact with group, $F < 1$.

Similar results were found when examining only primacy and recency components, as done previously. There was an interaction between primacy and recency components and time on task, $F(1, 147) = 17.10$, $MSE = .01$, $p < .01$, $\eta_p^2 = .10$. Specifically, in the beginning of the task participants tended to begin recall with primacy items ($M = .19$, $SE = .01$) rather than recency items ($M = .11$, $SE = .01$). At the end of the task participants tended to begin recall with either primacy ($M = .13$, $SE = .01$) or recency ($M = .14$, $SE = .01$) roughly equally. As before this did not interact with group, $F < 1$. Thus, although the groups differed in their PFR functions, and the PFR functions changed as a function of time on task, the group changes were largely equivalent as a function of time on task.

External correlates

In the last set of analyses, we examined group differences on the cognitive ability measures. For the working memory capacity (WMC), fluid

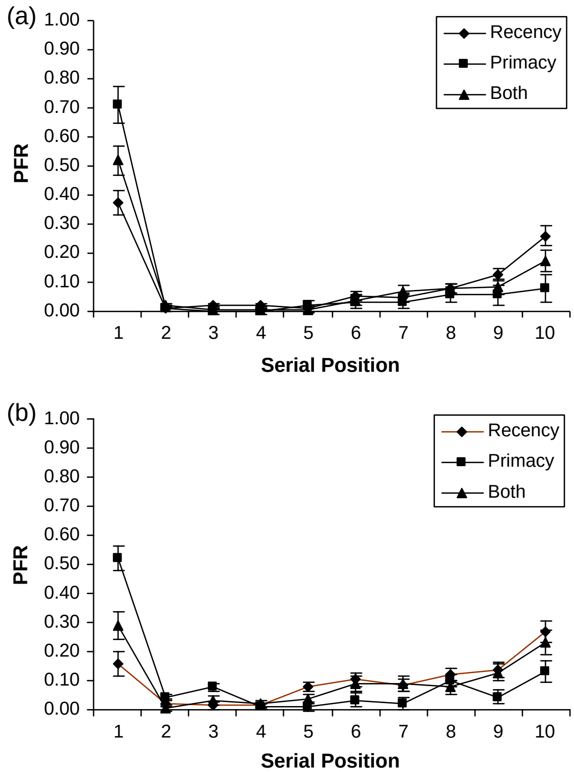

Figure 7. (a) Probability of first recall as a function of serial position and Group for the first three lists. (b) Probability of first recall as a function of serial position and Group for the last three lists. Error bars represent one standard error of the mean.

intelligence (gF), and vocabulary measures we *z*-transformed each of the measures and formed *z*-score composites. Thus we had a composite of WMC, gF, and vocabulary abilities. The magnitude of the proactive interference (PI) effect in the Brown-Peterson task, was the proportional PI effect associated with each individual within a category (e.g., Kane & Engle, 2000). Specifically, this was calculated by subtracting performance on Trial 4 from Trial 1 and then dividing by Trial 1 for each individual. Accuracy on the Brown-Peterson task was simply the total number of items correctly recalled. Shown in Table 2 are the group and overall scores on the cognitive ability measures. Like the examination of internal variables, it is clear that the groups differed in a number of ways on the external variables. For instance, there were overall main effects of group in terms of WMC, gF, vocabulary, total number of correct on the Brown-Peterson task, and the amount of PI on the Brown-Peterson task. Post-hoc analyses suggested that the Both group had significantly higher WMC scores than the Recency group, $p < .01$. The Primacy group did not differ from either the Recency group or the Both group, both *p*s > .17. In terms of gF, the Both group had higher gF scores than both the Recency and the Primacy groups, both *p*s < .06, but the Recency and Primacy groups did not differ from one another, $p > .41$. In terms of vocabulary, the Recency group had lower vocabulary scores than both the Primacy and the Both groups, both *p*s < .05, and the Primacy and Both groups did not differ from one another, $p > .69$. For the Brown-Peterson task, the Recency group recalled fewer total items than both the Primacy and the Both group, both *p*s < .05, and the Primacy and Both groups did not differ from one another, $p > .25$. Finally, the Recency group demonstrated more proactive interference (PI) than both the Primacy and the Both group, both *p*s < .08, and the Primacy and Both groups did not differ from one another, $p > .13$. Thus not only did the groups differ in their serial position functions and internal variables on the immediate free recall task, but the groups also differed on a number of other cognitive ability measures. This

TABLE 2
Descriptive statistics and omnibus ANOVA results for each group and overall performance on cognitive ability measures

	Group					
Measure	*Recency*	*Primacy*	*Both*	*Overall*	*F*	η^2
WMC	−0.16 (0.72)	0.01 (0.84)	0.23 (0.63)	0.01 (0.73)	4.4	.06
gF	−0.24 (0.92)	−0.07 (0.98)	0.32 (0.81)	0.01 (0.92)	5.6	.07
Vocabulary	−0.26 (0.73)	0.18 (1.0)	0.25 (0.87)	0.00 (0.87)	6.2	.08
BP Correct	14.9 (2.3)	16.3(2.4)	16.9 (2.3)	15.9 (2.5)	11.8	.14
BP PI	0.26 (0.17)	0.19 (0.16)	0.14 (0.17)	0.20 (0.17)	7.9	.10

WMC = *z*-score composite of working memory capacity measures; gF = *z*-score composite of fluid intelligence measures; Vocabulary = *z*-score composite of vocabulary measures; BP Correct = total number correct on the Brown-Peterson task; BP PI = proportional proactive interference effect on the Brown-Peterson task. Numbers in parentheses are standard deviations. All *F*-values are significant at the $p < .05$ level.

provides important external validation for the groups and suggests that the differences seen in immediate free recall likely reflect fundamental differences in cognitive processes. That is, the differences between the groups are not simply due to idiosyncratic task effects, but instead reflect more fundamental differences between the groups that are evident on other cognitive ability measures.

DISCUSSION

The aim of the current study was to explore both inter- and intra-individual differences in immediate free recall. Specifically, we examined participants' serial position and probability of first recall functions in order to determine if subgroups of participants could be identified who differed in recall initiation strategies. The results suggest that three groups were present in the data, with 65% of participants adopting a recency strategy in which recency items were recalled best and recalled first during output leading to overall serial position functions, similar to what is traditionally found with immediate free recall (i.e., Murdock, 1962). Additionally, 20% of participants adopted a primacy strategy in which primacy items were recalled the best and were recalled first during output with overall serial position functions resembling those seen in immediate serial recall (i.e., Madigan, 1971). Finally, the remaining 35% of participants tended to use both a primacy and a recency strategy in which primacy and recency items were recalled equally well and equally as the first items during output. Thus the results clearly demonstrated that not all participants performed the immediate free recall task the same. Rather there were large inter-individual differences in recall initiation strategies that led to differential serial position functions. This is important because, as noted previously, prior individual differences studies of immediate free recall have largely been concerned with overall mean differences. As such, participants who recall roughly 80% of items would be ranked ordered the same in a correlation analysis. Yet the current work shows that individuals can recall the same average number of items (and hence have the same rank order), but how they recall those items may differ substantially. Some participants may rely on a primacy recall strategy, whereas others may rely on a recency recall strategy. The current results suggest that a more fine-grained examination of an individual's recall is needed to fully understand why and how individuals differ.

The results also demonstrated intra-individual differences in that some participants demonstrated a clear primacy–recency shift as a function of time on task whereas other participants tended to maintain the same basic strategy throughout the task. Specifically, the group that tended to emphasise recency items initially demonstrated strong primacy effects, but these effects were strongly attenuated as a function of time on task. However, the other groups tended to recall primacy items as well early and late in the task. As suggested by Goodwin (1976) and Huang (1986), this primacy–recency shift likely reflects the accrual of proactive interference (PI) for primacy items, which leads participants to adopt a recency-based strategy to actively maintain the last few items. This suggests that the group that emphasised recency items and demonstrated the strongest primacy–recency shift likely did so because they were more susceptible to PI. Indeed, this group recalled more previous list intrusions than the other groups and demonstrated the most PI on the Brown-Peterson task. Thus there were not only inter-individual differences in recall initiation strategies, but these differences also changed as function of time on task resulting in intra-individual differences.

Importantly, not only were there clear inter- and intra-individual differences on the immediate free recall task, but these differences were also related to differences on other cognitive ability measures including measures of working memory capacity, fluid intelligence, vocabulary, as well as PI, as mentioned previously. This provides important evidence that these group differences on immediate free recall reflect more than just idiosyncratic task effects, rather, these groups likely reflect more fundamental cognitive differences between the groups which manifest themselves differentially in immediate free recall.

This could mean that individuals differ in their control processes and which control processes they choose to use on a given task (Atkinson & Shiffrin, 1968, 1971). Specifically, in immediate free recall individuals may choose a particular control process (e.g., phonological rehearsal vs imagery), they may be given a set of instructions that emphasise one process over another (e.g., report the last items first emphasising maintenance or retrieval), or the task characteristics may influence the choice of control processes (e.g., a long task vs a short task may emphasise more passive than active processes). In each, different combinations of processes will be utilised, thereby changing task performance and the pattern of performance that is generated. In many ways this can be seen as an example of differences in metamemory (Koriat, 2000; Nelson & Narens, 1990) whereby individuals will tend to utilise those strategies that they know will help them and will under-utilise those strategies that they know have not worked for them in the past.

As an example consider the serial position function shown in Figure 8, which is the aggregate serial position function across all lists and all participants. This function has clear primacy and recency effects, with performance on the first and last serial positions roughly being equal. However, the resulting function differs somewhat from what can be considered typical of immediate free recall serial position functions. Specifically, as shown by Murdock (1962) and others many times immediate free recall serial position functions have stronger recency (i.e., proportion correct approaching 1.0) than primacy effects. In the present case, however, recency is well below 1.0. Why might this be the case? The arguments presented in the current paper suggest that these differences are in part a function of the combination of processes that are used to perform the task. In some situations, with certain participants, it is possible to get serial position functions with equal primacy and recency effects (e.g., Glanzer & Cunitz, 1966; Postman & Philips, 1965). Specifically, when a short list of items (e.g., 10) is presented and only a few lists are presented (e.g., 10) then participants sometimes generate u-shaped serial position functions with equal primacy and recency. However, when longer lists are used and more lists are presented to the participant, recency effects tend to dominate primacy effects (e.g., Craik, 1970; Murdock, 1962). When presented with a very long list of items, or presented with many lists of items, participants may adopt a strategy where more effort is devoted to maintaining and emitting the last items presented (a somewhat passive strategy) rather than devoting much effort to rehearsing all of the items (see also Hockey, 1973 for a similar notion in running memory span). Additionally, it is possible to get serial position effects where recency is larger than primacy by encouraging participants to output last items first thereby influencing the probability of first recall (e.g., Bhatarah et al., 2008; Craik & Birtwistle, 1971; Dalezman, 1976). In other situations it is possible to get primacy effects that are larger or of equal magnitude to recency effects in immediate free recall. For instance, in Glanzer and Cunitz's (1966) Experiment 2, participants were given both immediate and delayed free recall trials in the same testing situation. Participants did not know if the trial was an immediate free recall trial or a delayed free recall trial until after presentation of the last word. Glanzer and Cunitz found that in the immediate free recall condition there was strong recency effect, but it did not approach 1.0 and it was slightly smaller than the primacy effect. In such a situation it is possible that participants adopted a rehearsal and retrieval strategy (as opposed to a maintenance strategy) on most trials because this strategy would provide the best performance on delayed free recall trials (which were two-thirds of all trials). Thus the reliance on some combination of processes is determined not only by participant characteristics, but also by the very nature of the task itself. In one situation participants may rely on one process more than another, but in another situation the very same participants may rely on a different combination of processes. What control processes participants utilise and in what combination or proportion will be determined by the participants abilities as well as different task and instructional characteristics (e.g., Jenkins, 1979). That is, the control processes will likely be determined by factors such as working memory capacity and susceptibility to proactive interference.

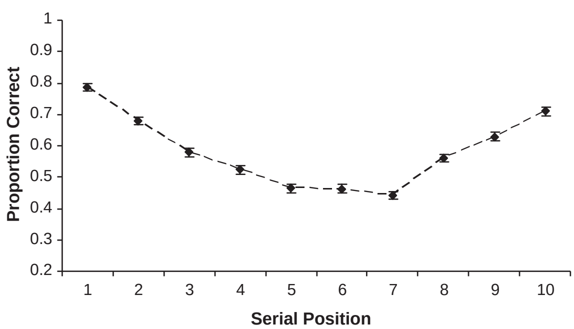

Figure 8. Proportion correct as a function of serial position. Error bars represent one standard error of the mean.

It should be noted that throughout we have emphasised the need for differences in strategic control processes in order to account for both inter- and intra-individual variation in immediate free recall. Although it may be possible to explain the current inter-individual differences results in terms of models that localise the differences to a single parameter (such as size of the primary memory that would influence the number of items that can be co-rehearsed) it is unlikely that such models would also be able to account for the intra-individual results as well. That is, it is unclear how a model would be able to fully explain why individuals differ in their pattern of performance, and why some individuals change their pattern of performance whereas others do not without invoking some notion of control processes and changes in control processes.

The current results have important implications for models of free recall. As noted previously, many memory models exist that can adequately account for serial position functions in immediate free recall. Most of these models rely on Murdock's (1962) dataset because it is one of the most comprehensive datasets ever collected. These serial position functions demonstrate both primacy and recency effects with the recency effects being much larger than the primacy effects. In order for a model of free recall to be considered viable it should (generally) be able to account for these serial position functions. However, as shown in the current paper, it is possible to generate several different serial position functions that differ in the magnitude of primacy and recency. Many models of free recall would likely be able to handle some of these variations in serial position functions with minor adjustments of parameter values, but this typically is not explored in terms of examining inter- and intra-individual differences and how these can lead to different functions. Furthermore, current models typically do not implement various control processes and allow for changes in control processes throughout the task, which both seem important in accounting for the current results. Hopefully as more data are collected demonstrating inter- and intra-individual variation in a number of tasks, cognitive models will follow suit and attempt to better explain the pattern of results. Note this is not to say that some models do not incorporate individual or group differences, rather many models don't (e.g., Lewandowsky & Heit, 2006).

Conclusion

In the current study we examined inter- and intra-individual variability in recall initiation strategies in immediate free recall. It was found that there was large and systematic inter- and intra-individual variation in recall strategies that were related to different profiles of performance on immediate free recall and were differentially related to cognitive ability measures. These results suggest that performance on a task can be due to the utilisation of different control processes that emphasise different components of task over others. Indeed, in discussing Jenkins' (1979) tetrahedral model, which suggests interactions involving acquisition variables, test variables, materials, and individual participants, Craik, Byrd, and Swanson (1987) noted, "There can be no simple general laws of memory; instead, we must look for lawful patterns of interactions to provide the basic data for our theories" (p. 79). Hopefully future research will be devoted to better examining inter- and intra-individual variation in cognitive processes with the aim of gaining a better understanding of how individuals utilise different control processes to a perform a task and how this variation interacts with other task variables.

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