PSIHOLOGIJA, 2002, Vol. 35 (3-4) 261-285 UDC 159.937.52.075

DYNAMICS OF SERIAL POSITION CHANGE IN PROBE-RECOGNITION TASK

Mario Fifić[1]
Laboratory of Experimental Psychology
University of Belgrade, Serbia, Yugoslavia

Relationship between practice and serial position effects was investigated, in order to obtain more evidence for underlying short-term memory processes. The investigated relationship is termed the dynamics of serial position change. To address this issue, the present study investigated mean latency, errors, and performed Ex-Gaussian convolution analysis. In six-block trials the probe-recognition task was used in the so-called fast experimental procedure. The serial position effect was significant in all six blocks. Both primacy and recency effects were detected, with primacy located in the first two blocks, producing a non-linear serial position effect. Although the serial position function became linear from the third block on, the convolution analysis revealed a non-linear change of the normal distribution parameter, suggesting special status of the last two serial positions. Further, separation of convolution parameters for serial position and practice was observed, suggesting different underlying mechanisms. In order to account for these findings, a strategy shift mechanism is suggested, rather then a mechanism based on changing the manner of memory scanning. Its influence is primarily located at the very beginning of the experimental session. The pattern of results of errors regarding the dynamics of serial position change closely paralleled those on reaction times. Several models of short-term memory were evaluated in order to account for these findings.

Key words: *short memory, serial position, probe-recognition task*

The probe-recognition task is a standard paradigm in short-term memory research. It was introduced by Sternberg (1966), and consists of a list of memorized items (memory list) and a subsequently presented probe-item. The subject has to decide whether a probe-item had been a member of the previously presented memory list. Response latency is measured from the probe onset. The probe recognition task is also referred to as the memory search task. The present study will focus on the effects of practice and serial position on memory search.

[1] Author's address: mfific@indiana.edu

The effect of **practice** on short-term memory retrieval has been demonstrated in a number of investigations, showing that practice speeds up retrieval time and improves accuracy (Burrows & Murdock, 1969; Krueger, 1970; Simpson, 1972; Schneider & Shiffrin 1977; Shiffrin & Schneider, 1977). These studies also showed that extensive practice reduced the set-size effect, suggesting that short-term memory retrieval becomes independent of the number of items to be scanned. It should be noted that the effect of practice on memory search has been mostly investigated in the consistent mapping procedure (CM), in which distractors are drawn from a set of items which are not members of memory set ("no" responses), i.e. they are never used as targets ("yes" responses). This procedure is largely influenced by prolonged practice and produces a flat set-size effect, which suggests that retrieval time does not depend on the number of items that are to be scanned in memory. Reduction of the set-size effect is explained as a shift from controlled to automatic processing or, to put it differently, from serial to parallel processing (Schneider & Shiffrin 1977; Shiffrin & Schneider, 1977; Shiffrin & Schneider, 1977). In the varied mapping procedure (VM) targets and distractors are drawn from the same set (for example, Sternberg, 1966, 1969; Burrows & Murdock, 1969). In contrast to the consistent mapping procedure, in the varied mapping procedure extensive practice has little influence on memory search. Although the varied mapping procedure reduces the set-size effect, it remains stable at 20-40 ms (Burrows & Murdock, 1969; Logan, 1978). The VM procedure has received less attention, and most of investigations focused on the CM procedure. Regardless of this fact, in the present work it is postulated that the influence of the varied mapping procedure is substantial and necessary in order to understand memory mechanisms. In the present study the varied mapping procedure is used in order to investigate the effect of practice on serial position.

In the “yes” responses a probe-item could be differently positioned within the memory list. This is referred to as the serial position of the probe-item and was one of the main factors of interest in short-term memory research. In his standard probe-recognition task, Sternberg obtained linear and parallel set size functions for both “yes” and “no” responses. Additionally, he did not find a significant relationship between serial position of a probe and a response latency (Sternberg 1966, 1969). Sternberg suggested exhaustive serial short-term memory search: in the memory search task, all memorized items are serially compared with the probe, regardless of the possible positive match that may occur somewhere in the list.

In contrast to Sternberg’s findings, a large number of studies reported significant serial position effects with a strong **recency** effect (i.e. faster processing of last presented items) in addition to rarely observed somewhat weaker **primacy** effect (i.e. faster processing of first items in the list) (Corballis, 1967; Morin, De Rosa, & Shultz, 1967; Clifton & Birenbaum, 1970; Burrows & Okada, 1971; Corbaliss, Kirby, & Miller, 1972; Forrin & Cunningham, 1973; Aube & Murdock, 1974; Ratcliff, 1978; Monsell, 1978; McElree & Dosher, 1989). More generally, subsequent investigations demonstrated that the so-called "slow procedure" is most likely not producing serial position effects. This procedure is characterized by long exposure of items in the memory list (about 1sec), and long pre-probe delays (about 2sec). On the other hand, the so-called "fast procedure" is most likely to produce significant serial position effects with typical recency and primacy components. The fast procedure uses short exposure of memory items (less then 1sec) and shorter pre-probe delays (1sec or less).

The standard serial hypothesis implies equality between all short-term memory representations. Sternberg suggested than in a probe-recognition task total retrieval time consists of the following additive components: encoding, decision, response, plus matching each memory representation with the probe-representation (Sternberg, 1969). If the first three processes are kept constant in an experiment, with the number of items in the memory list being the only variable, retrieval time will depend only on the number of items to be scanned. If the scanning process is assumed to be serial and exhaustive, with a constant rate (Sternberg, 1969), and if memory representations are equally represented in memory, no serial position effect is expected. The absence of the serial position effect was demonstrated in several studies, which used the slow experimental procedure (Sternberg, 1969; Clifton & Birenbaum, 1970; Hockley, 1984).

Another class of serial models is the serial self-terminating models. They assume that scanning is serial and performed up to the last memory representation. If a positive match occurs, the scanning stops resulting in a decision. These models predict a positive serial position effect, under assumption that short-term memory representations are equally represented. If scanning goes from the first to the last memory representation, and if scanning is terminated as soon as the positive match occurs, reaction time will increase as a function of serial position, indicating a strong primacy effect. This type of serial position effect is rarely observed in probe-recognition tasks. It is more often obtained in the visual scanning task, where subjects visually scan multielement displays in search for a pre-memorized probe (for more reviews see Van Zandt & Townsend, 1993).

The serial position effect obtained in the fast procedure challenged the exhaustive serial short-term memory model. It was a matter of controversy whether serial models could account for the serial position effect, at all. Modifications of Sternberg's serial-exhaustive model were suggested in order to preserve serial processing. In addition to serial exhaustive search, a kind of rapid non-serial search was postulated: Clifton & Birenbaum (1970) proposed a distinct temporal store for last presented items, previously suggested by Waugh & Norman (1965). The store is assumed to have capacity of 2-3 items with persistence of one or two seconds. Similarly, Forin & Cunningham (1973) proposed a two-process model, suggesting that in active memory two-comparison process run off concurrently. While some memory representations are accessed by exhaustive serial scan, others are accessed by a process similar to physical identity match, suggested by Posner et al. (1969). It is implied that the second comparison is influenced by the time period during which the representations have been stored. Posner (1969) suggested that within short retention interval, memory representation is based primarily on the sensory codes that are easily accessed. In a memory search task with short delays, last presented items have the strongest memory representation based on additional sensory codes, and therefore are easy to retrieve. This may account for the recency effect of serial position. On the basis of Posner’s finding, Burrows & Okada (1971) suggested two different modes of accessibility: each memory item could be either in a high or a low accessibility state. If an item is in the high accessibility state it can be more easily compared with the probe-item.

The presented models are based on modifications of Sternberg's original serial-exhaustive processing model (1969). Modifications were made in order to account for recency effects obtained in the fast experimental procedures. Modified serial-exhaustive models will be referred to as "hybrid two-process models". Their common assumption is the existence of two separate retrieval mechanisms (or processes).

The class of hybrid serial models lessened the implication of equality of short-term memory representations (Clifton & Birenbaum, 1970; Forrin & Cunnigham, 1973; Burows & Okada, 1971). It is suggested that short-term memory representations, which entered memory last, are stored in a different format. This class of models preserved serial exhaustive processing combined with fast direct processing which is likely to be based on sensory information (Posner 1969, Sperling 1960). This view can be criticized on the basis of plausibility of functional and temporal distinctiveness of short-term store. It was demonstrated that the immediate repetition effect was not due to the physical match between the last item in the list and the probe-item. If memory items are uppercase and probe-items are lower-case letters, the magnitude of the recency effect remains the same, as if both are from the same letter case set (McElree & Dosher, 1989). A second line of evidence in favor of a single-process mechanism is based on the recency effect for negative probes: it was demonstrated that recent presentation of negative probes from previous trials produced slower and less accurate responses (Atkinson, Herrman & Westcourt, 1974; Monsell, 1978; McElree & Dosher, 1989). Thus, both findings suggest more abstract properties of memory representations, such as strength or familiarity, to be the principal factor in retrieval.

The alternative class of models assumed that the short-term store is scanned in parallel, with simultaneous processing of all memory items. This may suggest that parallel processing produces neither set-size nor serial position effects. However, some parallel models are capable of mimicking some serial models (Townsend, 1971, 1972 for a further discussion see also Townsend 1990) producing a pattern of results, which could be interpreted as serial processing.

Direct and/or parallel models account for set-size and serial position effects in two ways. The first approach is advocated by Murdock (1971) and Ratcliff (1978), (see also Townsend & Ashby 1983) who suggested a dependence between the number of items in memory and the comparison process. The size of the memory set is assumed to affect the comparison process. In Ratcliff’s (1978) model, set-size affects comparison time indirectly through the strength of the memorized representation. As outlined by Ratcliff, the larger the comparisons set, the lower the degree of relatedness with the probe-item. A second line of reasoning is presented in the direct-access approach, which assumes that the strength of an item's representation is determined by the item's serial position. The strength value determines reaction time, while comparison time is independent of the number of processing items (Corballis, Kirby & Miller, 1972; Baddeley & Ecob, 1973; Anderson, 1973). The direct-access approach is based on an extension of principles of the trace-strength theory (Norman & Wilckgren 1969, Wilckgren & Norman, 1966), and is consistent with a number of strength-based memory models such as Matched-filter Model (Anderson, 1973), MINERVA (Hintzman, 1984), SAM (Gillund & Shiffrin, 1984), and TODAM (Murdock, 1982; 1996).

Strength-based models can account for the recency effect observed in the fast experimental procedure. Memory strength of the last presented items is more vigorous allowing easy access during short-term memory scanning. In contrast to the two-process models, the strength-based models account for the position effect by postulating a one-dimensional strength value of memory representations, stored along with item information. If we assume that the representation strength value decreases by decay or interference, it could be expected that representations which entered memory last should have the strongest trace, and therefore should be accessed faster, thus producing the recency effect. It is suggested that in the slow experimental procedure, longer retention intervals allow partial rehearsal to affect stored memorized representations, thus reducing the recency effect (Seamon & Wright, 1976).

Serial processing models could also be accommodated to account for the recency effect. In the conveyor-belt model, Murdock suggested serial-backward scanning of memorized items (Murdock & Anderson, 1975; Murdock, Hockley & Muter, 1977). The consecutively presented items are encoded and stored with their serial order maintained, much like items on a conveyor belt. Because the belt is constantly in motion, items are getting older continuously. A comparison process starts from the memory presentation, which entered short-term store last, and stops on the positive match. Retrieval speed depends on the item's position in the list that is on the relative duration of an item. Unlike some serial models which assumed equality of memorized items, the conveyor-belt model allows memory representations to have different statuses, while maintaining the order of scanning, but in the opposite direction, i.e. from the most recent ones to the remotest one. If constant scanning rate for each item is assumed, the conveyor-belt model predicts linear decrease of reaction time as a function of serial position.

ANALYSIS OF RESPONSE TIME DISTRIBUTIONS

Additional insight concerning distinctions between cognitive structures can be obtained from the properties of response time distribution. Several studies examined whether convolutions of normal and exponential distributions provide a good description of the observed response distributions. They also tested whether convolutions yield parameters that are relevant for evaluation of specific models of cognitive processing (Ratcliff, Murdock, 1976; Ratcliff, 1978; Hockley, 1984). The ex-Gaussian distribution is a convolution of the normal and the exponential distribution. It is characterized by three parameters: μ and σ being the mean and the standard deviation of normal distribution, and τ being the mean of the exponential distribution. The convolution analysis applied to a variety of recognition paradigms showed that the distinction between different recognition paradigms could be made by observing the change of convolution parameters (Ratcliff & Murdock, 1976; Ratcliff, 1978; Hockley & Corballis, 1982, Hockley, 1982; Hockley, 1984).

Convolution analysis was used to distinguish between memory search models. It is assumed that serial processing with constant comparison rate should be largely reflected in change of μ (shifting the body of normal distribution). In contrast, it was generally observed that increase of reaction time is paralleled by increase of the τ parameter (positive tail of distribution) (Ratcliff & Murdock, 1976; Ratcliff, 1978; Hockley & Corballis, 1982, Hockley, 1982). Although those findings seriously challenged standard serial processing models, Hockley (1984) suggested that if the comparison process is assumed to be extremely variable, serial processing is still tenable. Thus, to completely distinguish between serial/parallel processing it is not sufficient to detect separation of the of convolution parameters.

The relationship between **serial position** of a probe-item and convolution parameters was discussed in several investigations. In a probe-recognition task which maximized the serial position effect (fast procedure), while set-size and serial position varied, Ratcliff (1978) reported a change of convolution parameters which supported his random-walk diffusion memory model. Ratcliff assumed that latencies for “yes” responses vary with set-size and "relatedness". Relatedness value was defined as the degree of match between a probe-item and a retrieved item representation, and is assumed to vary as a function of serial position. Ratcliff reported parallel set-size effects (“yes” and “no” responses), while serial position indicated a recency effect. Both μ and τ decreased as function of serial position, that is paralleled by decrease in mean reaction time as well. He discussed whether the relatedness value of each serial position item could be treated as a free parameter or as a functional relation. Ratcliff left this problem for some future explorations. For the present study this relationship is of the utmost interest.

Using a probe-recognition task with the slow procedure, Hockley (1984) varied both set-size and serial position. He replicated Sternberg’s (1969) parallel set-size functions for both “yes” and “no” responses, with a non-significant serial position effect. Hockley did not report the outcome of convolution analysis on serial position. Nevertheless, some conclusions could be drawn from his forced-choice recognition task (Hockley, 1984). This task is similar to the single-probe recognition task, the only difference being the presentation of two-item probe (top and bottom items). Subjects have to decide whether one of the probe items was a member of the previously memorized set. In addition to this procedural difference, Hockley's forced-choice recognition task utilized the fast procedure, which maximizes serial position effects. Serial position was significant for each set size (3 to 6) with the strong recency and weak primacy effects. The fact that the position of the probe-item did not differentially affect the pattern of serial position functions may suggest that inferences derived from Hockley's (1984) forced-choice experiment could be used in the evaluation of convolution parameters in the same manner as it was in the standard probe-recognition task. However, Hockley demonstrated that both μ and τ decrease as a function of serial position at relatively comparable rates.

SUMMARY

The influence of **practice** on probe-recognition reaction time was extensively investigated. Nevertheless, there is no evidence for the effect of practice on **serial position** in the fixed set-size recognition paradigm. Most studies focused on the relationship between practice and set-size. The set-size effect is believed to be the crucial variable to affect the number of memory comparisons in serial short-term memory modeling, while serial position is considered to be of secondary importance. The aim of this study is to allow for more detailed insights into the relation between practice and serial position, when set-size is kept constant. In the present investigation a fixed-sized memory set is used in order to minimize task complexity. On the other hand, it should allow for fast processing accommodation, which could help easier observation of the dynamics of change within a few blocks of trials. Also, the fast procedure will be used in order to produce significant serial position effect.

Although there is general agreement that the fast procedure produces recency effects, it is questionable which conditions produce the rarely observed primacy effect. Some authors suggested that faster processing of the first presented items could be attributed to partial rehearsal of the items at the beginning of the memory list (Corballis, 1972).

It is generally acknowledged that practice has strong effects on short-term memory retrieval. In the present study the effect of practice on item retrieval with respect to its serial position will be referred to as the **dynamics of serial position change**. Nevertheless, in most investigations this variable is kept constant and is not elaborated in detail.

Of secondary interest is the relationship between **practice** and **serial position** on one hand, and the change of the **convolution parameters** on the other hand. It is somewhat surprising that there is no detailed study of the effects of practice on convolution parameters. Practice is considered to take information processing to the optimal level. The optimization of short-term memory processing reduces the average processing time and improves accuracy. If practice produces systematic variability of reaction time, which is non-homogeneous with respect to the overall shape of latency distribution, it may influence our inferences about short-term memory processing based on the convolution analysis. If this is not taken into consideration, practice could be confounded with some properties of processing mechanisms.

If practice affects mechanisms of short-term memory processing differently, and if convolution parameters are influenced by these mechanisms, we may observe separation of these parameters.

EXPERIMENT

Method

Subjects. 21 students from the Faculty of Transport and Traffic Engineering of the University of Belgrade participated in the experiment. Subjects were divided in two groups and were tested simultaneously in six blocks of tasks.

Stimuli and procedure: The stimulus set consisted of digits ranging from 0 to 9. Each trial was self-paced. A warning signal (three asterisks) with exposure duration of 1000 ms preceded the memory set which consisted of six digits consecutively presented for 1000 ms at the fixation point in the middle of the screen. After a preprobe delay of 750 ms, a warning signal (three blank characters) was presented at the fixation point for 200 ms. 50 ms after the warning signal the probe-item was presented for 100 ms. Subject's task was to answer by pressing a yes/no key whether the probe-item has been a member of a preceding memory set. Response latency was measured from the probe-item onset. Subjects were instructed to respond as quickly and as accurately as possible. The experiment was performed on PC-586 computers.

The practice session consisted of 24 trials. The experimental session consisted of six blocks, while each block consisted of 8 practice trials, and 48 experimental trials. Each block had an identical structure of trials, since every subsequent block was made from the previous one by increasing its digits' value by one (new value = old value+1). Subjects performed three blocks in a row, and after a 15 minutes break continued with another three blocks. Each subject saw the same order of blocks.

Three factors were manipulated: a. type of response (yes/no), b. practice expressed as the number of trial blocks (1-6), and c. serial position of the probe item (1-6) for the positive responses.

Results

Mean response latencies as a function of practice, for both “yes” and “no” responses are presented in Figure 1. An analysis of variance on subject variability showed no significant main effect of practice. The type of response was significant $F(1,20)=46.11$, $p<0.01$; “yes” responses were significantly faster. The type of answer by practice interaction did not reach significance. The analysis for “yes” responses indicated that the effect of practice for “yes” responses was not significant.

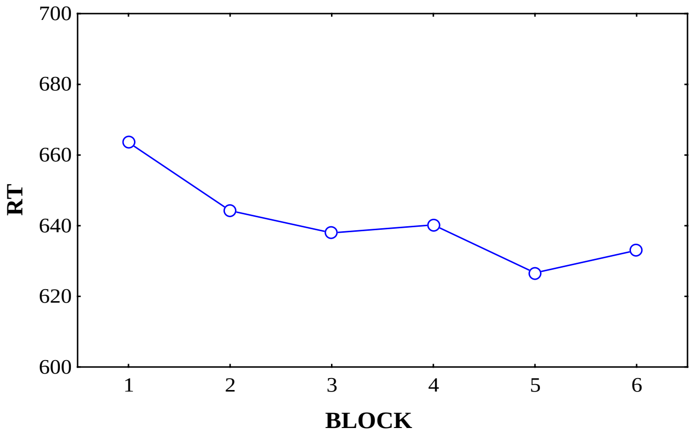


Figure 1: Mean response latencies as a function of block of work (practice).

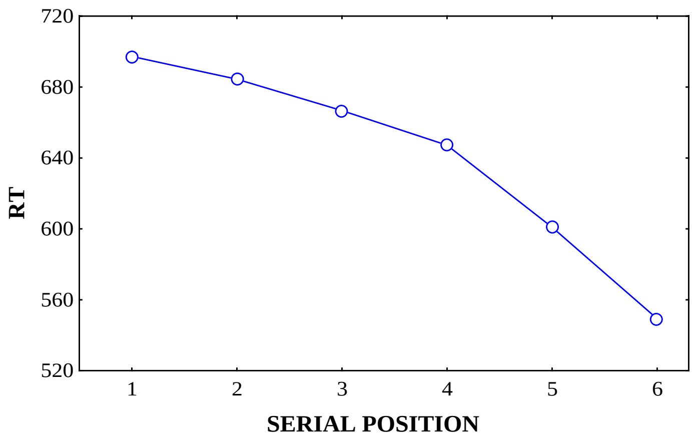


Figure 2: Mean response latencies as a function of serial position of the probe in the memory list, for "yes" responses.

The serial position effect for "yes" responses, averaged across order of blocks was significant: $F(5,100)=26.46$, $p<0.01$, indicating strong recency effect (Figure 2). The practice by serial position interaction was also significant $F(25,500)=2.14$, $p<0.01$. The serial position effect for each block was tested, and results are presented in Table 1. Each block produced a significant serial position effect.

Table 1: Partial ANOVA tests for serial position effect for blocks of work, d.f.(5,100).

Block No	F value	significance
1	3.17	$p<0.05$
2	9.06	$p<0.01$
3	18.85	$p<0.01$
4	10.15	$p<0.01$
5	8.54	$p<0.01$
6	6.09	$p<0.01$

The further analysis will take a more detailed look at the practice by serial position interaction. The results of 5 partial interactions between each of two subsequent trial blocks by serial position are presented in Table 2.

Table 2: Partial interaction for each two subsequent trial blocks by serial position, d.f. (5,100), "ns" denotes nonsignificant interaction.

Trial Blocks	significance
1-2	$F=2.075$, $p=.075$
2-3	$F=3.83$, $p<0.01$
3-4	$F=2.3$, $p=0.05$
4-5	ns
5-6	ns

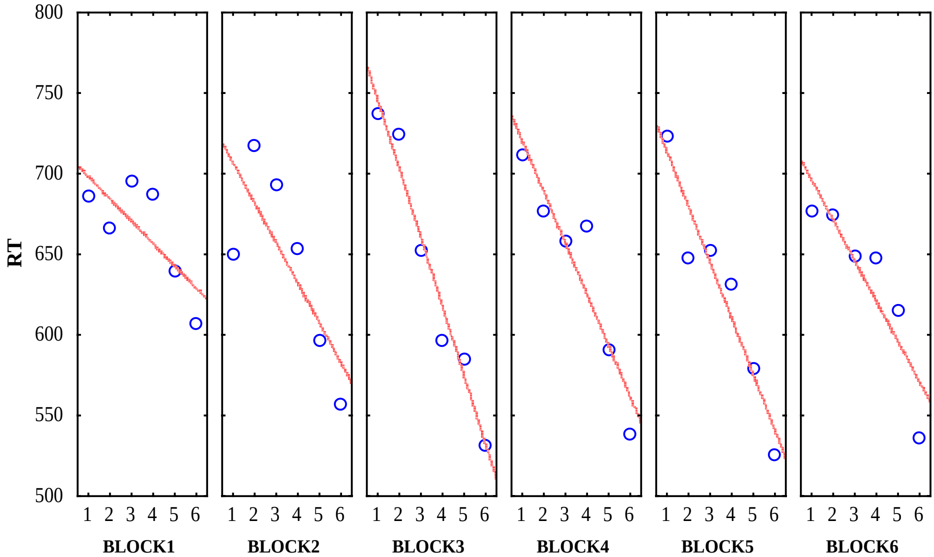
Inspection of Table 2 shows that for the last three trial blocks, there is no interaction between subsequent blocks and serial position. This suggests that from the fourth block on the retrieval function reaches some processing optimum, producing very small differences in retrieval.

Regression analyses of serial position functions

Regression analyses between serial position and reaction time were performed to determine the dynamics of retrieval change for each block. Quadratic and linear relation between mean reaction times and serial position for each block are presented in Table 3. Figure 3 depicts relation between reaction time and serial position for each block.

Inspection of Figure 3 suggests a primacy effect in the first and the second block, i.e. faster processing of the first items in the memory. The primacy effect is reduced with the beginning of the third block. The recency effect, which is evident in faster processing of the last presented items, appears in all blocks. Practice increases the recency effect immediately after the first block, and after that the recency effect maintains its value until the last block.

Figure 3: Relation between mean reaction time and serial position of the probe for "yes" responses.



Additional insights about the dynamics of serial position change could be deduced from the intercept and slope change in linear regression. In the following analyses the first and the second block will be excluded, assuming that they are heavily influenced by practice. Table 3 and Figure 3 indicate that intercept values for functions 3, 4, 5 and 6 decrease with blocks. The significant proportion of explained variability indicates that the intercept value linearly decreases with practice, which can be calculated as follows: intercept = -21*block + 803, $F(1,2)=23.34$, $r2=0.92$, $p<0.05$ This relationship accounts for 92% of intercept variability. Although the slope value does not correlate with practice, inspection of Table 3 suggests that there is a reduction of slope value due to practice from the third block on.

Table 3 and Figure 3 indicate quadratic relationship between reaction time and serial position for most blocks. Nevertheless, after the substantial reduction of primacy (from the third block on), this relationship appears to become linear, with quadratic and linear regression models giving similar predictions. Additional analyses were performed on each block in order to test the difference between linear and quadratic linear regression models (see Appendix 1). The analyses were performed on blocks 4 and 6, which indicated a higher coefficient of determination (r^2) for the quadratic then for the linear regression model. The outcome showed nonsignificant differences between linear and quadratic trends: block 4,

$F(1,3)=2.769$, p=n.s.; block 6, $F(1,3)=9.061$, $p=0.057$. Thus, from the third block on, the quadratic regression model did not give a substantially better prediction[2].

Table 3: Regression analyses of quadratic and linear trends of mean reaction times as a function of serial position, for each block. Data are averaged across all subjects. The following regression parameters are presented: regression model (LIN - linear and, QUA - quadratic regression), Rsq - proportion of explained variance, d.f. - degrees of freedom, F and p; C, A and B are parameters of regression equations. Linear regression model: $RT = A*sp + C$, Quadratic regression model: $RT = B*sp^2 + A*sp + C$ ("sp" denotes serial position value 1-6).

BLOCK	Mth	Rsq	d.f.	F	p	C	A	B
1	LIN	.575	4	5.42	.080	712	-14	
1	QUA	.852	3	8.63	.057	651	32	-6.58
2	LIN	.605	4	6.12	.069	731	-25	
2	QUA	.902	3	13.88	.030	620	59	-11.9
3	LIN	.966	4	113.93	.000	788	-43	
3	QUA	.967	3	43.34	.006	794	-47	.64
4	LIN	.875	4	27.93	.006	752	-32	
4	QUA	.935	3	21.52	.017	698	8	-5.71
5	LIN	.921	4	46.33	.002	748	-35	
5	QUA	.928	3	19.27	.019	728	-20	-2.10
6	LIN	.803	4	16.35	.016	721	-25	
6	QUA	.951	3	29.03	.011	653	26	-7.36

In conclusion, it can be suggested that serial position function turns from quadratic into linear after the second block; while the intercept and the slope values tend to decrease with practice (actually, slope value increases from negative toward zero value).

Partial ANOVA for "yes" responses performed on the first and on the second part of the memory list

The previous analyses showed significant serial position by practice interactions (block 1 to 4, Table 2). Additional analyses may be required in order to clarify these interactions. Since the greatest effect of practice was manifested in the reduction primacy and increase of recency effects, two separate sets of analyses ANOVA were performed: (a) on the first three serial position (primacy component), and (b) on the second three serial positions (recency component). The contrast between these two sets of tests may provide further insights into the dynamics of serial position change.

[2] In testing the difference between regression models, F ratio for the last block was of marginal significance, which means that quadratic relationship is somewhat better then linear, and could be excepted from previous suggestion.

Partial ANOVA performed on the **first three positions** did not indicate significant effects of practice and serial position, while position by practice interaction was significant: $F(10,200)=2.357$, $p<0.05$. Partial ANOVA performed on the **last three positions** showed significant main effect of practice: $F(5,100)=3.2$, $p<0.05$; mean reaction time monotonically decreases in non-linear fashion as a function of practice. In addition, serial position was significant: $F(2,40)=36.9$, $p<0.01$, indicating a strong recency effect, while serial position by practice interaction did not reach significance.

The outcomes of the two tests are inversely related, suggesting a difference in dynamics of primacy and recency components of reaction time. Main discrepancies derive from differences in primacy and recency sensitivity due to practice. Practice heavily affects the last three positions, producing monotonic decrease of reaction time. In contrast, the effect of practice on the first three positions shows non-specific change: the practice effect is non-monotonic, that is evident from the significant interaction between the first three positions and practice. Thus, both primacy and recency effects are sensitive to practice, although practice influences recency in more straightforward manner.

Analyses of errors

An analysis of variance based on subject mean errors showed no significant effect of practice. The type of response (“yes” and “no) and type of response by practice interaction did not reach significance.

Separate analyses for “yes” responses indicated no significant effects of practice, while serial position reached significance: $F(5,100)= 13.1$, $p<0.01$, indicating a recency effect (table 4, column on the right). Serial position by practice interaction was not significant, although it was of marginal significance $F(25,500)= 1.42$, $p=0.08$. Mean percent of errors as a function of the serial position for each block of work is presented in Table 4 (bottom row).

Table 4: Mean percent of errors as a function of serial position for each block. Left and bottom marginal tables show mean percent error as a function of serial position and practice, respectively.

Serial position	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	mean
1	10.71	9.52	10.71	13.10	15.48	8.33	11.31
2	14.29	11.91	13.10	21.43	15.48	10.71	14.48
3	20.24	16.67	7.14	9.52	9.52	4.76	11.31
4	5.95	7.14	8.33	3.57	2.38	2.38	4.96
5	9.52	4.76	8.33	2.38	4.76	4.76	5.75
6	0.00	1.19	1.19	0.00	1.19	1.19	0.79
mean	10.12	8.53	8.14	8.33	8.14	5.38	

Regression analysis on errors

In order to determine the dynamics of change of retrieval functions, regression analyses on mean percent of errors as a function of serial was performed for each block. Results from the regression analysis (quadratic and linear) are presented in Table 5. The regression analyses are performed on the mean percent of errors as a function of serial position for each block.

The regression analyses on errors (Table 5) parallel those performed on reaction time. The relation between reaction time and serial position becomes linear from the third block on. It is evident from Tables 4 and 5 that serial position functions for the first and the second block show similar shape: error rates increase up to the third position, afterward they sharply decrease, indicating primacy and recency effects. A peak of percent of errors was produced at the middle serial position. From the third to the sixth block serial position functions are linear, while the peak of error percent shifted to the first position. (Table 4). Although practice did not significantly reduce the overall error rate, the marginal interaction between practice and serial position suggests that practice had reallocated the high error rate from the middle of the list position to its beginning. At the same time, practice transformed the non-linear serial position error curve to the linear one.

Table 5: Regression analyses of quadratic and linear trends of mean percent of errors as a function of serial position, for each block. Data are averaged across all subjects. Following regression parameters are presented: regression model (LIN - linear and, QUA - quadratic regression), Rsq - proportion of explained variance, d.f. degrees of freedom, F, and p ; C, A and B are parameters of regression equations. Linear regression model: Error% = A*sp + C, Quadratic regression model: Error% = B*sp^2 + A*sp + C ("sp" denotes serial position value 1-6).

BLOCK	Mth	Rsq	d.f.	F	p	C	A	B
1	LIN	.401	4	2.68	.177	.73	-.09	
1	QUA	.680	3	3.18	.181	.23	.28	-.054
2	LIN	.507	4	4.11	.113	.63	-.08	
2	QUA	.779	3	5.29	.104	.24	.21	-.042
3	LIN	.656	4	7.61	.051	.57	-.07	
3	QUA	.739	3	4.24	.134	.41	.05	-.017
4	LIN	.731	4	10.88	.030	.85	-.15	
4	QUA	.735	3	4.17	.136	.78	-.09	-.007
5	LIN	.865	4	25.60	.007	.77	-.13	
5	QUA	.879	3	10.91	.042	.87	-.20	.011
6	LIN	.692	4	9.00	.040	.44	-.06	
6	QUA	.695	3	3.41	.169	.46	-.08	.003

Averaged error serial position curve highly correlates with reaction time curve (r(mean RT, mean error%) = 0.89, $p<0.05$). This suggests that errors accurately reflect properties of memory processes, which are indicated in reaction time. Therefore, they could be used as an additional confirmation of previous conclusions about the dynamics of memory properties drawn from the reaction time analyses. Also, the relationship between reaction time and error rate suggests the absence of the speed-accuracy trade-off.

Analyses of reaction time distributions

In the present experiment the two principal variables, serial position (1-6) and practice (block 1-6) give a total of 36 response latencies distributions. These distributions were fitted by the convolution of normal and exponential distributions by the SIMPLEX method (Nelder & Mead, 1965). The goodness of fit of the convolution analysis was determined by a Chi-square goodness of fit statistic. Out of 36 fits, only one fit was significant by the Chi-square test.

A cross-correlation of all convolution parameters was performed. Of the three cross-correlated tests, only the correlation between μ and σ was significant. A linear regression model shows significant linear relationship between μ and σ: $F(1,34) = 135.25$, $R^2=0.80$, $p<0.01$, for $\mu = 1.21*\sigma + 347$. This means that 80% of μ variability can be explained by variability of σ. This finding will be discussed later.

Analysis of convolution parameters as a function of serial position, pooled over practice

The obtained parameters μ, σ and τ for each serial position, averaged across subjects and block, are presented in Figures 4, 5, 6 respectively.

Regression analyses were performed in order to determine the relationships between convolution parameters' estimates and the serial position. Figures 4, 5, 6 show that all parameters' values decrease with serial position.

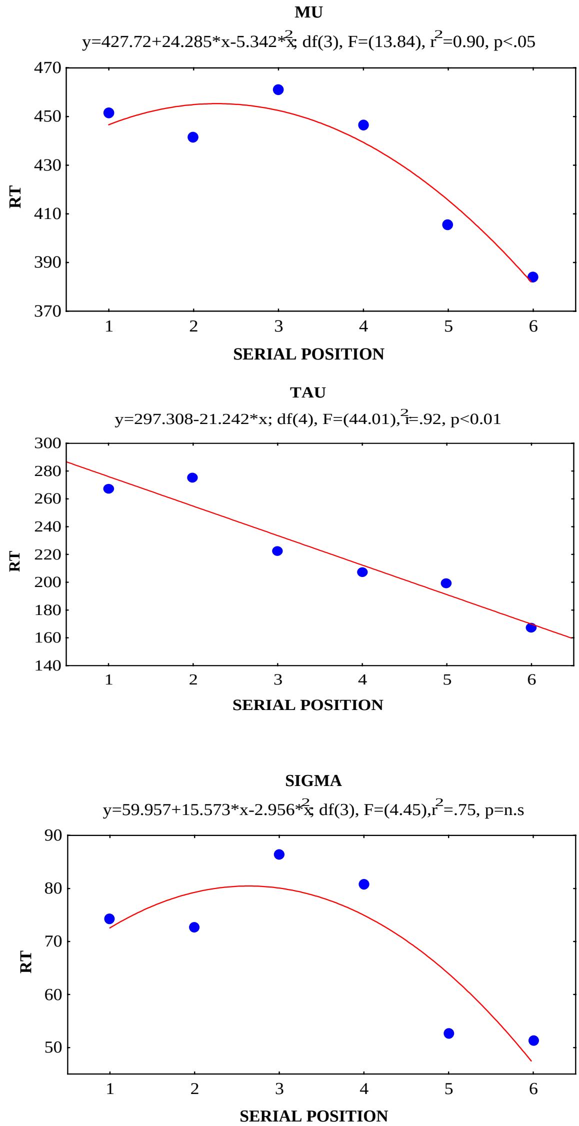
Regression analyses revealed a quadratic relation between μ and serial position (Figure 4), df(3), F=(13,84), $r^2=0.90$, $p<0.05$; the value of μ is sharply decreasing after the fourth position. The relationship between σ and the serial position could not be captured neither with linear nor with quadratic function (Figure 5). The shape of the σ serial position function is similar to the one of μ.

Mean parameters' estimates μ and σ pooled over blocks are highly correlated: $r(\mu, \sigma)= .957$, $r^2=.92$, $p<0.01$. A slope parameter of linear regression between μ and σ is 1.98, $F(1,4) = 43.4$; $r^2=0.92$, $p<0.01$; for $\mu = 1.98*\sigma + 293$; this suggests that the magnitude of change in μ is twice as big as that in σ.

In contrast to μ and σ, the relationship between the value of τ and the serial position is linear (Figure 6). A linear regression showed that the value of the τ parameter linearly decreases with serial position, averaged over block: $F(1,4)=44.01$, $r^2=0.92$, $p<0.01$. The value of slope (21ms) indicates the rate of decrease of the tail of the latency distribution as a function of serial position.

The value of τ, averaged over trial blocks, does not correlate either with the value of μ or with σ.

Figures 4, 5 & 6: Mean distribution parameter estimates (μ, τ and σ) for "yes" responses as a function of serial position. Regression analyses performed on mean parameter estimates are presented at the top of each Figure.



In convolution analyses both μ and σ reflect properties of the normal distribution. In the present experiment revealed that they are closely related. This suggests either their mutually dependency, or that they are affected by some common process. Changing the value of one parameter produces linear change in other parameter. When serial position of the probe produces decrease of mean value of normal distribution, deviation will decrease as well, and vice-versa. In contrast to μ and σ values, which decrease sharply as a function of the serial position, τ parameter decreases at constant rate. This suggests that serial position affects tail component independently form the mean and the deviation components of normal distribution.

Analysis of convolution parameters as a function of practice, pooled over the serial position

The obtained parameters μ, τ, and σ for each block, averaged across subjects and serial position, are presented in the Figure 7.

Non-linear regression analyses were performed in order to determine the relationship between convolution parameters' estimates and practice. Goodness of fit of the non-linear regression was determined by a Chi-square goodness of fit statistic. Results of the non-linear regression analysis are presented in Figure 7. The same polynomial function was used to fit both μ and σ, while inverse of that function was used to fit τ values (see top of the Figure 7). An estimate of regression parameters was performed using both Simplex and quasi-Newton algorithms. Obtained estimation parameters for both algorithms showed similar values of estimated parameters.

Regression analyses indicated that the first block produced the most dramatic changes in all convolution parameters. Beginning with block two, convolution values get stable and show moderate changes. After the first block, the mean and the deviation of the normal distribution decrease, unlike the value of the tail parameter which sharply increases.

As in previous analyses, which were pooled over serial positions, the present analyses, pooled over blocks, demonstrate a positive correlation between convolution parameters μ and σ: the linear regression shows a significant correlation between μ and σ: $F(1,4) = 79$; $r^2=0.95$, $p<0.01$; for $\mu = 1.1^* \sigma + 355$. The slope value of 1.1 suggests that both parameters change equally with practice.

MU=456.81+(-202.66)/b+(232.12)/b^2, r^2=0.96, Chi=n.s.

TAU=1/((0.0052)+(-0.0044)/b+(0.0045)/b^2), r^2=0.90, Chi=n.s.

SIGMA=80+(-122.486)/b+(160.6618)/b^2, r^2=0.97, Chi=n.s.

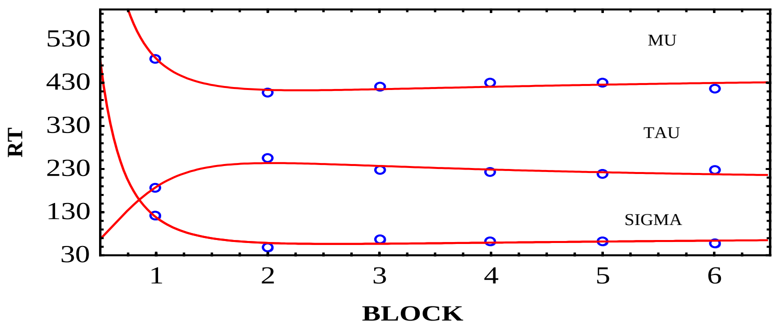


Figure 7: Non-linear regression of convolution parameters μ and τ and σ as a function of practice. Regression functions are presented on the top, together with goodness of fit statistics (d.f. 5).

The τ parameter is fitted by the function inverse to the one used to fit μ and σ (see Figure 7). A linear regression between μ and τ shows significant correlation: $F(1,4)=32.8$; $r^2=0.89$, $p<0.01$; for $\mu = -1.2\ \tau + 711$. The negative slope value of -1.2 indicates an inverse relationship between μ and τ; decrease in μ is accompanied with an increase in τ and vice-versa; the increase of 1 ms of τ value is followed by the decrease of 1.2 ms in μ value.

Inspection of Figure 7 indicates that the main source of variability of convolution parameters comes from the first block. If the first block mean value diverges from others, it may spuriously induce a high correlation. Thus, the obtained high correlation between μ and τ could be brought into a question. In order to test whether there is a practice effect, an additional analysis was performed with the first block being excluded. A linear regression shows significant correlation between μ and τ: $F(1,3)=19.4$, $r^2=0.87$, $p<0.05$; for $\mu = -0.65^*\ \tau + 571$. So, even with the first block being excluded, linear regression indicated a significant correlation, with the slope value being -0.65. Contrasted with the analysis performed with the first block, the relation between μ and τ has the same negative trend, i.e. they are inversely related. The outcome of this analysis suggests that practice significantly influences convolution parameters μ and τ, even with the first block being excluded.

Conclusions on convolution analysis

The convolution analysis performed on reaction time distributions demonstrated that practice and serial position significantly influence values of estimated convolution parameters.

In the present experiment, using all fitted samples of latency distribution (36), a high correlation between μ and σ was found. The linear regression between μ and σ accounted for 80% of variability. This outcome suggests either their mutual dependence or some common underlying mechanism. One ms increase in σ values is paralleled by 1.2. ms increase in μ values. If a similar finding is obtained in other recognition paradigms it may challenge the three parameters convolution model.

Serial position affects all convolution parameters' values in the same direction: increase of the serial position value is paralleled by a decrease of each convolution parameter value, but with different rates of change. μ and σ show quadratic serial position functions, with a plateau at the beginning of the list, and substantial decrease for the last two serial positions, thus demonstrating strong recency effect. The recency effect is also indicated in the τ serial position function, with significant linear decrease due to serial position. This suggests that the observed shape of the latency distribution is influenced by serial position in two distinct ways: after a relatively stable stage for the first memorized positions, the mean value and deviation of the normal distribution sharply decrease for the last position, while the latency distribution is steadily decreased in its tail value. Thus, as the memory representation gets older, or is shifted by incoming new items, the shape of its latency distribution will move toward normality, with minimal tail stretch.

The present study showed differences in the effects of **practice** and serial position on convolution parameters: while μ and τ are negatively correlated, both demonstrated convergence toward a constant value. At the beginning of the experimental session, the shape of the reaction time distribution is more likely to be of a high mean value, accompanied by reaction time widely spread around the mean, with a short positive tail. After the first block, practice reduces the mean value of normal distribution and its deviation, while the positive tail value gets increased. Thus, the effect of practice is one of the factors responsible for positive skewing of the latency distribution. In other words, practice shifts the latency distribution away from normality. This is somewhat surprising, for it might be expected that the long positive tail is a product of unpracticed processing. Our results, on the other hand, suggest that it is a product of some relevant memory mechanism, which is influenced by practice. By ascribing the observed changes of shape distribution to some memory mechanism, this finding supports the standard convolution approach of analysis in latency distribution.

GENERAL DISCUSSION

The aim of the this study is to present further evidence concerning the relationship between practice and serial position, in order to obtain more data on the underlying processes. The relationship of interest is termed the **dynamics of serial position change**. The question posed is what cognitive structures (processes) are influenced by serial position and practice. To address this issue, the present study investigated mean latency, errors, and Ex-Gaussian convolution using the probe-recognition task in the fast experimental procedure.

The analyses of **reaction times** showed that the **serial position** effect was significant, with both recency and primacy effects being observed. While the primacy effect was detected within the first two blocks, recency was observed in all blocks, but in the first block to a lesser degree. Non-linearity of serial position curves derives from the first two blocks, while in the last four blocks the serial position function is most likely to be linear.

The same pattern of results was observed in the **error** analyses as well: from the third block on, the serial position function is linear. A primacy component was observed within the first two blocks, indicated by a slight increase of accuracy. From the third block on the primacy effect disappeared.

The primacy effect was reported in several studies (Corballis et al., 1972; Morin et al., 1967; Burrows & Okada, 1971; Ratcliff, 1978; Monsell, 1978; McElree & Dosher, 1989). It was assumed that primacy was associated with more extensive rehearsal of the first memorized items (Corballis et al., 1972). In my opinion there is no unequivocal evidence to support this assumption. In the fast procedure items from the set are briefly presented, so subjects are not in a position to make partial rehearsals.

It has been debated which mechanisms underlie changes in performance due to practice. Critics took issue with the Schnider and Shiffrin (1977) model of automatization. The alternative approach put emphasis on a strategy shift, rather then shifting from capacity-demanding to capacity-free mode of processing (Cheng, 1985; Ryan 1983; Logan & Stadler, 1991). In the present work the observed dynamics of primacy/recency change indicated a rather different mechanism. One of the important findings is the inverse effect of primacy and recency due to **practice**: when recency increased, primacy decreased. Therefore, a common mechanism may be assumed: at the beginning of the session the first memorized items can get more attention, and therefore be better encoded and stored, and consequently - faster retrieved. On the other hand, the last presented items receive less attention and are therefore retrieved slower. After enough practice retrieval seems to enhance the recency strategy, i.e. the emphasis is now put on the last presented items, while at the same time accessibility of the first few items is reduced. As a consequence, the overall processing is preserved at a relatively stable level, i.e. main effects of practice for mean reaction time and mean errors are insignificant. This suggests the existence of a conservation principle: the reduction of the primacy effect is paralleled by the increase of the recency effect, while on average, short-term memory keeps processing efforts at relatively constant level. The tenability of this hypothesis must be submitted to further tests. A less plausible hypothesis of the observed dynamics assumes that this effect could be accounted by postulating a change in the way of scanning (serial vs. parallel). Rather, a strategy shift is suggested and the present work demonstrates that it is located at the initial part of the experiment.

After the decrease of the primacy effect (from the third block on), linear regression has been successfully performed on the last four serial position functions. Analyses of slope and intercept values obtained on serial position functions for each block suggest a decrease of the serial position effect: while values of intercept decrease with practice, the slope values decrease toward zero. Theoretically, it could be assumed that after enough practice the serial position effect would disappear: the slope value would reach zero, and the intercept value would converge to some constant value. This could only partially be supported by results of the present study. To obtain sufficient evidence, more practice blocks of trials are needed.

Additional evidence for the dynamics of serial position change is obtained from **Ex-Gaussian convolution analysis.** The rate of change of normal and exponential parameters (μ and τ), by serial position and practice, is of the utmost interest for the present study.

Obtained values of μ and τ as a function of serial position mainly replicated those of Hockley (1984) and Ratcliff (1978).

Different effects of serial position and practice on convolution parameters were demonstrated. It could be assumed that **serial position** differently affects the rate of change for both parameters, although the direction and the range of change (approximately 100ms) do not differ substantially. As a function of serial position latency distribution is moving toward minimal mean reaction time, with the smallest positive tail stretch. On the other hand, **practice** affects μ and τ in such a way that the correlation between them is negative. The effect of practice is primarily located in the first experimental sessions; the latter sessions exhibit reduced effect of practice ranging within 50 ms.

The present work demonstrates that serial position and practice affect different levels of processing. This assumption is derived from the analysis of convolution parameters: practice produces negative correlation between μ and τ, while serial position similarly affects the two, i.e. both are reduced as a function of position in the list. In other words, it could be suggested that practice affects processing by means of other processes than those affected by the serial position. This is in accord with the previous analysis, which suggested that the practice effect was produced by means of a strategy shift at initial trials (first two blocks), rather than by the change of the manner of memory scanning.

In contrast to the reaction time analysis, which suggests that longer practice tends to produce linear serial position functions (Table 3), the convolution analysis reveals non-linear changes of the μ parameter of the latency distribution. Averaged over blocks, serial position functions for both μ and σ parameters reveal sharp decrease for the fifth and the sixth serial position. Linearity of serial position functions on mean reaction time is put into question when contrasted to convolution analysis which showed non-linear change of μ and σ. In other words, although linearity of mean reaction time functions is induced by practice, it is actually concealed with convolution of linear τ and non-linear μ distributions parameters. Influenced by serial position, convolution of the two distribution components produce a linear-like serial position function for mean reaction times.

The more pronounced recency effect of μ and σ indicates a special status of the memory representation of the last two presented items. A similar finding was demonstrated by McElree and Dosher (1989) and Wickelgren, Corbet and Dosher (1980).

The present findings offer additional evidence against the standard serial hypothesis of equality of short-term memorized items status, thus being inconsistent with serial-exhaustive models with constant scanning rate (Sternberg, 1969). Hybrid models which postulate serial and direct-parallel search can account for serial position functions, but not for factors such as the effect of recent negative probes (Atkinson, Herrman, Westcourt, 1974; Monsell, 1978; McElree & Dosher, 1989). Therefore, they are of limited explanatory power. In contrast to recency based strength models that account for these results by means of a single retrieval mechanism, hybrid models appear to be less parsimonious.

Ratcliff’s random-walk model of memory retrieval (1978) can easily account for the serial position effect by specifying the relatedness value for each serial position. As Ratcliff (1978) suggested, this relation could be described by the continuous function, which is partly indicated in present work by regression analyses of μ and τ. However, the hypothesis that the very last serial positions have special status is also tenable, which is evident in change of μ as a function of serial position. In that case, the relationship between relatedness and serial position could not be describe by the continuous function.

An extensive study on the influence of temporal factors (duration of item exposure, and pre-probe delay) on convolution parameters is needed.

Another candidate for explanation of these findings is the conveyor-belt model which assumes backward self-terminating search (Murdock & Anderson, 1975; Murdock, Hockley & Muter, 1977). This model predicts a negative linear function between mean reaction time and serial position, that is observed from the third practice block on. Furthermore, in present study the value of τ constantly decreases as a function of serial position. This can also be predicted by backward serial processing if high variability of comparison time is assumed (Hockley, 1984). Unfortunately this model is incapable of coping with the obtained non-linear relationship between μ, σ and serial position.

The effect of practice was introduced in the present study in order to obtain a more detailed picture of short-term memory processing. Practice should not be ignored in studies of this kind, because many investigations use a large number of trials, thus allowing for easy analysis of practice effects.

REFERENCES

Anderson, J. A. (1973). A theory for the recognition of items form short memorized lists. *Psychological Review*, 80, 417-438.

Aube, M., & Murdock, B. B., Jr. (1974). Sensory stores and high speed scanning. *Memory & Cognition*, *2*, 27-33.

Atkinson, R. C., Herrman, D. J., & Westcourt, K. T. (1974). Search processes in recognition memory. *In R. L. Solso (Ed.), Theories in cognitive psychology: The Loyola symposium* (pp. 101-146). Hillsdale. NJ: Erlbaum.

Baddeley, A. D. & Ecob, J. R. (1973). Reaction time and short term memory: Implications of repetition effects for the high speed exhaustive scan hypothesis. *Quarterly Journal of Experimental Psychology, 25,* 229-240.

Burrows, D. & Murdock B. B., Jr. (1969) Effects of extended practice on high-speed scanning. *Journal of Experimental Psychology, 82* (2), 231-237.

Burrows, D. & Okada, R. (1971). Serial position effects in high-speed memory search. *Perception & Psychophysics*, *10* (4B), 305-308.

Clifton, C. & Birenbaum, S. (1970). Effect of serial position and delay of probe in a memory scan task. *Journal of Experimental Psychology*, Vol. 86, No. 1, 69-76.

Cheng, P. W. (1985). Restructuring versus automaticity: Alternative accounts of skill acquisition. *Psychological Review, 92*, 414-423.

Corballis, M. C. (1967). Serial order in recognition and recall. *Journal of Experimental* Psychology, *74* (1), 99-105.

Corballis, M. C., Kirby, J., & Miller, A. (1972). Access to elements of a memorized list. *Journal of Experimental Psychology*, *94,* 185-190.

Forrin, B. & Cunningham, K. (1973). Recognition time and serial position of probed item in short-term memory. *Journal of Experimental* Psychology, Vol. 99, No. 2, 272-279.

Gillund, G., & Shiffrin, R. M. (1984). A retrieval model for both recognition and recall. *Psychology Review, 91,* 1-67.

Hintzman, D. L. (1984). MINERVA2: A simulation model of human memory. *Behavior Research Methods, Instruments, & Computers 16,* 96-101.

Hockley, W. E. (1982). Retrieval processes in continuous recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *8,* 497-512.

Hockley, W. E. Corballis, M. C. (1982). Tests of serial scanning in item recognition. *Canadian Journal of Psychology*, *36,* 189-212.

Hockley, W. E. (1984). Analysis of response time distribution in the study of cognitive processes. *Journal of Experimental* Psychology: Learning, Memory and Cognition, *10* (4), 598-615.

Kerlinger, F. N., Pedhazur, E. J., (1973). Multiple regression in behavioral research. *Holt, Rinehart and Winston Inc*.

Krueger, L. E. (1970). Effect of stimulus probability on two-choice reaction time. *Journal of Experimental Psychology*, *84,* 377-379.

Logan, D. G. (1978) Attention in character classification: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General*, *107,* 32-63.

Logan, D. G., & Stadler, A. M. (1991). Mechanisms of Performance improvement in consistent mapping memory search: Automaticity of strategy shift? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17,* (3), 478-496.

McElree, B. & Dosher, B. A., (1989). Serial Position and set size in short-term memory: the time course of recognition. *Journal of Experimental Psychology: General. 118* (4), 346-373.

Morin, r. E., DeRosa, D.V., & Shultz V., (1967) Recognition memory and reaction time. In A. F. Sanders (Ed.), *Attention and performance. Acta Psychologica*, *27,* 298-305.

Monsell, S. (1978). Recency, immediate recognition memory, and reaction time. *Cognitive Psychology*, *10,* 465-501.

Murdock, B. B., Jr. (1971). A parallel-processing model for scanning. *Perception & Psychophysics*, *10,* 289-291.

Murdock, B. B., Jr. & Anderson, R. E. (1975). Encoding, storage, and retrieval of item information. *In R. L. Solso (Ed.), Information processing and cognition: The Loyola symposium* (pp. 145-194). Hillsdale. NJ: Erlbaum.

Murdock, B. B., Jr. (1982). A theory for the storage and retrieval of item and associative information. *Psychological Review*, *89,* 609-626.

Murdock, B. B., Jr., Hockley, W. Muter, P. (1977). Two tests of the conveyor-belt model for item recognition. *Canadian Journal of Psychology*, 31 (2), 71-89.

Murdock, B. B., Jr. (1996). Item, associative, and serial-order information in TODAM. *In Models of Short-Term Memory, edited by Susan Gathercole, by Psychology Press, an imprint of Erlbaum (UK) Taylor & Francis LTD*.

Norman, D. A., & Wickelgren, W. A. (1969). Strength theory of decision rules and latency in short-term memory. *Journal of Mathematical Psychology, 6,* 192-208.

Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. (1969). Retention of visual and name codes of single letters. *Journal of Experimental Psychology, 79* (1, pt. 2).

Ratcliff, R., & Murdock, b. B., Jr. (1976). Retrieval processes in recognition memory. *Psychological Review*, *83,* 190-214.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 85,* 59-108.

Ryan, C. (1983). Reassessing the automaticity - control distinction: Item recognition as a paradigm case. *Psychological Review*, *90,* 171-178.

Seamon, J. G., & Wright, C. E. (1976). Generative processes in character classification: Evidence for a probe encoding set. *Memory & Cognition*, *4,* 96-102.

Simpson, P. J. (1972). High-speed scanning: stability and generality. *Journal of Experimental* Psychology, *96,* 239-246.

Schneider, W. & Shiffrin, R. (1977). Controlled and Automatic Human Information Processing: Detection, Search, and Attention. *Psychological Review*, *84* (1), 1-66.

Shiffrin, R. & Schneider, W. (1977). Controlled and Automatic Human Information Processing: Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84* (2), 127-190.

Shiffrin, R. & Schneider, W. (1984). Automatic and controlled processing revisited. *Psychological Review*, Vol. 91, No. 2, 269-276.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74* (11).

Sternberg, S. (1966). High-speed scanning in human memory. *Science*, *153,* 652-654.

Sternberg, S. (1969). Memory-scanning: Mental processes revealed by reaction time experiments. *American Scientist*, *5,* 421-457.

Townsend, J. T., (1971). A note on the indetifiability of parallel and serial processes. *Perception and Psychophysics*, *10,* 161-163.

Townsend, J. T., (1972). Some results on the identifiability of parallel end serial processes. *British Journal of Mathematical and Statistical Psychology*, *25,* 168-199.

Townsend, J. T., (1983). Stochastic modeling of elementary psychological processes. *Cambridge, UK: Cambridge University Press*.

Townsend, J. T., (1990). Serial vs. Parallel Processing: Sometimes they look like Tweedledum and Tweedledee but they can (and should) be distinguished. *Psychological Science, 1* (1), 46-54.

Van Zandt, T. & Townsend, J. T. (1993). Self-terminating versus exhaustive processes in rapid visual and memory search: An evaluative review. *Perception & Psychophysics*, *53* (5), 563-580.

Waugh, N. C., & Norman, D. A. (1965). Primary memory. *Psychological Review*, *72,* 89-104.

Wickelgren, W. A. & Norman, D. A. (1969). Strength models and serial position in short-term recognition memory. *Journal of Mathematical Psychology*, *3,* 316-347.

APPENDIX 1

Significance of difference between regression trends (quadratic and linear) were calculated using following formula for F ratio (Kerlinger & Pedhazur, 1973):

$$F = \frac{\dfrac{R^2_{x,x^2} - R^2_x}{k1 - k2}}{\dfrac{1 - R^2_{x,x^2}}{N - k1 - 1}}$$

where $\mathbf{R}^2_{\mathbf{x},\mathbf{x}^2}, \mathbf{R}^2_{\mathbf{x}}$ are determination coefficients of quadratic and linear regression respectively; k1 and k2 are degrees of freedom of quadratic and linear regression respectively (2,1), and N is a number of subjects or observations (6).