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EFFECTS OF PRACTICE ON A TYPING-LIKE KEYING TASK *

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Twenty hours of practice on a sequential keying task were administered to determine the mechanisms responsible for practice-related improvement. Sensitivity to varying stimulus probabilities was evident from the earliest stages of practice and did not shift with continued experience. The efficiency of making keystrokes involving overlap of successive finger movements improved more than that for keystrokes with no possibility of overlap, and an index of eye–hand span revealed that with practice subjects expanded their degree of anticipatory preparation. It was suggested that one of the most important things acquired with skill is the ability to execute several processes simultaneously.

Although practice-related improvements in a variety of perceptual-motor tasks have been well-documented (e.g., see Salthouse and Somberg (1982) for a brief general review and Leonard and Newman (1965) for a relevant study involving sequential keying), very little is yet known about the exact mechanisms responsible for those improvements. The purpose of the present study was to attempt to address this deficiency by examining the detailed effects of practice on a sequential keying task.

The task was designed to be similar to the activity of typing in order to examine possible parallels with skill-related differences previously observed in transcription typing. For example, both Gentner (1983) and Salthouse (1984b) found that typing skill was closely associated with improvements in the speed of making keystroke sequences involving alternate hands, but that there was less improvement in the speed

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of sequences involving repetition of the same keystroke. This pattern suggests that one factor contributing to the acquisition of keying skill is learning to overlap successive finger movements efficiently. That is, no overlap is possible with sequences involving the same finger, and the greater improvement with other finger sequences may be attributable to improved efficiency of preparing for future finger movements while simultaneously executing current movements.

Salthouse (1984b, 1985) also reported that more skilled typists needed a larger number of visible characters in the display in order to maintain their normal rate of typing than did less skilled typists. This number of characters was designated the eye–hand span, and the greater eye–hand spans on the part of more skilled typists suggest that one of the things learned with skill is the ability to anticipate, and prepare for, forthcoming keystrokes.

While not found to be related to skill in the typing studies, differential sensitivity to stimuli of varying frequencies of occurrence seems plausible as a mechanism responsible for at least some of the practice-related improvement in keying efficiency. That is, with increased experience on a keying task subjects may learn the probabilities of individual stimuli, or sequences of stimuli, and consequently alter their response efficiencies in accordance with the probabilities of specific events.

These three potential concomitants of improved skill were investigated in a sequential keying task performed across 20 hours of practice. Performance was analyzed on four types of keystroke transition – involving the same finger and the same digit (1D), different digits but the same finger (1F), different fingers of the same hand (2F), and fingers from different hands (2H) – and stimuli were presented with different probabilities to allow an examination of practice-related changes in the effects of stimulus frequency on keystroke efficiency. In addition, the number of visible characters was manipulated on each session to allow an assessment of the number of characters needed to maintain one's normal rate of keying, i.e., the individual's eye–hand span.

Method

Subjects

Four adults (three males and one female) between 23 and 36 years of age participated in 20 experimental sessions of approximately one hour each.

Apparatus

Responses were entered via two numeric keypads separated by 8.5 cm from one another on a response panel. The keypads were arranged in a touch telephone format, i.e., with the '0' key on the bottom and '1', '2', and '3' on the top row, etc. A laboratory computer monitored the responses, and also controlled the display of the stimulus sequences on a video monitor.

Procedure

The basic task for the subjects was to key the digits displayed on the monitor as rapidly and accurately as possible. The digits were displayed in two sizes; the large ones were to be entered on the left keyboard and the small ones were to be entered on the right keyboard. A 'touch keying' strategy was to be employed with the middle three fingers of each hand assigned to the 4–5–6 'home row' keys. Finger position was not monitored but all subjects reported that they complied with this strategy. Seven digits were presented in the normal conditions, with the display shifting one digit to the left with each successive keystroke. That is, pressing a key caused the leftmost digit on the display to disappear, the remaining digits to shift one space to the left, and a new digit to be displayed on the right edge of the display.

Specific digits were presented with probabilities of 0.20 (for '0' which could be pressed with the '0' key on either keypad), 0.14 (for one digit on each keypad), 0.06 (for two digits on each keypad), 0.03 (for four digits on each keypad), and 0.01 (for two digits on each keypad). Two of the subjects received one assignment of probabilities to specific digits, while the other two subjects had those probabilities assigned to different digits. It was impossible to balance the probabilities perfectly across fingers and rows because of the existence of the 0.14 probabilities (assigned alternately to the '4' and '6' keys on each keyboard), but with this exception each finger and each row had a similar distribution of the 0.01, 0.03, and 0.06 probabilities.

Each session consisted of 32 blocks of 100 digits each under the conditions described above, and 7 blocks of 100 digits each with a systematically varied number of displayed digits. The display contained 7 digits on the first of these special blocks, but on subsequent blocks contained 5, 3, 1, 2, 4, and 6 digits, respectively. This manipulation of preview was designed to determine the number of characters needed by the subject to achieve his or her normal rate of keying with the standard display of 7 characters. Stimulus probabilities in these conditions were the same as those in the standard display condition.

Results

The median interval between successive keystrokes averaged 708 msec on session 1, and was reduced to 252 msec by the 20th session. Mean accuracy ranged from 92.1% to 94.6% across sessions, with three of the four subjects consistently averaging about 5% errors and the remaining subject about 8% errors. Because the accuracy level was

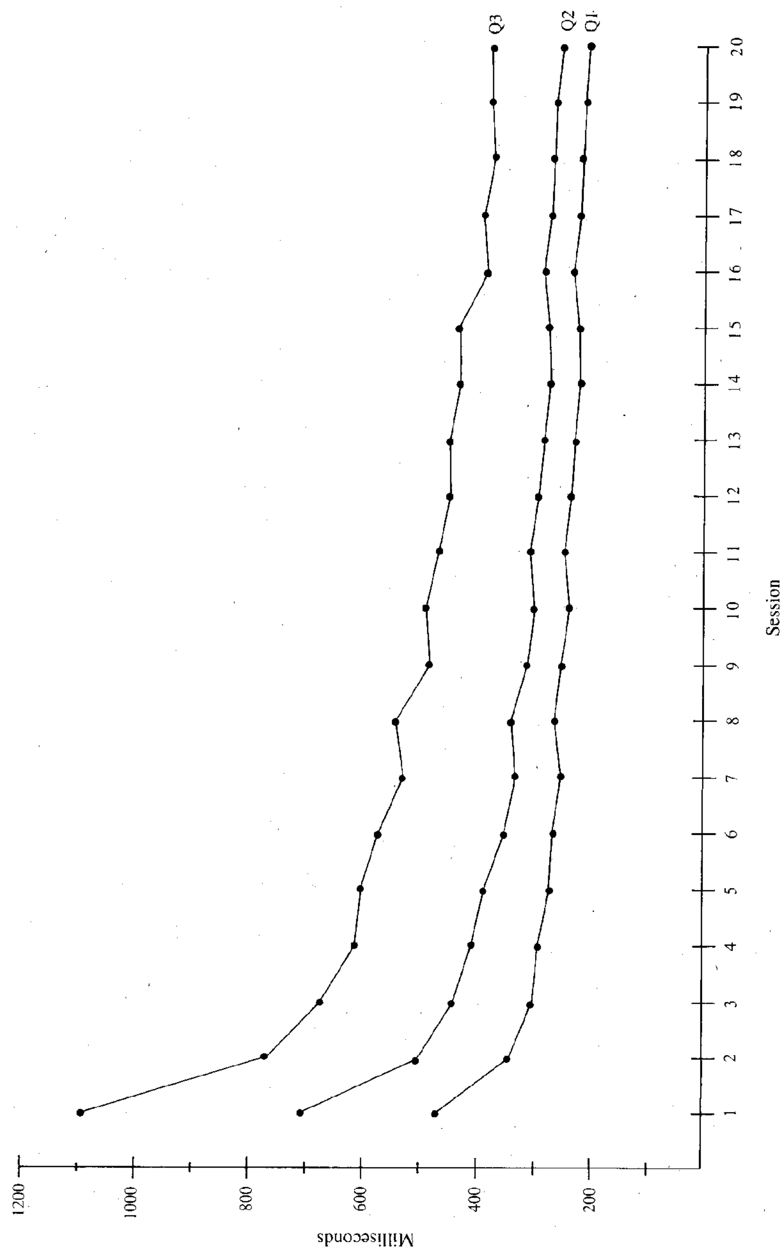

Fig. 1. Means across the four subjects of the first (Q1), second (Q2 or median), and third (Q3) quartiles of the distribution of interkey intervals as a function of practice.

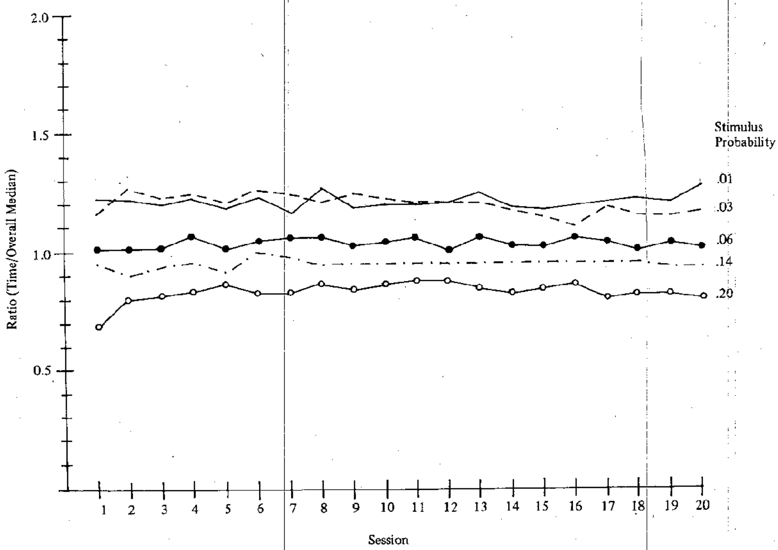

Fig. 2. Relative efficiency of keystrokes to stimuli with different probabilities of occurrence as a function of practice.

reasonably high, and because few relations between skill and type of error have been reported in previous studies of typing, all remaining analyses were based exclusively on the time variable. The means of these medians, and of the first and third quartiles of the interkey interval distributions, across the 20 experimental sessions are illustrated in fig. 1. The same pattern was evident for each subject as the median interkey interval on the 20th session was 0.48, 0.23, 0.40, and 0.40 that of the 1st session, respectively, for the four subjects. Fig. 1 clearly indicates that performance improved dramatically as a function of practice, and hence subsequent analyses focused on determining the reasons for this improvement.

One analysis examined the effects of stimulus probability on interkey interval across different stages of practice. Each response key was categorized according to the probability of its associated stimulus digit, and the mean of the median interkey intervals in that category computed for each subject. These means were then averaged across the four subjects for each of the 20 sessions of the experiment. However, in order to indicate the changes in these measures relative to the overall practice-related shift in performance, the means were converted to ratios by dividing them by the average median interkey interval for the standard conditions on each respective session. For example, the interkey interval for the digits with a 0.14 probability was 675 msec on session 1, the interkey interval for all digits on session 1 was 708 msec, and consequently the relevant ratio was 0.95. This procedure was followed for all probability categories on each session, with the results displayed in fig. 2.

The striking feature of fig. 2 is that the differences among the various probabilities remain quite stable across the 20 sessions of the experiment. Least-squares linear regression slopes for the average data were all less than 0.003, and none of the r^2 values exceeded 0.34. Each subject exhibited this same pattern as 18 of the 20 r^2 values (5 probability conditions for each of 4 subjects) were less than 0.5, and the remaining two (from different subjects) had slopes of only 0.004 and −0.005. These findings suggest that a changing sensitivity to the frequencies of different stimulus events is not responible for the practice-related improvement because there is no apparent shift in the relative efficiency of keying sequences with different probabilities of occurrence.

The data were also examined with respect to the probability of the transition between particular keystrokes (e.g., going from a 0.14 probability digit to a 0.01 probability digit), but there was little overall effect of prior probability, and virtually no influence of practice on relative performance with different prior probabilities.

The effects of type of transition between successive keystrokes were examined by first categorizing each digit-key pair according to its assigned hand and finger, and then determining whether successive keystrokes involved fingers from different hands (2H), different fingers on the same hand (2F), the same finger but different keys (1F), or the same finger on the same key (1D). Median interkey intervals were computed for each of these categories for each session, and then means determined across the four

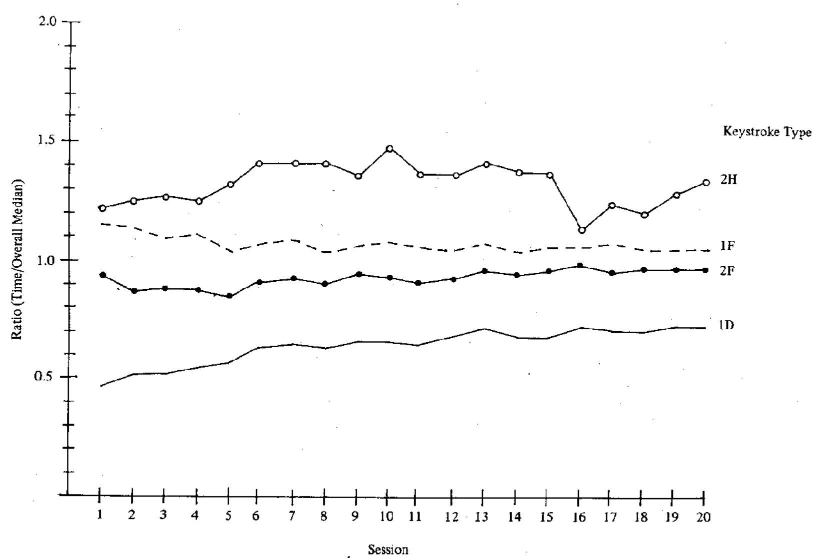

Fig. 3. Relative efficiency of different types of keystroke transitions as a function of practice. The terminology is 2H for keystroke sequences involving different hands, 2F for sequences involving different fingers of the same hand, 1F for different keys pressed with the same finger, and 1D for the same key pressed by the same finger.

subjects. Ratios of these means relative to the interkey interval for all digits are displayed in fig. 3. Least-squares linear regression slopes were 0.000 for 2H, −0.002 for 1F, 0.006 for 2F, ond 0.012 for 1D, with r^2 values of 0.00, 0.21, 0.70, and 0.86, respectively. All subjects were consistent in exhibiting the steepest slopes with the 1D keystrokes, with generally small or unsystematic changes on the other types of keystrokes.

The results of fig. 3 are substantially different from those obtained in skilled typing because fast typists are invariably much faster with 2H (two-hand) transitions than 1D (one-digit, or repetition) transitions. The ratio for 1D keystrokes appears to be approaching 1.0 with practice, however, suggesting that there is less absolute improvement with practice on these keystrokes compared to the other types of keystrokes. In fact, the mean of the median interkey intervals decreased a total of 546, 522, and 414 msec between sessions 1 and 20 for the 1F, 2H, and 2F keystrokes, respectively, but only decreased 151 msec for the 1D keystrokes.

A final analysis was based on measures of the eye–hand span. These values were derived from the results with the systematically varied preview windows by first determining the median interkey interval with each preview size. The span was then identified as the preview window at which the median interkey interval exceeded the third quartile (75th percentile) of the distribution of interkey intervals from the standard (preview = 7) conditions. This procedure is analogous to that employed in studies of typing (e.g., Salthouse 1984a, 1984b, 1985), and can be interpreted as

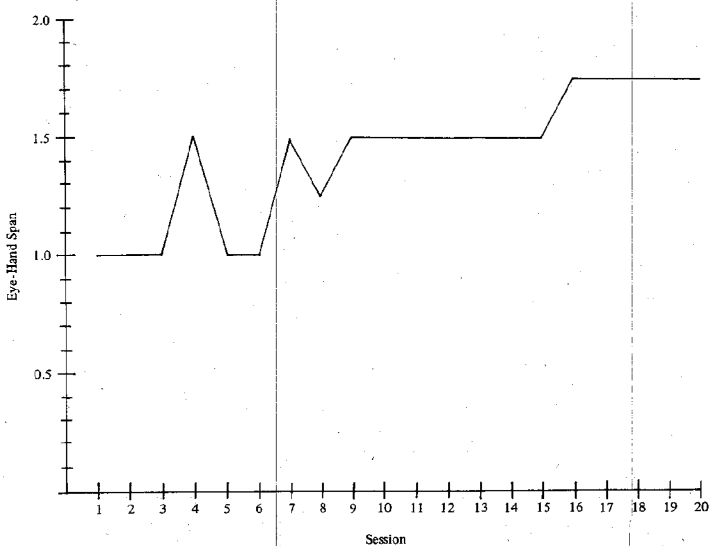

Fig. 4. Mean eye–hand span, reflecting the number of visible characters needed to maintain a normal rate of keying, as a function of practice.

indicating the number of characters needed to maintain one's normal rate of keying. The means of the four subjects across the 20 sessions of practice are displayed in fig. 4, where it can be seen that there is a consistent trend for the span to increase with practice. The parameters of the least-squares regression equation were: span = 0.937 + 0.045 (Session), $r^2 = 0.77$. One subject did not exhibit an increase in eye–hand span across the practice sessions, but each of the other subjects went from a span of 1 in the initial sessions to a span of 2 for at least the final five sessions.

Discussion

Despite experience limited to 20 hours, keying performance improved substantially across the duration of this experiment. By the last session the median interkey interval was reduced to 36% the initial value, and the interquartile range reduced to 28% the initial value. Some of the improvement across the initial sessions may be a matter of becoming familiar with the key positions and learning to execute novel keystrokes, but factors such as these are probably of only minor importance after the first few hours on the task.

Very little of the improvement across any of the sessions appears attributable to learning and utilization of stimulus probabilities. Highly probable stimuli were responded to more efficiently within the first session of 3200 responses, and relative performance did not vary systematically with subsequent experience. A similar invariance of frequency effects across different levels of typing skill was reported by Salthouse (1984b), and thus it seems unlikely that keying proficiency develops by increased sensitivity to varying event probabilities.

The relative efficiency of certain keystroke sequences did change across practice, but the absolute pattern was quite different than that characteristic of skilled typists. Repetitions of the same keystroke improved less over the 20 sessions than did other types of keystroke transitions, but they remained the digrams with the shortest interkey interval. With skilled typists, on the other hand, repetitions are usually the slowest type of keystroke transition (cf., Gentner 1983; Salthouse 1984b). The differential rates of improvement across the four digram types may account for this pattern reversal because extrapolation of the present results to additional levels of practice would eventually yield the configuration characteristic of typists. Gentner (1983) and Salthouse (1984b) also reported that keystroke repetitions were relatively fast among the least skilled typists, and exhibited the smallest amount of absolute difference across typists of varying skill levels. The typing and keying results are therefore compatible with one another, and differ largely with respect to the amount of experience and the associated level of performance. In other words, the final level of performance achieved in the current study was probably comparable to only the very lowest levels of skill examined in the typing studies.

One unambiguous shift with practice is the number of displayed characters needed to maintain one's normal rate of keying. On the first session only the to-be-keyed digit had to be visible in order to perform at the rate achieved with seven visible characters, but by the 20th session three of the four subjects needed two visible digits to perform at their, now much faster, normal rate. It seems reasonable to expect that these eye–hand spans would continue to expand with increased experience because Salthouse (1984b, 1985) found that the size of the spans was positively correlated with typing skill.

The changes in eye–hand span and efficiency of certain keystroke sequences both indicate that improvement in keying tasks is associated with greater preparation for forthcoming keystrokes. A larger eye–hand span means that the subjects are beginning to process impending stimuli before the completion of the prior keystroke, and the greater improvement for keystroke sequences involving the possibility of overlap of current and future finger movements implies that subjects are learning to respond to stimuli in a less discrete and sequential manner. In light of the confirmation of these conclusions in recent studies of skilled typing (e.g., Gentner 1983; Salthouse 1984a, 1984b, 1985), it seems safe to infer that these factors play a major role in the practice-related improvements observed in several types of manual keying tasks.

In summary, the present study provides some initial answers to the question of what is learned when an individual improves on a sequential perceptual-motor skill. One answer is that there is more efficient execution of the motor responses, particularly those in which there is the possibility of overlap in preparatory processes. Perhaps because of this greater execution efficiency, there is also a temporal expansion of the preparation with processing beginnning on characters progressively farther in advance of the relevant keystroke as the skill develops. It is still not clear whether this enlarged span reflects a single buffer that increases in capacity, or the gradual development of qualitatively distinct types of processing each with its own unique time course of preparation. A final, and somewhat surprising, negative answer to the question of what is learned is that it is apparently not the relative frequencies of different stimulus events. In neither the present longitudinal study of sequential keying nor in the earlier cross-sectional studies of typing has a relation been found between overall level of skill and sensitivity to the probability of alternative stimulus events (i.e., digits or letters). It is possible that more complex tasks may reveal an effect of practice or skill on sensitivity to stimulus probability, but the discovery that probability effects were evident in the first session of the current study suggests that information of this type is detected very early and is probably not an important factor in skill acquisition occurring after the initial encounters with the task.

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