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Visual Feedback and Skilled Keying: Differential Effects of Masking the Printed Copy and the Keyboard*

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Visual Feedback and Skilled Keying: Differential Effects of Masking the Printed Copy and the Keyboard*

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The results of three experiments are reported. They were designed to substantiate the importance for skilled keying behaviour of information derived from the printed copy and the keyboard. Experiment 1 showed that consulting the copy and the keyboard during transcription constituted part of normal keying activity and that the frequency of consultation was a function of the specific demands of the task. Experiment 2, with no requirement to correct errors, and Experiment 3, with a requirement to correct errors, involved the independent masking of the copy and the keyboard as well as an unmasked control condition. Both experiments showed that an adverse effect on performance, as measured by speed and accuracy, occurred only in the keyboard masked condition. Experiment 3 revealed an additional adverse effect on performance, as measured by the reduced percentage of errors corrected, which occurred only in the copy masked condition. It was concluded that the keyboard provides 'guidance' information, permitting the appropriate co-ordination of fingers and keys and the location of unfamiliar keys by sight, and the printed copy provides 'feedback' information concerning the commission of errors. It is argued that the results resolve a contradiction reported in previous research and suggest that visual feedback has a continuing role even in highly practised skills, such as keying.

1. Introduction

Feedback is essentially a relational concept. The most general definition supposes the relation to hold between parts of a dynamic system when one part acts on, and is in turn acted on, by another part (Ashby 1956). As applied to behaviour, it is identified with the 'sensory after-effects of responding' (Adams 1968). In typical keying tasks, feedback information is provided both by an operator's movements: pressing and pulling; and by their effects on the keyboard device: key activation and print-out. Consideration, here, is given only to visually perceived feedback, although audition and kinaesthesis are also assumed to be involved (West 1967, Klemmer 1971).

Human factors research on feedback has been concerned largely with evaluating operator requirements (Diehl and Seibel 1962). The motivation has come from improved technology, making flexible the provision and elimination of hard and soft copy facilities. For example, in telecommunications changes in copy facilities have arisen: with telephones used for international dialling (Bray 1970), and for slow data transmission (Schott 1972); and with teleprinters using a buffer-store (Long 1975). The aim of the research reported here was to add to current information concerning the function of visual feedback in skilled keying.

The most general hypothesis identifying the function of visual feedback in the context of perceptual-motor tasks was proposed by Fitts (1951). He suggested that visual control is important early in learning, but that as performance becomes habitual, 'feel' becomes the more important. Dependence

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on kinaesthetic feedback is one way of conceptualizing the final, autonomous phase in the acquisition of perceptual-motor skill (Miller, Galanter and Pribram 1960, Fitts and Posner 1967). Evidence for greater kinaesthetic dependence as the acquisition of a two-handed co-ordination skill progressed was furnished by Fleishman and Rich (1963). A strong version of this proposal constitutes the null hypothesis for the function of visual feedback in keying, namely, visual feedback has no function. The hypothesis would be supported if the removal of visual feedback were to leave skilled performance unchanged.

Evidence relevant to the evaluation of the hypothesis was provided by Diehl and Seibel (1962) and West (1967), who assessed keying performance with and without vision. As shown by a summary of the relevant data in Table 1 the outcomes of the experiments appear contradictory, only those of Diehl and Seibel supporting the hypothesis.

Table 1. Mean typing performance with and without vision; data taken from Diehl and Seibel (1962) and West (1967).

Author	Diehl and Seibel		West	
Condition	With vision	Without vision	With vision	Without vision
Gross words per minute	72·92	73·42	45·30	44·46
Nett words per minute	58·97	57·52	—	—
Total errors	—	—	25·74	40·10

A number of subsequent attempts to explain the discrepancies failed because the factors invoked were common to both experiments (Galloway 1968; Alden *et al.* 1972; Seibel 1972). Klemmer (1971), however, pointed out an important difference between the experiments: Diehl and Seibel's subjects, by means of a cardboard mask attached to the typewriter, were prevented only from seeing the copy; while West's subjects, by means of a paperboard shield attached to their neck and waist, were prevented from seeing both the copy and the keyboard. He went on to identify two functions of visual feedback: (1) to maintain the fingers in the home row position; and (2) to detect errors. He concluded that the home row function persisted at all levels of keying skill, but that the error detection function might be limited to unskilled keying. West, in a later discussion of his own data, also identified two functions of visual feedback for unskilled subjects (1969, p. 78): (1) to make the key-stroke itself; and (2) to confirm the correctness of the stroke. In the absence of direct measures of the use of vision by skilled subjects, neither Klemmer nor West were able to substantiate their suggestions. Experiment 1 thus sought to establish whether consultation of the copy and the keyboard forms part of the normal keying behaviour of skilled subjects, and to identify the functions associated with visual consultation.

2. Experiment 1

2.1. *Aim*

Rather than test several subjects over a narrow range of keying conditions, it was decided to test a single experienced subject over a wide range of conditions. In this way it was hoped to obtain a broad view of the functions of visual consultation.

2.2. *Method*

2.2.1. *Subject and apparatus*

The subject was female and had typed regularly for 18 yr. She was a member of the Applied Psychology Unit's panel and was paid for her participation. She used her own standard, manual typewriter in her normal working environment. The time taken to complete each part of the test was recorded by stopwatch. Consultation frequency was recorded by the experimenter on a set of 3 counters, one for the source material, one for the copy and one for the keyboard. When source material was presented visually, it was placed on the left of the typewriter. A ' consultation ' was defined as a look at any of the 3 sources of information. Under Condition 2 the experimenter also recorded the subject's verbal reports.

2.2.2. *Procedure and design*

The subject was requested to type as fast as possible in line with the instructions of a particular experimental condition. When errors were permitted, the subject was instructed not to exceed a rate of 1%. Each condition was tested at a single session, made up of 5 tests each 2000 key-strokes long. Sessions lasted 1–2 h. Conditions were tested in the same order used in Table 2. When required, the procedure for correcting errors consisted of double spacing and re-typing from the incorrect word or symbol. When source material consisted of text, it was chosen from standard English prose passages published in the Pitman magazine *Memo* as speed and accuracy tests for typists.

2.3. *Experimental Conditions and Results*

Six conditions were tested. The results of each are shown in Table 2. Each condition with its associated outcome is described separately:

Table 2. Experiment 1: interresponse time, percentage errors and consultation frequency per 100 responses.

Condition	Mean interresponse time (ms)	Percentage errors			Consultation frequency per 100 responses	
		Detected	Missed	Total	Copy	Keyboard
1. Normal	166	0·25	0·06	0·31	0·40	0·30
2. Verbal report (*a*)	161	0·25	0·13	0·38	0·59	0·69
(*b*)					0·17	0·27
3. Own margin	158	0·25	0·08	0·33	1·79	0·46
4. Errorless copy	264	0	0	0	4·21	1·45
5. Alphanumeric material	260	—	—	0·53	2·38	3·25
6. Auditory presentation	205	0·33	0·05	0·38	0·45	—

Condition 1. The subject typed text, using the error correction procedure. The right hand copy margin was determined by the length of the lines in the source text, which were always shorter than those required for the copy. This was to avoid the possibility of a consultation of the copy occurring at the end of a line. This condition served to demonstrate the level of the subject's skill (between 70 and 80 words min^{-1}) and to establish a baseline against which to compare the remaining conditions, especially Condition 2. Table 2.1 shows that although consultation frequency was low, both the copy and the keyboard were consulted.

Condition 2. As for Condition 1 except that immediately following a consultation the experimenter interrupted the subject's typing to establish by enquiry the purpose of the consultation. The consultations classified in Table 2.2 (*a*) included those associated with recommencing typing following an interruption. Those classified in Table 2.2 (*b*) excluded the latter. Speed and error scores and the consultation frequency excluding re-start procedures were similar under Conditions 1 and 2. Performance under Condition 2 was, therefore, assumed to be representative of normal keying. Examination of the subject's verbal reports showed two consultation functions associated with the interruption of the experimenter. Following each interruption, the subject consulted the copy to identify the place in the source text from which to re-start, and the keyboard to re-establish the correct relation between fingers and keys, i.e. placing the fingers on or over the home row keys. Hence the lowered frequency of consultation in Table 2.2 (*a*) compared to Table 2.2 (*b*). Of the non-restart consultations, 65% of copy consultations involved symbols and 35% involved lay-out (e.g. new line, end of line, line length). Of the consultations involving symbol checking, 80% were associated with an actual error which was corrected. The keyboard consultations were all associated with the location of keys by sight—often punctuation—which the subject felt unable to press without looking at the keyboard.

Condition 3. As for Condition 1 except that the length of the lines in the source text exceeded those required for the copy. The subject thus had to establish her own right-hand copy margin. There was no auditory signal provided by the typewriter indicating the end of the line in the copy. Although only 35% of copy consultations under Condition 2 involved lay-out, Table 2.3 shows a minimal requirement concerning layout to have radically changed the frequency of copy consultation.

Condition 4. As for Condition 1, except that the subject was instructed to produce an errorless copy as for a legal document. Table 2.4 shows the requirement to have been met and to have resulted in a radical increase in both copy and keyboard consultations over Condition 1.

Condition 5. As for Condition 1, except that the source material consisted of Post-Office trunk call names and numbers (containing approximately 25% numeric material), and no error correction procedure was required. This condition demonstrated the function of the keyboard in the location of unfamiliar keys. Table 2.5 shows keyboard consultations to have radically increased over Condition 1, because like most touch-typists the subject was less familiar with the numeric than the alpha keys. According to the subject the increase in the frequency of copy consultations was associated with those responses for which no keyboard consultation occurred, and the correctness of which she wished to confirm.

Condition 6. As for Condition 1, except that the source material was presented auditorily by means of a *Grundig Stenorette SL tape recorder* under the subject's control (including a rewind facility). Table 2.6 shows that when not required to fixate the source material, the subject looked at the keyboard while typing, changing only to consult the copy (hence the absence of a frequency count for the keyboard in Table 2.6).

2.4. *Discussion and Conclusions*

The results show that for the experienced subject tested, copy and keyboard consultations constitute part of normal keying behaviour. Although only one subject was tested, the results are not likely to reflect either adaptation to the testing procedure or random variability. Since Conditions 3, 4 and 5 were tested after Conditions 1 and 2, adaptation would have been more likely to reduce not increase consultation frequency. Random variability can be reasonably excluded on the basis of the large number of responses per condition (10,000) and the magnitude of the changes in consultation frequency.

The results are consistent with the assumption of two functions for both copy and keyboard consultations. Consulting the printed copy establishes the place in the source text from which to start or re-start (Table 2.2 (*a*)), and provides information concerning errors (Table 2.2 (*b*)) and layout (Table 2.3). Consulting the keyboard establishes the correct relations between fingers and keys (Table 2.2 (*a*) and (*b*)), and provides information concerning the spatial location of unfamiliar and therefore difficult keys. Note that following the definition of feedback given earlier, the information derived from the keyboard ought more properly to be considered as ' guidance ' information, since it is processed prior to a response being made. These findings confirm the appropriateness of the distinction between the functions of information derived from the copy and the keyboard made by Klemmer (1971) and West (1969).

3. Experiments 2 and 3

3.1. *Aim*

Examination of the experiments by Diehl and Seibel and by West revealed a second difference between them, in addition to the method used to deprive the subjects of visual information. Under some conditions West's subjects corrected their errors, whereas Diehl and Seibel's subjects did not. It was hypothesized that these differences, coupled with the error information function of the copy and the key location function of the keyboard, demonstrated by Experiment 1, might explain the discrepancy between the two earlier studies. On this basis, disruption of the key location function would have occurred only in the West study, which involved masking the keyboard, thus decreasing the accuracy of performance. Disruption of the error information function would also have occurred only in the West study, thus decreasing the percentage of errors corrected, because although both studies masked the copy, Diehl and Seibel's subjects were not required to correct errors. The hypothesis implies differential effects of masking the two sources of information, provided the functions of place marker for the copy and finger-key co-ordination for the keyboard are excluded. Experiments 2 and 3 were designed to test this implication. The experiments were identical except for the error correction procedure, which was required only in Experiment 3. Two separate experiments were run to ensure that any effect of keyboard masking was independent of the requirement to correct errors.

3.2. *Method*

3.2.1. *General*

Both experiments are described together. Each included three conditions; (1) involving no masking (termed Normal); (2) masking of the copy only (termed Copy Masked); and (3) masking of the keyboard only (termed Keyboard Masked). According to the hypothesis under test the expected relationship between the error scores for the three conditions in both experiments was:

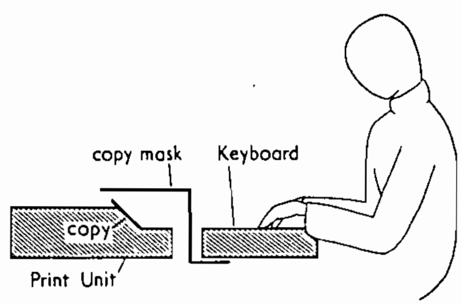
Normal = Copy Masked < Keyboard Masked.

On the grounds that subjects might trade speed for errors (Fitts 1966), the same relationship was expected for speed scores in the absence of a change in performance accuracy. Substitution errors rather than other types were expected to increase under the Keyboard Masked Condition, on the grounds that responses normally made with the aid of vision would still be made in its absence, but less accurately. In Experiment 3 the expected relationship between corrected errors following the hypothesis was:

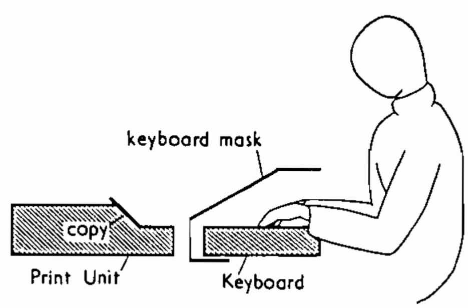
Normal = Keyboard Masked > Copy Masked.

3.2.2. *Apparatus*

The experiments were run by means of a *Modular One computer* linked to a standard teletype (*ASR* 33), modified to take a *Honeywell solid state keyboard*, with standard ' Qwerty ' letter layout. Carriage return and line-feed keys followed the ' @ ' key on the top alpha line. Additional non-standard and non-required keys were masked with cardboard. The key tops ' a ' and ' ; ', which bounded the home key row were artificially raised at the near edge to permit the identification of the row under the Keyboard Masked condition. This was to exclude the need for co-ordinating fingers and keys by means of vision. The computer recorded the total time to type a text and the time



(*a*)



(*b*)

Figure 1. Diagram showing (*a*) the copy mask and (*b*) the keyboard mask used in Experiments 2 and 3.

between each pair of key-presses, termed interresponse time. Errors were analysed by the experimenter. The teletype was set up in a quiet testing cubicle and communication with the subject was by intercom.

The printed copy was concealed in Condition 2 by means of a shaped aluminium mask, 25 cm × 30 cm. The keyboard was similarly concealed in Condition 3. The mask measured 40 cm × 45 cm and was angled, having a depth of 12 cm at the front of the keyboard, rising to 22 cm at the back. The masks are illustrated in Figure 1 (*a*) and 1 (*b*) respectively.

3.2.3. *Source material*

The source material was text, as for Experiment 1, modified to minimize the subjects' concern with layout. The source line lengths were restricted to 60 characters. Copy line length could therefore be determined by the subjects without reference to the copy itself. In order to standardize the keyboard for the subjects all numeric material and punctuation were excluded, except for comma, semi-colon and full-stop. This arrangement undoubtedly eliminated a number of unfamiliar keys and reduced the need for keyboard consultation. Potentially it also reduced the effect of keyboard masking. However, since the carriage return and line-feed keys were unfamiliar to most of the subjects, who use normal typewriters, the arrangement still allowed for the inclusion of this class of unfamiliar keys which, moreover, could be identified.

3.2.4. *Design and subjects*

A repeated measures design was used for both experiments. For Experiment 2, 12 subjects were tested. They were re-tested on average a week later for Experiment 3. The 12 subjects were divided into two matched groups of 6, based on pre-test practice speed and error performance. Each experiment involved 4 tests. For Experiment 2 the first and last tests, 1000 characters in length, were run under Normal conditions for all subjects. The second and third tests, 2000 characters each, were run in the order Copy Masked, Keyboard Masked for Group 1 and the reverse for Group 2. For Experiment 3 the initial and final tests were again Normal, but the two groups had the Copy Masked and Keyboard Masked tests in the reverse order to that experienced in Experiment 2. Each condition for each subject in each experiment thus involved 2000 keystrokes. The 12 subjects were members of the Applied Psychology Unit's panel and were paid for their participation. All were female and their ages ranged from late teens to early fifties. All were touch typists and all were current typists—to varying degrees.

3.2.5. *Procedure*

The testing procedure was as follows:

(*a*) The operation of the teletype was briefly explained and the aim of the experiment was described as: ' an evaluation of how important it is for typists to be able to see both the copy and the keyboard while they are typing.'

(*b*) The three conditions were described. The subjects were instructed to type as fast as possible without exceeding an error rate of 1%.

(*c*) They were instructed to correct errors only in Experiment 3. Examples of all error types were provided.

(*d*) Carriage return and line-feed keys were demonstrated. The minimal punctuation of the texts was pointed out as well as the raised keys at the end of the home row and the line lengths of the source texts. A drawing of the keyboard was at all times visible on the wall of the testing cubicle.

(*e*) The subjects were practised under Normal conditions for between 1000 and 2000 key-strokes before beginning either experiment. For Experiment 3, the practice included error correction. Further, 200 key-strokes practice with the keyboard mask in place for line-feed and carriage return keys only, was given prior to all tests involving keyboard masking. This was to reassure the subjects and to ensure that the task could be performed adequately.

(*f*) The subjects were assigned to an order group and the 4 test texts were administered. The subjects corrected their printed copies between conditions and rested. The sessions lasted between 1½ and 2 h.

3.3. *Results*

3.3.1. *Overall results*

The overall mean speed and error scores for both experiments are shown in Table 3. A *Sign test* showed the difference between the mean interresponse times for the two experiments not to be significant (1 ms, $p > 0{\cdot}05$). Separate *Sign tests* for the two experiments also showed that interresponse times and errors did not differ significantly between the pre-test and post-test versions of the Normal condition (Experiment 2, 6 ms; Experiment 3, 10 ms; Experiment 2, 0·08%; Experiment 3, 0·23%; $p > 0{\cdot}05$ in all cases). The pre-test practice thus adequately familiarized the subjects with the keyboard and the test data represented normal asymptotic performance. In subsequent analyses the two versions of the Normal condition for each experiment were pooled.

Table 3. Experiments 2 and 3: interresponse time and percentage errors

	Condition	Mean interresponse time (ms)	Mean errors percent
Experiment 2	1. Normal pre-test	257	0·95
	1. Normal post-test	263	0·87
	1. Normal mean	260	0·91
	2. Copy masked	249	1·36
	3. Keyboard masked	335	2·54
Experiment 3	1. Normal pre-test	266	1·01
	1. Normal post-test	256	0·78
	1. Normal mean	261	0·90
	2. Copy masked	241	0·80
	3. Keyboard masked	342	2·58

3.3.2. *Speed*

Analyses of variance on the speed scores from each experiment (using a logarithmic transformation of the data to meet normality assumptions) showed no significant difference between groups ($F < 1{\cdot}0$). The differences between conditions, however, were significant (Experiment 2, $F = 34{\cdot}95$; Experiment 3, $F = 26{\cdot}33$; d.f. 2,20, $p < 0{\cdot}001$ in both cases). In the absence of a significant Group × Condition interaction (Experiment 2, $F = 1{\cdot}11$; Experiment 3, $F = 1{\cdot}90$; d.f. 2,20, $p > 0{\cdot}05$ in both cases), it was concluded that the presentation order of the Copy Masked and Keyboard Masked conditions was not a significant factor in the outcomes and the effect of conditions was, therefore, interpreted directly. A *Newman-Keuls test* for differences between condition means showed responses under the Normal and Copy Masked conditions to have been significantly faster than under the Keyboard Masked condition ($p < 0{\cdot}01$ for all cases). All the findings were confirmed individually by *Sign tests* ($p < 0{\cdot}001$). The differences between the Normal and Copy Masked conditions were not significant in either experiment ($p > 0{\cdot}05$). The speed scores thus exhibited the expected relationship:

$$\text{Normal} = \text{Copy Masked} < \text{Keyboard Masked}.$$

3.3.3. *Accuracy*

The same relationship was shown by the error data. *Analyses of variance* (using a logarithmic transformation) showed no significant differences between groups (Experiment 2, $F < 1{\cdot}0$; Experiment 3, $F = 4{\cdot}24$; d.f. 1,10, $p > 0{\cdot}05$). The difference between conditions, however, was significant (Experiment 2, $F = 9{\cdot}69$; Experiment 3, $F = 14{\cdot}10$; d.f. 2,20, $p < 0{\cdot}01$ in both cases). Since the Group × Condition interaction was not significant (Experiment 2, $F = 1{\cdot}05$; Experiment 3, $F = 1{\cdot}09$; d.f. 2,20, $p > 0{\cdot}05$), the main effect of conditions was interpreted directly. A *Newman–Keuls test* showed that significantly more errors were committed under the Keyboard Masked condition than either under the Normal (Experiments 2 and 3, $p < 0{\cdot}01$) or under the Copy Masked condition (Experiment 2, $p < 0{\cdot}05$; Experiment 3, $p < 0{\cdot}01$). All findings were confirmed individually by non-parametric tests. The differences between the Normal and Copy Masked conditions were not significant ($p > 0{\cdot}05$).

In conclusion, therefore, masking the printed copy left normal keying performance unchanged, while masking the keyboard led to significantly slower responses and more errors. The finding applied both to typing with and without the error correction procedure.

3.3.4. *Interresponse time distributions*

Since it was not originally expected that both speed and error scores would change significantly under the Keyboard Masked condition, the matter of the slower responses was analysed further. If, under the Keyboard Masked condition, the increase in errors was due to the miskeying of difficult characters, then the increase in mean interresponse time might have been due either to a strategy which reduced speed to minimize the number of errors, or to the time spent locating difficult keys in the absence of the usual and necessary visual information. If, with Shaffer and Hardwick (1970), the peak of the interresponse time distribution is identified with typing speed in the absence of input discontinuities and the tail is identified with such discontinuities, a speed reduction strategy would be reflected principally by a shift in the peak, while slower, difficult key location would be reflected principally by a change in the

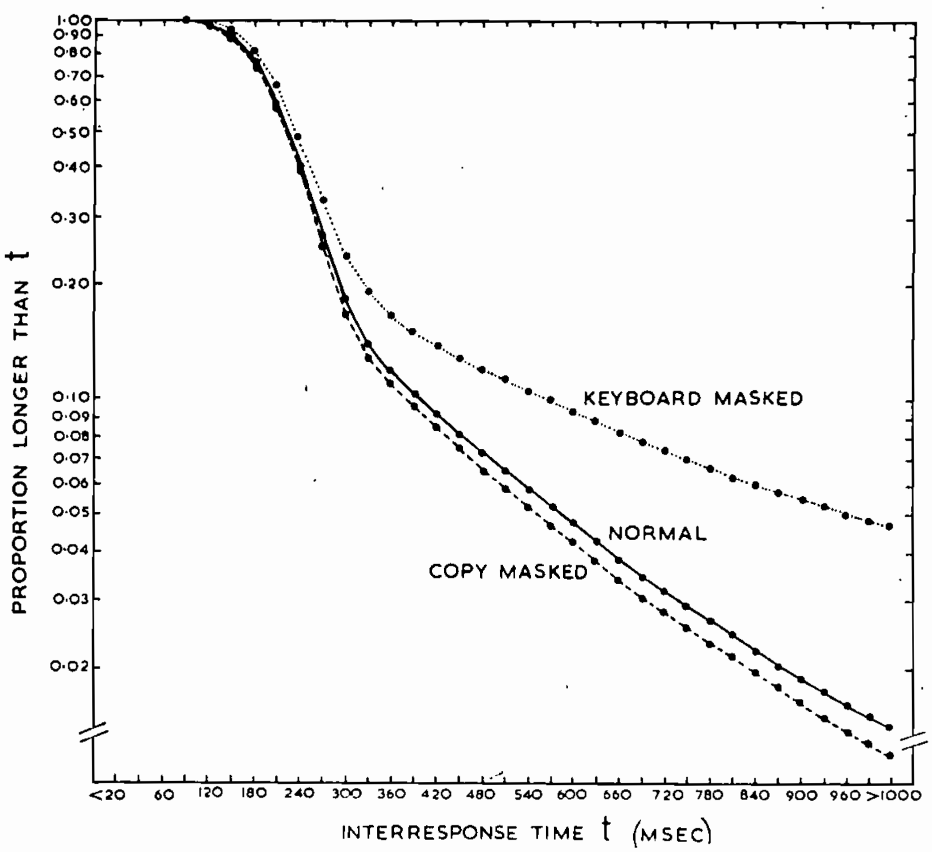


Figure 2. Experiment 2. Distributions of interresponse times. Points shown are drawn at mean interval values.

tail. The relevant data are shown in Figures 2 and 3. Normal and Copy Masked conditions showed similar distributions, except for the tails in Experiment 3—a fact consistent with the assumed increase in consultations of the copy under Normal conditions required by the error correction procedure. In both experiments the distribution of the Keyboard Masked condition compared to the Normal and Copy Masked conditions, however, showed both a shift in the peak (as early as the 110–130 ms interval) and the tail of the distribution (percentage interresponse times greater than 1 s: Experiment 2: Normal—1·4; Copy Masked—1·2; Keyboard Masked—4·8; Experiment 3: Normal—1·9; Copy Masked—1·0; Keyboard Masked—4·9). These shifts are consistent with the view that when subjects could not see the keyboard, they both reduced their typing speed and increased the number of long interresponse times, which presumably reflected the time required to locate the difficult keys.

3.3.5. *Substitution errors*

It was assumed earlier that in the absence of information permitting the location of unfamiliar keys by sight, substitution rather than other types of error would increase, since the subjects were forced to key on the basis of an imperfect memory specification for key location. The relevant data concerning

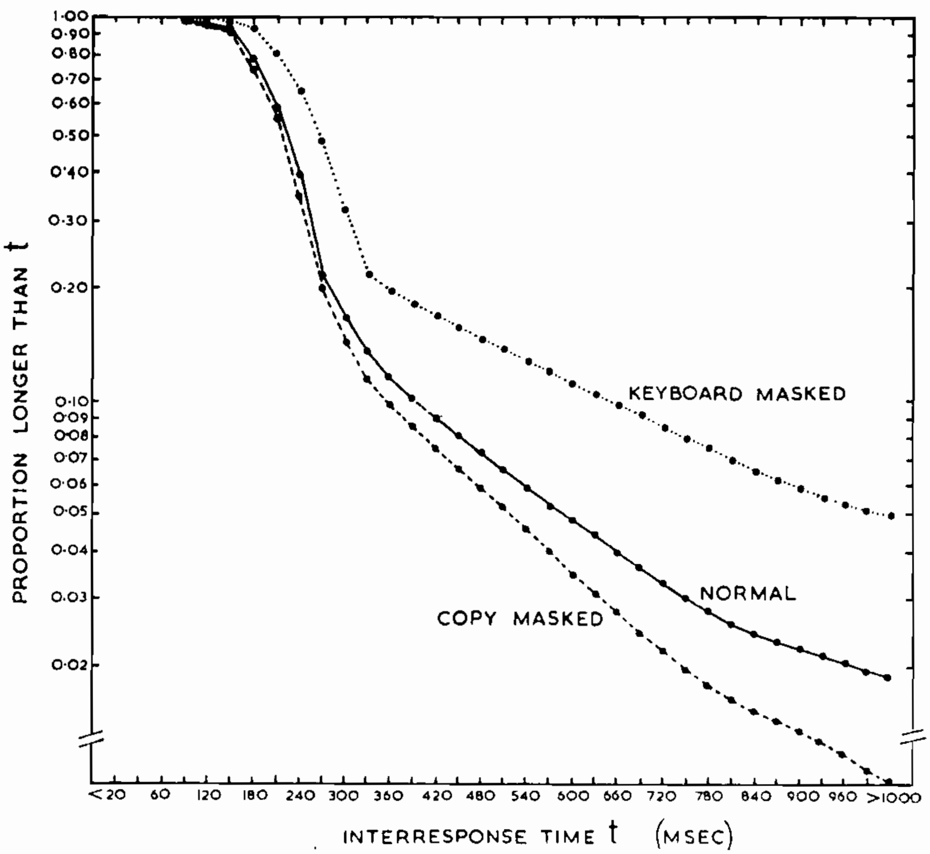


Figure 3. Experiment 3. Distributions of interresponse times. Points shown are drawn at mean interval values.

errors are shown in Table 4. ' Substitution ' was defined as the replacement of a letter in the source text by one which maintained the same order relation; for example, ' i ' for ' u ' when ' hige ' was typed instead of ' huge '. In Experiment 2 substitution errors represented a greater percentage of total errors under Keyboard Masked than under Copy Masked or Normal conditions. *Wilcoxon matched-pairs tests* showed no significant differences between Normal and Copy Masked conditions ($p > 0{\cdot}05$), a significant difference between Normal and Keyboard Masked conditions ($p < 0{\cdot}05$), and an almost significant difference between Copy and Keyboard Masked conditions ($T = 15{\cdot}5$, critical value, $p = 0{\cdot}05$, $T = 14$). In Experiment 3 the Normal condition was not significantly different from the Copy Mssked condition ($p > 0{\cdot}05$). In both, however, substitution errors were significantly fewer than in the Keyboard Masked condition ($p < 0{\cdot}05$ in both cases). Taken together the results indicated that under Keyboard Masked conditions, substitution errors increased significantly as a percentage of total errors. The finding is consistent with the assumption that the increase in substitution errors resulted from the impossibility of using the keyboard for the location of difficult keys by visual means.

In order to amplify this conclusion, substitution errors were analysed further. Three types of error were distinguished: ' adjacency ', ' hand ' and ' direction '.

Table 4. Experiments 2 and 3: substitution errors as a percentage of total errors.

	Condition	Substitution errors as a percentage of total errors
Experiment 2	1. Normal	29
	2. Copy masked	24
	3. Keyboard masked	54
Experiment 3	1. Normal	42
	2. Copy masked	39
	3. Keyboard masked	72

The absence of visual information under the Keyboard Masked condition would be expected to lead to more adjacent than non-adjacent errors (the spatial specification from memory for all keys would be assumed inadequate in the case of difficulty, not totally absent). It would also be expected to produce more right than left-hand errors (because the two most difficult keys, line-feed and carriage return, were pressed by the right hand), but to similar numbers of vertical and horizontal substitutions (because inadequate non-memory specification would presumably involve both). Adjacency was defined as those vertical and horizontal keys situated next to the key in question; in the case of ' h ' the adjacent keys were ' y ', ' u ', ' g ', ' j ', ' b ' and ' n '. ' Bast ' instead of ' vast ' was a ' b ' for ' v ' substitution and an adjacent error. ' Picce ' instead of ' piece ' was a ' c ' for ' e ' substitution and a non-adjacent error. Left and right-hand keys were assigned on the basis of a vertical division between ' 5, t, g, b ' and ' 6, y, h, n ', according to the ' straight ' fingering method (Crooks 1964). Direction was defined as either horizontal, involving a row, or vertical, involving a column substitution. ' Bast ' instead of ' vast ' was a horizontal (adjacent) substitution. Only adjacent substitution errors were evaluated for direction. The relevant data appear in Table 5.

In both experiments the data showed that under Keyboard Masked conditions, compared to the others, there were more adjacent than non-adjacent errors. There were also more right hand than left hand errors. Both trends

Table 5. Experiments 2 and 3: percentage of substitution error types: adjacency, hand and direction (adjacent)

		Condition		
		1	2	3
	Error type	Normal	Copy masked	Keyboard masked
Experiment 2	Adjacent	53	66	79
	Non-adjacent	47	34	21
	Left hand	52	49	37
	Right hand	48	51	63
	Horizontal (adjacent)	63	62	89
	Vertical (adjacent)	37	38	11
Experiment 3	Adjacent	62	28	80
	Non-adjacent	38	72	20
	Left hand	43	57	40
	Right hand	57	43	60
	Horizontal (adjacent)	73	47	94
	Vertical (adjacent)	27	53	06

were consistent with the location function for keys ascribed to the unmasked keyboard. Not consistent with the function, however, was the trend showing more horizontal (adjacent) than vertical (adjacent) errors. It is not clear why this should have been the case. It may have resulted from the different interkey distances (which are less horizontally than vertically). Alternatively, it may have resulted from poorer (horizontal) maintenance of the relation between fingers and keys. This point is taken up later. Although the paucity of the data made statistical assessment impractical, they have been included because the similarity of the outcomes for the two experiments suggested that the findings were not random.

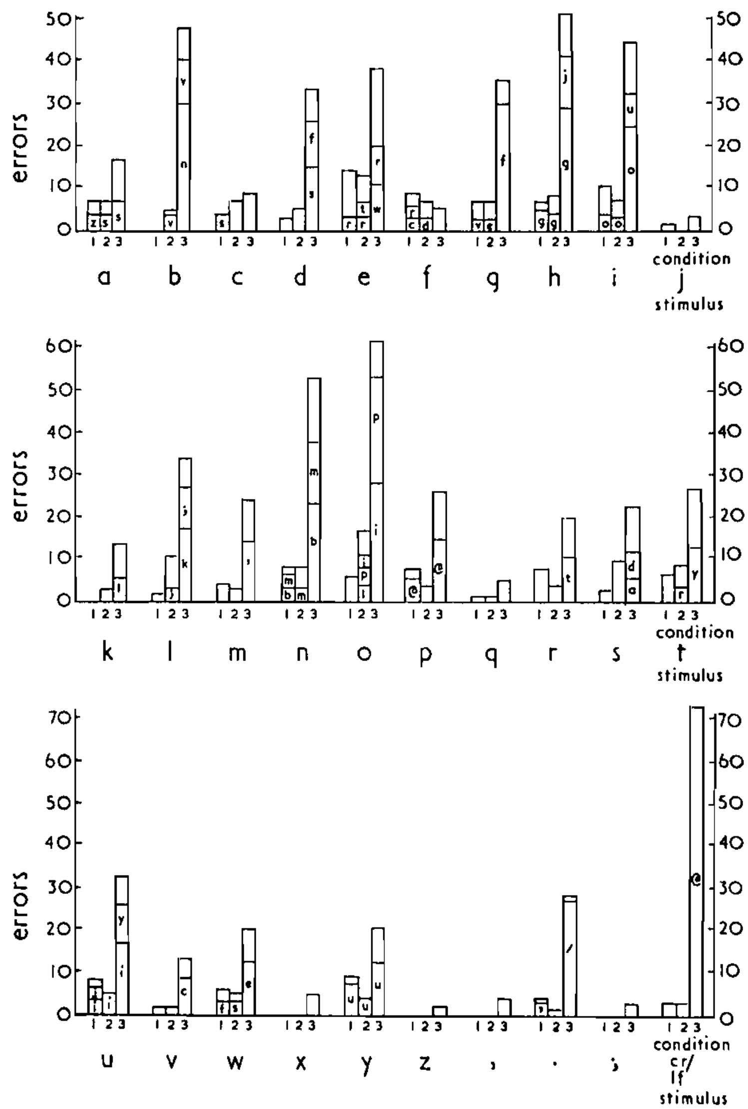


Figure 4. Experiments 2 and 3. Substitution errors (only major errors have been labelled separately).

Major individual substitution errors are shown in Figure 4. Errors from both experiments were combined. They showed no obvious differences and the amount of data for each experiment alone was small. Only individual substitutions having a frequency of occurrence of at least 3 for Normal and Copy Masked conditions, and at least 6 for the Keyboard Masked condition have been labelled separately. Figure 4 shows that keys known to be difficult, i.e. carriage return and line-feed, were strongly associated with the commission of substitution errors under the Keyboard Masked condition, but not under the other two. Sight of the keyboard permitted accurate use of these keys—its absence led to error. However, although some characters contributed little to the number of substitutions (for example: ' c ', ' f ', ' j ', ' q ', ' x ', ' z ', ' , ', ' ; ') and others involved substitutions under the Keyboard Masked condition, not strongly represented under the others (for example: ' g ', ' k ', ' m ', ' s ', ' t ', ' w '), the rest showed a similar pattern of substitutions under all three conditions. The substitution of ' u ' for ' y ' provides such an example. Since, for experienced subjects, it would be unreasonable to suppose that in all these cases location by visual means would have been the normal procedure, it might be assumed that masking the keyboard also led to the poorer maintenance of the correct relations between fingers and keys.

Table 6. Experiments 2 and 3: substitution error runs having more than one error and involving the same hand

	Condition	Mean number of runs per test
Experiment 2	1. Normal	0·33
	2. Copy masked	0·42
	3. Keyboard masked	2·90
Experiment 3	1. Normal	0·17
	2. Copy masked	0·09
	3. Keyboard masked	2·30

This suggestion was supported by the data shown in Table 6, which shows the number of substitutions involving more than one consecutive substitution on the same hand with the same spatial deviation holding between them. For example, ' such statements ' was typed by one subject as ' sycg statenebts ' and constituted four substitution errors. Since it is only a remote possibility that these constituted four separate substitution errors, it must be assumed that they represented an extreme case of the poorer maintenance of the appropriate relation between fingers and keys referred to above, in which an initial constant deviation was continued.

For both experiments *Sign tests* showed the Keyboard Masked condition to have had significantly more substitution error runs per test than the other two conditions ($p < 0{\cdot}05$ in both cases). The findings are consistent with the view that masking the keyboard led to the poorer co-ordination of fingers and keys, in spite of the raised key tops. With hindsight, raising the key edges was probably most adequate as a way of identifying the home row, when the hands were at rest. During typing, however, the hands are poised above the keys for much of the time, and the raised key tops would be only partially effective.

3.3.6. *Errors corrected*

The percentage of errors corrected in Experiment 3 is shown in Table 7. An *analysis of variance* (using a logarithmic transformation of the data) showed no significant difference between the groups ($F < 1 \cdot 0$). Since the Group × Condition interaction was not significant either ($F < 1 \cdot 0$), the significant difference between conditions was interpreted directly ($F = 3 \cdot 73$, d.f. 2,20, $p < 0 \cdot 05$) A *Newman–Keuls test* showed the percentage of errors corrected under the Normal condition to have been significantly greater than under the Copy Masked condition (by 22%, $p < 0 \cdot 05$; and *Sign test*, $p < 0 \cdot 01$) with no significant differences between the other two conditions ($p > 0 \cdot 05$). However, the difference between the Copy and Keyboard Masked conditions (16%), was not significant, although it was in the direction hypothesized on the basis of the error information function ascribed to the printed copy ($p < 0 \cdot 08$; and *Sign test* $p < 0 \cdot 073$). Thus, the expected relationship for error corrections: Normal = Keyboard Masked > Copy Masked held only for Normal and Copy Masked conditions. The significantly larger number of runs of substitution errors under the Keyboard Masked condition suggested one reason why the expected relation failed to occur. The expectation was based on the assumption that the co-ordination of fingers and keys by sight would be replaced without cost by the tactile information provided by the raised home row keys. The error run data indicated that this was not so and that poorer co-ordination also contributed

Table 7. Experiment 3: percentage of all errors corrected.

Condition	Mean errors corrected percent
1. Normal	77
2. Copy masked	55
3. Keyboard masked	71

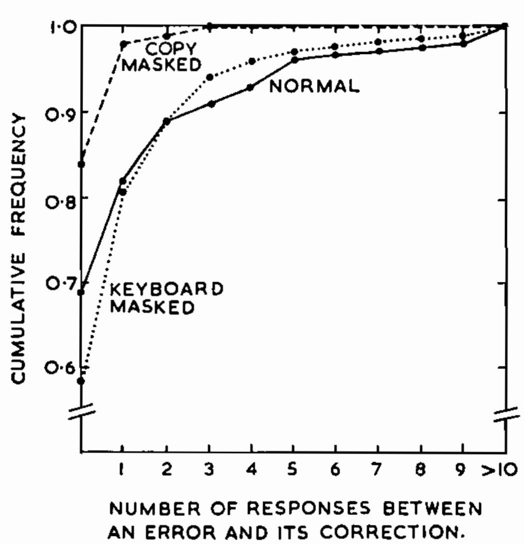


Figure 5. Experiment 3. Cumulative frequency of responses intervening between an error and its correction.

to the increase in substitution errors. Since this type of error was less susceptible to detection by non-visual means, it might be expected to have decreased the proportion of errors corrected under the Keyboard Masked condition.

Further evidence supporting the involvement of the printed copy in error correction is shown in Figure 5, which plots the cumulative frequency of corrected errors against the number of letters intervening between the incorrect response and the initiation of its correction. For example, 'himself' was typed by one subject as 'himsl himself'. This was an omission error ('e'), with zero responses intervening between commission and correction. 'Smoulders' was typed by another subject as 'smo ulders smoulders'. This was an addition error ('space'), with 6 responses occurring between commission and correction. All corrections under the Copy Masked condition were made by the third intervening response. Under the remaining conditions in which the copy was available for consultation, corrections were still being made up to 10 responses later. This indicated that some errors did not require the sight of the copy for correction but that others did.

4. Discussion

Taken together, the results of these experiments indicate that consultation of both the printed copy and the keyboard forms an integral part of skilled keying. Eliminating the error information provided by the copy, by masking the printout, reduced the percentage of errors corrected. Eliminating location information for the keys, by masking the keyboard, decreased the speed and accuracy of performance. The subjects typed at a slower rate and produced more long interresponse times. Proportionally more of the errors were substitution errors associated with adjacent horizontal keys and unfamiliar keys. Since their absence resulted in impaired performance, the location and error functions in keying must be considered important. The range of major substitution errors and runs having identical spatial deviations also underline the importance of vision for co-ordinating fingers and keys during keying.

The results support the hypothesis tested concerning the differential effects of masking the copy and the keyboard. Thus, they resolve the apparent contradiction between the study of Diehl and Seibel and that of West. Elimination of the error information provided by the copy has no effect on performance unless there is a requirement to use that information.

To return to the general issue of visual versus kinaesthetic dependence of highly practised perceptual-motor skills (Fitts 1951) raised in the Introduction. In the light of the importance for keying of both guidance and feedback information, the original null hypothesis attributing to visual feedback no function in skilled keying, ought more properly to be re-formulated in terms of visual control. The present results, however, do not support such a modified hypothesis. Visual guidance provides a back-up system to memory for the location of difficult keys, and aids kinaesthesis in the co-ordination of fingers and keys. Visual feedback likewise provides a back-up system to other procedures for error information. The other procedures, which result in the correction of about half the errors in the absence of visual copy, are presumably: kinaesthetic, a comparison between appropriate and inappropriate sensations of motion and position furnished by the muscles and joints; and pre-kinaesthetic, a comparison of the internal representations which preceed the initiation of the movement itself. Some errors appear to require visual feedback. These may include instances: where kinaesthetic or other non-visual information is adequate to detect an error but not to identify it; where no positive non-visual information is acquired but the subject knows that a visual consultation is worthwhile on the basis of previously experienced difficulty with a particular word or character; and where routine inspection of the copy, perhaps at a frequency determined by the overall difficulty of the text, leads to the detection and the identification of an error.

The rejection of the null hypothesis concerning the visual control of skilled keying should not be taken to deny the changes in its dependence on different modalities which occur during skill acquisition, nor to append a trivial reserve to those changes. The continuing functions of vision suggest that it is wrong to consider only major and minor dependency relations. A more fruitful approach may be to consider the changing function of a modality as skill acquisition progresses. In the case of keying, for example, it may be precisely the change from visual to kinaesthetic dependence for making the key-stroke which both frees the visual modality and assigns to it new control procedures required by the development of the skill itself. This speculation is consistent with the finding that experienced subjects correct more errors with copy than in its absence (West 1967; Experiment 3 reported here); but that unskilled subjects appear to derive no similar benefit from the provision of copy facilities —at least when keying four-digit random numbers (Galloway 1968).

5. Conclusion

During keying, skilled subjects consult both the copy: to obtain information concerning errors; and the keyboard: to co-ordinate fingers and keys and to locate unfamiliar keys. In the absence of copy they correct significantly less errors, their performance remaining otherwise unimpaired.

Cet article présente les résultats de trois expériences qui ont été instaurées afin d'étudier l'utilisation de l'information issue de la copie et celle issue du clavier, au cours de la dactylographie. La première expérience montre que le fait de consulter la copie et le clavier pendent la transcription constitue une partie de l'activité de dactylographie et que la fréquence de la consultation dépend de la difficulté de la tâche.

La deuxième expérience dans laquelle aucune correction des erreurs n'était exigée et la troisième dans laquelle la correction des erreurs était requise, comportaient des conditions où le texte de la copie ou bien le clavier pouvaient être masqués, la condition de référence étant celle sans masquage. Les deux expériences ont montré que la détérioration des performances, appréciée au moyen des critères de rapidité et de précision ne se produisait que lorsque le clavier était masqué. Un autre effet défavorable est apparu dans l'expérience 3 où le masquage de la copie entraînait une réduction de la proportion de corrections des erreurs. On en a conclu que/le clavier fournissait de l'information de ' guidage ' qui permet une coordination des doigts et des touches, ainsi que la localisation par la vue des touches peu familières, alors que la copie fournit de l'information rétroactive concernant les erreurs de frappe. Par ailleurs, on pense que ces résultats lèvent une contradiction signalée dans des recherches antérieures et suggèrent que la rétroaction d'origine visuelle joue un rôle continu, même dans des activités motrices aussi hautement spécialisées telles que le maniement d'un clavier.

Die Resultate von 3 Experimenten werden berichtet. Sie wurden entworfen, um zu zeigen, wie wichtig es ist, den Einfluss der gedruckten Kopie und der Tastatur auch bei gübten Verschlüsseln zu berücksichtigen. Experiment 1 zeigte, dass Kopie und Tastatur während der Transskription zu Rate zu ziehen sind, Sie machen einen Teil Verschlüsselungs-Aktivität in ihrem normalen Ablauf aus. Die häufige Frequenz dieser Konsultation ist eine spezifische Anforderung dieser Aufgabe. Experiment 2, ohne Forderung, Fehler zu korrigieren, und Experiment 3, mit einer Forderung, Fehler zu korrigieren, hoben die unabhängige Verdeckung der Kopie und die

unmaskiert Kontrollbedingung der Tastatur auf. Beide Experimente zeigten, dass ein störender Einfluss auf die Leistung, gemessen an Geschwindigkeit und Genauigkeit, nur bei verdeckter Tastatur auftrat. Experiment 3 deckte einen zusätzlichen Störefekt auf die Leistung, gemessen an der verminderten Prozentzahl korrigieer Fehler, auf, der nur bei verdeckter Kopie auftrat. Es wurde geschlossen, dass die Tastatur für eine " Führungs "-Information sorgt, welche die richtige Coordination von Fingern und Tasten und die Lokation unfamiliärer Tasten durch Sicht erlaubt, während die gedruckte Kopie " feedback "—Information betreffs Beseitigung von Fehlern erlaubt. Es wird erörtert, dass diese Resultate einen Widerspruch zu früherer Forschung löst, und angenommen, dass visuelles Feedback eine fortgegestzte Rolle selbst bei hochgeübter Geschicklichkeit wie Verschlüsseln spielt.

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