PROCESSING OF VISUAL FEEDBACK IN RAPID MOVEMENTS

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The present study determined the minimum amount of time necessary to process visual feedback from a movement. The Ss rapidly moved a stylus from a home position to a target. On half the trials all lights turned off at the start of the movement so that they were made in the dark. Visual feedback did not facilitate accuracy in hitting the target when the movement was as short as 190 msec. For durations of 200 msec. or longer, having the lights on facilitated accuracy, suggesting that it takes 190-200 msec. to process the feedback.

Skilled motor performance typically involves a series of accurate movements. If a movement is made quite slowly, visual feedback may be used in guiding it to an accurate termination. However, visual feedback may not influence the accuracy of very rapid movements. Numerous studies (Woodworth & Schlosberg, 1954) have shown that visual choice reaction time is of the order of 1/2 sec. or longer. Therefore, it would be expected to take 1/2 sec. or longer to process visual error information.

Woodworth (1899) and Vince (1949) attempted to determine the processing time for visual feedback. They showed that accuracy was no better with the eyes open than with the eyes closed when movement rates were between 100 and 180 strokes per minute. They both used repetitive movements which include time spent in reversing direction. Thus, the stroke rate at which accuracy is no better with visual feedback than without overestimates the processing time. Although both Woodworth and Vince had additional experiments with interpolated time intervals between successive movements, they were not designed to estimate visual processing time.

The present study compared discrete movements with and without vision. The Ss rested a stylus on a home position. With the onset of a light, they rapidly moved the stylus from the home position to a small target. On half the trials all lights turned off as the home position was left and turned on again when the movement was completed. On those trials, therefore, the movement was performed in the dark. Visual processing time is estimated by the shortest movement time at which hitting the target is facilitated by having the lights on. There are two advantages of the present procedure. (a) The estimate of processing time is not biased by the time to reverse movements, because movement time is determined from the time the home position is left until the stylus hits either the target or a surrounding metal plate. (b) The S does not know in advance whether or not the light will turn off, insuring that his premovement strategy is the same under light on and light off conditions.

METHOD

Subjects.—Eight undergraduate and graduate male students from the University of Oregon were paid $3.00 for two 1-hr. ses-

1 This research was supported in part by National Science Foundation Grant GB 3939 to the University of Oregon.
The S was instructed to increase visual feedback by increasing the level of co
tact with the S. At a certain level of co
tact, the S showed less visual feedback. The 2Br group showed less visual feedback than the 1Br group.

The results showed a significant interaction between the two factors (level of co
tact and exposure to feedback). The F(1, 3) = 10.2, p < 0.05.

Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Time (sec)</th>
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<tbody>
<tr>
<td>1Br</td>
<td>15</td>
</tr>
<tr>
<td>2Br</td>
<td>20</td>
</tr>
<tr>
<td>3Br</td>
<td>25</td>
</tr>
<tr>
<td>4Br</td>
<td>30</td>
</tr>
</tbody>
</table>

The F(1, 3) = 3.5, p < 0.05.

The mean time per movement and the proportion of missed targets were determined for each S. The results were shown in Table 2. The mean movement times at the fastest and slowest combinations of the two targets were compared.

Results

The mean time per movement and the proportion of missed targets varied significantly across the different conditions. The F(3, 27) = 8.5, p < 0.05.

Table 2

<table>
<thead>
<tr>
<th>Condition</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>10.2</td>
</tr>
<tr>
<td>2</td>
<td>15.0</td>
</tr>
<tr>
<td>3</td>
<td>20.0</td>
</tr>
<tr>
<td>4</td>
<td>25.0</td>
</tr>
</tbody>
</table>

The F(3, 27) = 5.4, p < 0.05.
PROCESSING FEEDBACK IN RAPID MOVEMENTS

In equal time, but at other paces they were relatively close to the intended time. The times were slightly longer when the feedback light remained on than when it was turned off. An analysis of variance showed the difference in movement times at different paces to be highly reliable, $F (3, 21) = 312.0, \ p < .001$, and the difference between feedback conditions to be significant, $F (1, 7) = 10.1, \ p < .025$. Although the interaction between the variables was not significant, $F (3, 21) = 1.19$, individual $t$ tests ($7 df$) showed a reliable difference in feedback conditions at the .25- and .35-sec. movement durations ($p < .05$) but not at the other two paces.

At the fastest movement pace there was essentially no difference in proportion of target misses with and without visual feedback. As movement time increased, accuracy increased under both feedback conditions. The increase was greater with visual feedback so that at movement times of .25, .35, and .45 sec. the proportion of misses was much less than when the feedback light was turned off. An analysis of variance showed the effects of movement time, $F (3, 21) = 53.7$, feedback, $F (1, 7) = 55.2$, and the interaction, $F (3, 21) = 10.2$, to be significant at the .001 level of confidence. Normal approximations of the binomial distribution showed significant differences in feedback conditions at the .25-, .35-, and .45-movement times ($p < .001$ in each case).

**DISCUSSION**

The Ss in the present experiment took approximately 190 msec/movement when instructed to move for a duration of 150 msec. At that speed there was essentially no difference in accuracy between light-on and light-off conditions. With the 250-msec. instruction, movement times averaged about 260 msec. At that rate there was significantly greater accuracy in hitting the target when visual feedback was present. Thus, the minimum duration for processing visual feedback from a movement appears to be between 190 and 260 msec. This is about half the minimum duration suggested by Woodworth (1899) and Vince (1949). The difference is probably due to their use of repetitive movements which include the time for reversal. The present study eliminated the bias by using discrete movements with a 4-sec. pause between successive responses.

In a recent experiment by Pew (1966), Ss attempted to maintain a target in the center of an oscilloscope by sequentially pressing two keys, one of which caused target acceleration to the right and the other to the left. If the oscilloscope display was blanked out for periods up to 410 msec. after a response, the modal time before the next corrective response was 300–350 msec. after the end of blanking. Since some of the corrective responses required less than the modal time, Pew's data are consistent with the present data that indicate a minimum of 190–260 msec. for processing visual error information.

A second major result of the present study is that accuracy increased as movement time increased even when the feedback light was off, though not as much as when it remained on. One hypothesis for the speed-accuracy trade-off in the absence of visual feedback is that at slower speeds movement corrections are made on the basis of kinesthetic spatial information. Chernikoff and Taylor (1952) and Gibbs (1965) found evidence for kinesthetic reaction time as short as 11–13 sec. This is on the order of 50 msec. shorter than simple visual reaction time (Woodworth & Schlosberg, 1954). If corrections are made on the basis of kinesthetic feedback, movements of too short a duration for visual control could still be under kinesthetic control.

A second hypothesis for the speed-accuracy trade-off in the light-off condition is that the actual motor commands issued to the muscles are compared to the in-