 Korean Journal of Sport Science, 2, 1990, 14-33

The Role of Visual Feedback in Rapid Movements

Kang-Hun Lee, Hai-Mo Gu, Dong-Sung Shin
and Byung-Kee Lee, *Korea Sport Science Institute*
Chung-Hee Chung and Chung-Sik Hur, *Seoul National University*

The purpose of this study was to investigate the role of visual feedback information in rapid movements. Two experiments were conducted in order to test the minimum visual feedback processing time and the role of visual feedback information.

Experiment 1 was designed to examine minimum visual feedback processing time. Subjects participated in the experiment were 8 males, 25 years old on the average. The task in experiment 1 was single target aiming with stylus. The movement amplitude was held constant as 35cm. The data from experiment 1 was analyzed by 2x2x4 3-factors within subject design.

Experiment 2 was designed to examine the role of visual feedback information in movement phase. Subjects were 8 males, 21 years old on the average. The task in experiment 2 was also single target aiming with movement amplitude held 35cm. 30 trials was given to each subject under each condition in experiments. The data from experiment 2 was analyized by single factor within-subject design.

Analysis of data revealed the following results:

1. The time required to process the visual feedback information is about 120msec.
2. The effect of the visual feedback uncertainty on visual feedback processing time is not significant.
3. The visual information is more important as the hand approaches the target than as the hand moves in intial portion of the target aiming movements.

INTRODUCTION

The role of visual feedback in motor control has been a major concern in the study of movements since Woodworth's experiment in 1899. The visual feedback processing time, in particular, has become a key issue in the dispute between the open loop and closed loop views of motor control. The centralists claim that motor behavior is controlled by motor programs and suggest that visual feedback cannot be utilized in movements with durations shorter than 200 msec since it takes about that time to process visual feedback to initiate movement correction. Long visual feedback processing time lends evidence to motor control as an open loop, although not to the existence of a motor program itself.

Visual feedback processing time is the duration needed to identify a stimulus and to decide and initiate movement correction. Visual feedback can contribute to the accuracy of movements with longer durations than the processing time. However, it cannot influence the accuracy of fast movements. Woodworth (1899) and Vince (1949) found that there was no difference between open and closed eye conditions in the accuracy of movements when movements rates were between 100 to 180 strokes per minute, and indicated that visual feedback processing time is between 333 and 600 msec. However, it should be noted that the processing time could have been overestimated due to the time spent in reversing direction in repetitive movements used in the experiments.

Keele and Posner (1968) hypothesized that visual feedback cannot influence the spatial accuracy of fast movements since movement correction with visual feedback cannot take place in movements with durations less than visual feedback processing time. They withdrew visual feedback in single aiming tasks of various speeds and found that the withdrawal of visual feedback influenced the accuracy of movements with durations of 260 to 450 msec, but not the accuracy of movements as short as 190 msec. They suggested that visual processing time is between 190 to 260 msec.

Beggs and Howarth (1970) found that the time needed to process visual feed-back was between 200 to 300 msec, supporting the idea that visual feedback processing time is about 250 msec (Carlton, 1981; Legge & Barber, 1976; Poulton, 1974).

There is recent evidence, however, that visual feedback can be processed in much less time. Smith and Bowen (1980) delayed visual feedback during the performance of aiming movements with durations of 150 to 450 msec, using a video camera system. When the accuracy of movements with durations of 150 to 250 msec was compared between 66 msec delay and no-delay conditions, the accuracy of movements under the delay condition decreased. They concluded that visual feedback processing time is about 100 msec. Otherwise, the 66 msec feed-back delay could not have affected the performance of 150 msec movements.

Zelaznik and his colleagues (1983) pointed out that in the Keele and Posner (1968) experiment since visual feedback was manip ulated by randomly selected trials (.5 probability), there might have been an added delay in processing under Vision conditions due to the costs of preparing for No-vision trials, resulting in an overestimation of visual feedback processing time. In an experiment to examine the effect of certainty of visual feedback on the processing, Zelaznik and his colleagues obtained greater differences in the spatial accuracy of movements between Vision and No-vision conditions when visoin was certain. The result indicates that the uncertainty of vision reduced the effect of visual manipulation in the Keele and Posner (1968) experiment. Based on the results of their own experiment which compared the accuracy of single-aiming movements between the No-vision and Vision condition, they proposed that visual feedback can affect movements with durations much less than 190 msec.

There is another source of evidence that visual feedback is processed in much shorter duration than currently estimated. For example, Becker and Fuchs (1969) found that visual information processing time of saccadic eye movement was 130 msec. Carlton (1981) suggested that average time needed to initiate movement correction from visual error detection was 135 msec.

The observations point to a possibility that visual feedback may be processed in duration as short as 100 msec, and the certainty or uncertainty of visual feedback may bring about different strategies on the part of subjects, resulting in different estimation of the processing time. The present study examines these possibilities. The first experiment was designed to estimate visual feedback processing time by controlling movement rates, the expectancy of visual feedback, and visual feedback so as to eliminate factors contributing to overestimation of the processing time. The second experiment was designed to examine the role of visual feedback in rapid movements by varying the delay times of feedback during movements with minimal duration.

EXPERIMENT 1

This experiment was designed to estimate visual feedback processing time during movements of varrious speeds by manipulating visual feedback. Visual feedback processing time was defined as the shortest movement time (MT) at which a difference in accuracy between Vision and NO-vision conditions appears. The expectancy of feedback and MT goal were controlled. Subjects were informed of the availability of visual feedback to prevent the delaying effects of the uncertainty of feedback to the processing time (Hawkins et al, 1979; Zelaznik et al, 1983). It has been pointed out that a specific MT goal given to subjects may reduce attentional capacity to spatial accuracy and may result in an overestimation of visual processing time (Zelaznik et al, 1983). In order to control the effects of temporal accuracy on visual feedbadk processing time, the subject was instructed from the experimenter to perform slower or faster and the observed MT's were categorized into 20-msec class intervals and analyzed.

METHODS

Subjects. The subjects were eight right-handed male graduate students from Seoul National University (SNU) who had no prior experience in single-aiming tasks. They volunteered for the experiment, and were paid for their time after the experiment.

Task and apparatus. The task was to produce single target aiming movements. The subjects were pressing a home key with a stylus and at an auditory response signal attempted to land a stylus to a target 35 cm away to the left. The target was a cross of 1 cm in dimension, the center being 1 mm in diameter on a paper sheet (13.5 x 9.5cm).

The apparatus consists of a multi-purpose reaction timer designed by Lee and the colleagues (1988), which measures reaction time (RT) and MT on an Apple II-plus computer and can be programmed to manipulate visual feedback. A metal plate was secured to a wooden platform (45 cm x 35 cm; 4.5 cm high), a microswitch (2 mm tolerance), on the right side, and the target, 35 cm away to the left. The stylus weighed 15 g and had a sharp point so that when it landed on a target sheet, it could contact a copper plate underneath the sheet. A lamp (100 volts, 30 watts) was placed 45 cm high above the target sheet. The lamp (100 volts, 30 watts) was placed 45 cm high above the target sheet. The lamp was wired to a computer so that the light could stay on or be turned off at different delaying moments during the movent of the subject.

Design. There were three within subject factors. The first factor was visual feedback. In the Vision condition, the lamp remained on. In the vision condition, the lamp remained on. In the No-Vision condition, the lamp was turned off at the initation of the movement and was turned on when the stylus contacted the target. The second factor was visual feedback certainty, Certain or Uncertain. In the Certain condition, the subject was informed of whether the lamp would be on or off. The probability was 1.0 that there would be Vision or No-Vision. In the Uncertain condition, the probability was .5 that the lamp would remain on or would be extinguished. The third factor was MT, categorized into 20-msec intervals, with the means of intervals ranging from 120 to 180 msec, based on the actual MT scores. There were four condditions 120 msec, 140 msec, 160 msec, and 180 msec, each was obtained by averaging the scores ranging from 111 msec to 130 msec, 131 msec to 150 msec, 151 msec to 170 msec, and 171 msec to 190 msec.

Procedures. The experiment was performed individually in a sound and light proof room. The subject was briefed about the experiment and was told that the accuracy of the movement was important. The experimenter operated to start a trial when the subject sat comfortably on a chiar, held the stylus and pressed the home key. The subject heard a warning signal, was in preparation during randomly selected 1 to 3 second foreperiod, and then at an auditory response signal, he started the aiming movement. The target sheet was replaced after each trial and the absolute error of distance and direction from the center of the target was measured in millimeters.

Trials were proceeded in two blocks of Certain and Uncertain conditions, within each block the Vision and No-Vision conditions were randomly assigned. The order of blocks were controlled so as to counterbalance the effect due to the ordering. There were 120 trials preceded by 10 practice trials within each block. The actual MT scores were classified into 4 interval conditions. In the Certain condition, the subject was informed of the availability of visual feedback. The knowledge of results (KR) concerning MT was not administered directly after each trial, but the subject was instructed to move faster or slower on subsequent trials. Each trial lasted about 15 sec and it took 45 minutes to complete a block. There was a ten minute break between blocks and the whole task took 100 minutes.

RESULTS AND DISCUSSION

Data reduction. Data were sereened considering the RT, MT, and the accuracy of a movement. The movements with RT's of 400 msec and over or 130 msec and below were discarded. It was decided that RT's over 400 msec were probably due to lack of attention, and those below 130, to anticipation. MT's over 190 msec and below 110 msec were also excluded because they were out of defined MT ranges of the present study. The movements with the movement error of 35 mm and over were excluded since there was a possibility that the movements were performed without due attention to the target. The discarded trials were 312 (8. 13 % of all trials). From the remaining data, MT's and spatial accuracy were obtained by averaging the actual scores. Using this average scores, the mean and SD were calculated for each experiment condition.

MT. The mean difference between the MT interval class and average MT was examined to check whether the actual MT scores were classified into the right interval class and to compare the mean differences among the conditions. Table 1 presents the average MT as a function of the experiment conditions.

Table 1. Average MT Score under the Conditions in Experiment 1.

Condition		Movement Time			
		120	140	160	180
Certain	Vision	122.11	145.50	163.26	188.80
	No-Vision	121.80	143.05	162.27	186.72
Uncertain	Vision	122.38	143.87	160.68	186.36
	No-Vision	122.49	142.78	161.58	187.62

Unit : Msecond

The difference between an average MT and the interval class ranged from .68 msec to 8.80 msec. The maximal difference between the averages scores across the conditions was .696 msec at 120 msec interval, 2.722 at 140 msec, 2.591 at 160 msec, and 2.317 at 180 msec. Four one-way ANOVA's were administered to compare the mean differences within an interval class. The results showed that there was no significant difference within each class, the respective F-ratio being $F(3, 21) = .105, 2.007, 2.930, .297, p > .05$. Therefore, the categorization of the actual scores to interval classes were supported.

Distance errors. Table 2 presents the average error distance (E-distance) as a function of the experiment conditions. The main effect of visual feedback was significant when the E-distances were compared with an ANOVA, $F(1, 7) = 13.024$ $p < .01$. However, there was no significant interaction effect between visual feedback and MT, $F(3, 21) = .447$, $P > .05$. The results indicate that the E-distance showed a significant difference between Vision and No-Vision conditions at given MT.

Table 2. Average E-distance under the Condition in Experiment 1.

Condition		Movement Time			
		120	140	160	180
Certain	Visin	8.95	7.21	6.88	5.48
	No-Vision	9.77	5.22	7.11	6.27
Uncertain	Vision	9.06	7.91	6.71	5.64
	No-Vision	9.68	8.55	6.79	6.30

Unit : mm

The main effect of MT was also significant, $F(1, 7) = 41.906$, $P < .001$. However, there was no interaction effect between MT and feedback certainty, $F(3, 21) = .303$, $P > .05$. The main effect of feedback certainty was not significant, $F(1, 7) = .237$, $P > .05$, nor was there an interaction among visual certainty, visual feedback, and MT, $F(3, 21) = .306$, $P > .05$.

Direction error. Table 3 present the average direction error (E-direction) as a function of the experiment conditions. The main effect of visual feedback was significant when the E-directions were compared with an ANOVA, $F(1, 7)$

= 16.318, $P < .01$. However, there was no significant interaction effect between visual feedback and MT, $F(3, 21) = .066$, $P > .05$. The results indicate that the E-direction, similar to E-distance, showed a significant difference between Vision and No-Vision conditions at a given MT.

Table 3. Average E-direction under the Conditions in Experiment 1.

Conditions		Movement Time			
		120	140	160	180
Certain	Vision	4.50	3.87	3.65	3.51
	No-Vision	4.86	4.49	4.10	4.08
Uncertain	Vision	4.87	4.09	3.71	3.93
	No-Vision	5.10	4.05	4.03	4.05

The main effect of MT was also significant, $F(1, 7) = 11.55$, $P < .01$. However, there was no interaction effect between MT and feedback certainty, $F(3, 21) = .845$, $P > .05$. The main effect of feedback certainty was not significant, $F(1, 7) = .237$, $P > .05$. However, under the Certain conditions, the mean difference of the accuracy was .5 mm between Vision and No-Vision conditions, and under the Uncertain conditions, the difference was .16 mm, indicating that the accuracy increased when the subject was informed whether there would be vision or not. There was no interaction effect among feedback certainty, visual feedback, and MT.

DISCUSSION

The results of the Experiment 1 showed illustrate that visual feedback affects the accuracy of movements with durations from 120 msec to 180 msec. The effect of visual feedback persisted in E-distance and E-direction of the movements with the durations under examination, irrespective of the information concerning maintenance or withdrawal of vision. The movements under Vision conditions were more accurate than under No-Vision conditions. The results suggest that visual feedback processing time is much shorter than the 190 msec to 260 msec suggested by Keele and Posner (1968) and Beggs and Howarth

(1970), and indicate, instead, that visual feedback can be processed in shorter time than 120 msec.

MT had a main effect on the accuracy of movements. As the duration of movements. As the duration of movements becomes shorter, the movement errors increased. This speed-accuracy trade-off has been also noted in previous studies (Schmidt, Zelaznik, & Frank, 1978; Schmidt ET AL, 1979). The certainty or uncertainty of feedback could not discriminate the movements accuracy as measured by E-distance and E-direction between the Vision and No-Vision conditions. The results exclude the possibility of the delaying effect attributed to the costs of preparation for a no-vision trial in random assignment of visual feedback conditions (Hawkins, 1979; Zelaznik et al, 1983).

EXRERIMENT 2

Experiment 2 was designed to examine visual feedback processing time and the role of visual feedback. In this experiment, the No- Vision condition was further manipulated. The withdrawal of Vision was delayed until different points of movements. The contrast with the Vision condition will yield more accurate estimate of visual processing time and also activity ranges of visual feedback.

METHOD

Subjects. The subjects were 8 right-handed male students from College of Education at SNU who had no prior experience in single aiming tasks. They volunteered for the experiment and were paid afterwards.

Task and apparatus. The task for the experiment was a single target aiming task. The apparatus was the same as in Experiment 1.

Design. The experiment was a single-factor within subject design and the subject repeated the movements under five different. The conditions were one Vision and four different delayed with drawal of vision conditions. The Vision condition was the same as in Experiment 1. Under delayed vision withdrawal conditions, the vision was held back at the initiation of the movements, after 30 msec, 60 msec, or 90 msec. Under the Vision condition, the lamp was turned on throughout a trial, while under the No-Vision condition, it was turned off throughout a trial. Under delayed withdrawal conditions, the lamp was turned on until 30 msec, 60 msec, or 90 msec after the initiation of the movements and was turned off for the remaining duration of a trial. Figure 1 presents the points of vision withdrawal during the movements.

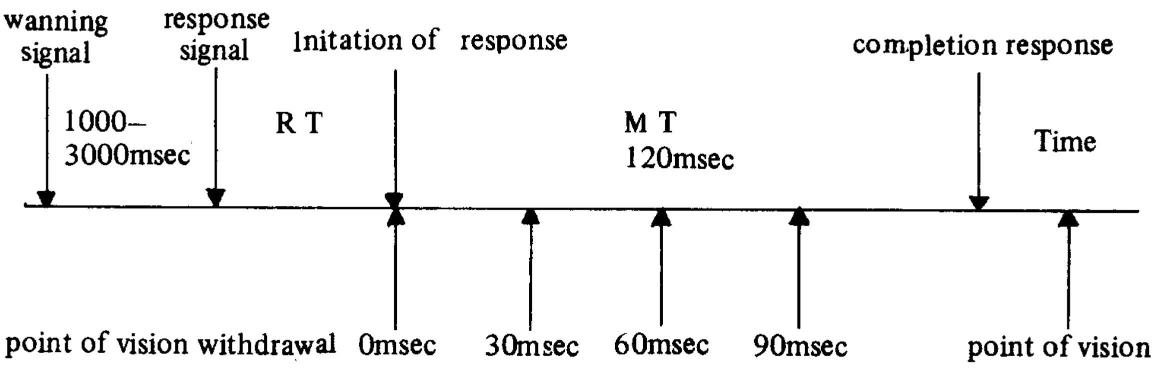

Figure 1. The points of vision withdrawal in Experiment 2.

Procedures. The experiment was performed individually in a sound and light proof room. The subject was briefed about the experiment and was told perform the task as fast as he could. Out of 120 possible combinations of trial orders eight orders were randomly selected to form partial counterbalancing. The subject was given 10 practice trials prior to each condition and repeated the movement under each condition for 30 times. All the other procedures were the same as in Experiment 1.

RESULTS AND DISCUSSION

Data reduction. Data were screened considering the RT, MT, and the accuracy of a movement. For the same reasons mentioned in Experiment 1, the movements with RT's of 400 msec and over or 130 msec and below were discarded. MT's over 200 msec and below 100 msec were also excluded from the analysis. The subject could not possibly make use of vision under 90 msec delay condition for the movements with less than 100 msec MT. MT's over

200 msec do not show a ballistic trajectory and were excluded from the analysis. The movements with the error of 30 mm and over were excluded since there was a possibility that the movements were performed without due attention to the target. The discarded trials were 47 (3.91 % of all trials). From the remaining raw data, MT's and spatial accuracy were obtained by averaging the actual scores. Using this average scores, the mean and SD were calculated for each experiment condition.

MT. Visual feedback can affect MT, and MT can in turn affect spatial accuracy of movements (Newell, 1980). In order to ensure a similar degree of temporal accuracy across the conditionS MT's were compared among the experiment conditions. The results of ANOVA showed that there was no significant difference in MT among the five conditions, $F\ (4,\ 28) = .464,\ p > .05$. This indicates that manipulation of vision had no effect on MT and that the movements under different conditions were performed with the same MT.

Table 4. Average MT and Spatial Accuracy in Experiment 2.

	Conditions				
	Vision	90D	60D	30D	0D
M T	121.61	117.47	117.64	117.26	119.58
E-distance	9.58	11.50	12.05	11.86	11.95
E-direction	4.65	5.65	5.19	5.72	6.72
Overall error	10.69	12.89	13.19	13.30	13.76

MT in msec ; errors in mm

Distance errors. Table 4 presents the average E-distance as a function of the vision conditions. The results of ANOVA show that there was a significant difference in the average E-distance among the conditions, $F\ (4,\ 28) = 8.017$, $p < .001$. The difference was further analyzed by Newman-Keuls post-hoc multiple comparison test and the result is presented in Table 5. There was a significant difference between Vision and all the other four withdrawal conditions, but there was no difference between No-Vision and delayed withdrawal conditions. However,

Figure 2 shows that as the available duration of vision became shorter, E-distance increased.

Table 5. Newman-Keuls Post-Hoc Multiple Comparison of E-distance in Experiment 2.

Conditions	0D	30D	60D	90D	Minimum critical difference 05	.01
ON	2.37**	2.3**	2.47**	1.92**	1.48	1.83
90D	0.45	0.38	0.55		1.39	1.74
60D	- 0.45	-0.17			1.26	1.61
30D	0.07				1.05	1.41

* p<.05

** p<.01

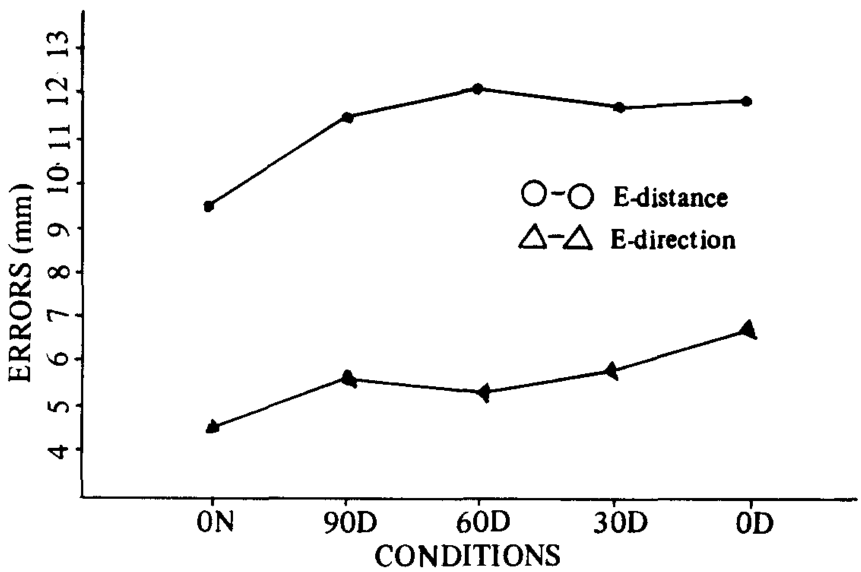

Figure 2. Spatial accuracy as measured by E-distance and E-direction in Experiment 2.

Direction errors. The average E-direction as a function of the vision conditions is presented in Table 4 above. The results of ANOVA show that there was a significant difference in the average E-direction among the conditions, $F(4, 28) = 4.773$, $p < .01$. The difference was further analyzed by Newman-Keuls post hocmultiple comparison test and the result is presented in Table 6. There were significant differences between Vision and No-Vision and between 60 msec delayed withdrawal and No-Vision. As was the case in E-distance, it was observed that as the available duration of vision decreased, E-direction increased (Figure 2).

Table 6. Newman-Keuls Post-Hoc Multiple Comparision of E-direction.

Conditions					Minimum critical difference	
	0D	30D	60D	90D	.05	.01
0N	2.07**	1.07	0.54	1.00	1.44	1.77
90D	1.07	0.07	- 0.46		1.35	1.68
60D	1.53*	0.53			1.22	1.56
30D	1.00				1.01	1.36

* p<.05
** p<.01

Overall errors. The overall errors in spatial accuracy in the movements were obtained from E-distance and E-direction. The average overall error as a function of the vision conditions is presented in Table 4 above. The results of ANOVA show that there was a significant difference in the average overall

Table 7. Newman-Keuls Post-Hoc Multiple Comparison of Overall Errors in Experiment 2.

Conditions					Minimum critical difference	
	0D	30D	60D	90D	.05	.01
0N	3.07**	2.61**	2.50**	2.20**	1.52	1.87
90D	0.87	0.41	0.30		1.43	1.78
60D	0.57	0.11			1.29	1.65
30D	0.46				1.07	1.44

* p<.05
** p<.01

error among the conditions, $F(4, 28) = 10.653$, $P < .001$. The difference was further analyzed by Newman-Keuls post hoc multiple comparison test and the result is presented in Table 7. The result was similar to that of E-distance analysis. That is there were a significant difference between Vision and all the other withdrawal conditions, but no difference between the No-Vision and delayed withdrawal. It was observed that as the available duration of vision decreased, overall errors increased (Figure 3).

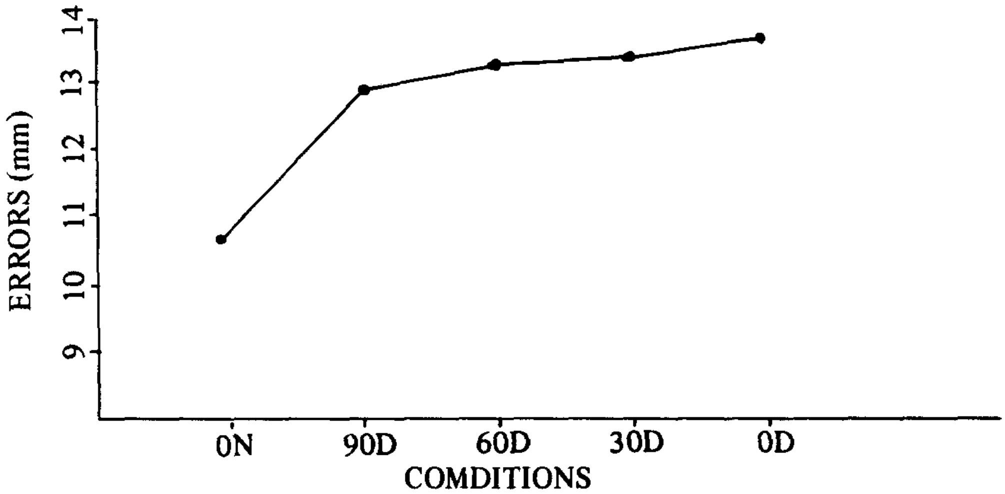

Figure 3. Spatial accuracy as measured by overall errors in Experiment 2.

DISCUSSION

There was a difference in spatial accuracy as measured by E-distance between the Vision and delayed withdrawal conditions. The average MT in Experiment 2 was 118.712 msec. These support the finding of Experiment 1 that visual feedback influence the movements with durations less than 120 msec. The finding indicates that visual feedback can be processed in less than 120 msec. The results concerning E-distance also suggest that vision affects the movement differentially along its temporal progress. There were no differences among the delayed withdrawal conditions, while there was a sharp difference between the 90 msec delayed withdrawal and the Vision condition. The finding points to a possibility that visual feedback is particularly pertinent to the later part of the movements.

The results of E-direction duplicate those of E-distance. There was a difference between the Vision and No-Vision conditions, lending further support to the finding that visual feedback can be processed in less than 120 msec. However , there was no clear indication that visual feedback affects the later part of the movements, although there was a sharp difference in accuracy between the No-Vision and 60 msec delayed withdrawal conditions. When the accuracy errors were considered together, the overall errors reflected the properties of E-distance. Thus, the finding that visual feedback is more pertinent to the later part of the movements is not refuted.

GENERAL DISCUSSION

In the present study, two experiments were performed with a single target aiming task to examine the role of visual feedback in rapid movements. In Experiment 1, visual feedback was controlled to estimate the minimal visual feedback processing time for the movements with various durations, reassessing the estimation by Keele and Posner (1968) and Zelaznik and the colleagues (1983). In the first experiment, MT and feedback expectancy were also controlled in order to exclude their possible influences to visual processing time. Especially, a specific MT goal may result in less attention to spatial accuracy and lead to overestimation of visual processing time (Zelaznik et al, 1983). Accordingly MT was controlled by not assigning a specific MT goal for subject and by analyzing the actual MT scores within interval classes.

The results of Experiment 1 showed that visual feedback can influence the accuracy of the movements with durations from 120 msec to 180 msec. There was no interation between vision and MT and the influence of visual feedback persisted in E-distance as well as in E-direction. The results indicate that visual feedback can be processed in less than 120 msec, refuting the claim made by Keele and Ponsner (1968) and Beggs and Howarth (1970) that visual processing time is between 190 msec to 240 msec.

The finding is in line with recent conclusions that visual feedback can be processed in much less time. For example, Smith and Bowen (1980), using a video camera system, demonstrated that errors increased when the visual feedback was delayed 66 msec in the movements with durations from 150 msec to 250 msec. The finding indicates that visual feedback can be processed in a duration as short as 100 msec. Carlton (1979, 1981) controlled vision in a single target aiming task and examined the movement patterns, and found that the duration from the visual error detection to the initiation of movement correction was 135 msec. The finding also suggests that visual feedback processing time is shorter than previously estimated. Zelazink et al (1983) manipulated the information concerning the withdrawal or maintenance of vision, and concluded that the manipulation of vision could affect the accuracy of the movements with a duration of 100 msec.

The support for the claim that visual feedback can be processed in much less time than previously estimated can be also found in the studies of saccadic eye movements and ball catching movements. Becker and Fuchs (1969) estimated visual feedback processing time to be 130 msec. Whiting (1970) manipulated vision.

during ball catching movements and estimated visual feedback processing time to be around 100 msec. Whiting (1970) found that the subject performed better when he or she saw the ball throughout its flight than when he or she saw the flight only up to 100 msec point before its arrival. The findings suggest that visual feedback can be processed in a short duration of 100 msec.

Zelaznik et al (1983) attributed the overestimation of visual feedback processing time in Keele and Posner (1968) to three factors. First, the use of the "probability to miss the target" as the dependent variable in a hot or miss score could result in overstimation of visual feedback processing. Keele and ponser used a 1/4 inch diameter target, which is not sensitive enough to measure spatial accuracy. In their Experiment 3, average error of the movements was less than 6. 35 mm, which did not produce a significant difference among the conditions. The second factor is the uncertainty of visual feedback. In the Keele and Ponser experiment, visual feedback was randomly manipulated (. 5 probability) by withdrawing the vision coincident with the initiation of the movements. the subject was uncertain of the availability of visual feedback. This uncertainty of visual feedback might have resulted in certain strategies on the part of the subject to prepare for the absence of visual feedback. Zelaznik et al (1983) assumed that due to the strategy, there may have been an added delay in the processing under the Vision condition. However, the possibility was rejected by the results of the present study. There was no differnce in accuracy between the Vision and No-Vision, irrespective of the information concerning the feedback. The only difference attributable to the certainty of visual feedback was found in the distance errors of the movements. When the subject was certain, there was a difference of . 5 mm between the Vision and No-Vision, while the difference increased to . 16 mm under the uncertain condition.

The final factor mentioned by Zelaznik et al (1983) concerning overestimation of visual processing time was the specific MT goal given to the subject. Given a specific MT goal, the subject might pay less attention to the spatial accuracy of the movements to meet the required temporal accuracy. Such a strategy would reduce the effect of visual feedback on spatial accuracy and would result in an overestimation of visual feedback processing. In the first experiment of the present study, the subject was not given a specific MT goal, but was instructed to perform faster or slower, instead, so that the MT's were dispersed within the range from 120 msec to 180 msec. when the actual MT scores were classified into 20 msec intervals and analyzed, it was found that the spatial accuracy decreased as the movements became faster, clearly indicating the trade-off between spatial and temporal accuracy (Schmidt, Zelaznik, & Frank, 1978; Schmidt et al, 1979).

The experiment 2 was performed to examine visual feedback processing for rapid movements by comparing spatial accuracy between the Vision and No-Vision conditions; and to investigate the role of visual feedback for the control of aiming movements by delaying withdrawal of vision at various points of the movements (0 msec, 30 msec, 60 msec, and 90 msec after the initiation). It was also attempted to weigh relative contribution of visual feedback along the progress of movements.

There was a difference in accuracy between the Vision and No-Vision (withdrawal at 0 msec) when the average MT was 118. 712 msec. The result, as with that of Experiment 1, suggests that visual feedback can be processed in less than 120 msec. There was no difference in accuracy among the delayed withdrawal conditions, but there was an apparent difference between the 90 msec delay and Vision conditions. The result indicates that visual feedback is more pertinent to later stage of the movements (90 msec delay enables the subject to use vision for the first three quarters of the movements). Moreover, it further supports the idea that visual feedback can be processed in less time than previous studies suggested.

It has been pointed out that the movement of an aiming task can be divided into two stages (Carlton, 1979; Langolf, Chaffin, & Foulke, 1976;

Annett, Golby, & Kay, 1958). The first stage consists of a movement of hand in distance toward the target and the second stage consists of follow-up or landing movement, which includes at least one error correction. It follows that not until the hand moves closer to the target, visual feedback is not available to the subject since up to that point, the subject is paying attention to the target rather than to the hand. In this context, visual feedback is important to the second stage of the movements.

Carlton (1981) explained visual feedback processing time with saccadic eye movements which share similar reaction properties with hand movements. He suggested that the saccadic eye movement with more than 15 degress typically consists of two saccades: primary and corrective (Becker and Fuchs, 1969). The primary saccade moves the eyes toward the target. and the corrective saccade fixes the focus to the target. Generally speaking, the primary saccade cannot fix the eyes to the target by its movement without error correction by the corrective saccade. The duration between the completion of the primary saccade and the initiation of the corrective saccade is analogous to the duration between vision and initiation of correction from visual feedback in an aiming movement.

The present study performed two experiments to examine the role of visual feedback in the control of rapid movements. The first experiment was to estimate visual feedback processing time by manipulating visual feedback to the movements with various speeds. The second experiment was to examine the role of visual feedback for the progress of the movements. Based on the results of the study, the following conclusions are drawn. First, visual feedback can be processed in less than 120 msec. Second, certainty or uncertainty of visual feedback does not affect visual feedback processing time. Third, visual feedback is more pertinent to the later stage of the movements than to the earlier one.

REFERENCE

Annett, J., Golby, C.W. & Kay, H., The measurement of elements in an assembly task-The information output of the human motor system. *Quarterly Journal of Experimental Psychology*, 1958, 10, 1-11.

Becker, W. & Fuchs, A.F., Further properties of the human saccadic system: Eye movements and correction saccades with and without fixation points. *Vision Research,* 1969, 9, 1247-1258.

Beggs, W.D.A. & Howarth. C.L., Movement control in a repetitive motor task. *Nature.,* 1970. 225, 752-753.

Carlton, L.G., Control processes in the production of discrete aiming responses. *Journal of Human Movement Studies,* 1978, 5, 115-124.

Carlton, L.G., The role of vision for the control of aiming movements. *Doctoral Dissertation:* University of Illionis: 1979.

Carlton, L.G., Processing visual feedback information for movement control. *Journal of Experimental Psychology*: Human Perception and Performance, 1981, 8, 1021-1032.

Crossman, E.R.F.W. & Goodeve, P.J., Feedback control of hand movements and Fitts Law. Oxford. England : Proceedings of the Experimental Society, 1963.

Dewhurst, D.J., Neuromuscular Control system. IEEF Transactions on Biomedical Engineering, 1967, 14, 167-171.

Fitts, P.M., The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology,* 1954, 47, 381-391.

Henry, F.M., Dynamic kinesthetic perception and adjustment. *Research Quarterly,* 1953, 24, 176-187.

Keele, S.W., Movement control in skilled motor performance. *Psychological Bulletin,* 1968, 70. 387-403.

Keele, S.W. & Posner, M.I., Processing of visual feedback in rapid movements. *Journal of Experimental Psychology,* 1967, 77, 155-158.

Langolf, G.D., Chaffin, D.B. & Foulke, J.A., An investigation of Fitts Law using a wide range of movement amplitudes. *Journal of Motor Behavior,* 1976, 8, 113-128.

Legge, D. & Barber, P.J., *Information and skill.* London: Methuen 1976.

Newell, K.M., The speed accuracy paradox in movement control : Errors of time and space. In G.E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior.* Amsterdam : North Holland. 1980.

Schmidt, R.A., Control Processes in motor skills. *Exercise and Sports Sciences Reviews,* 1976, 4, 229-261.

Schmidt, R.A., Zelaznik H.N., Frank J.S., Sources of inaccuracy in rapid movement. In G.E. Stelmach (Ed.), Information processing in motor control and learning. New York : *Academic Press,* 1978.

Schmidt, R.A., Zelaznik H.N., Hawkins B., Frank J.S. & Quinn J.T., Motor-output variability : A theory for the accuracy of rapid motor acts. *Psychological review,* 1979, 86, 415-451.

Schmidt, R.A., More on motor programs. In J.A.S.Kelso(Ed.), Human motor behavior : An introduction. Hillsdale, NJ : Erlbaum, 1982, 198-206.

Schmidt, R.A., Motor control and learning : A behavioral emphasis, Champaign, IL : *Human Kinetics Press,* 1982.

Smith, W.M., & Bowen, K.F., The effects of delayed and displaced visual feedback on motor control. *Journal of motor behavior,* 1980, 12, 91-101.

Vince, M.A., Corrective movements in pursuit task. *Quarterly Journal of Experimental Psychology,* 1948, 1, 85-103.

Whiting, H.T.A., Gill.E.B. & Stephenson, J.M., Critical time intervals for taking in flight information in a ball catching task. *Ergonomics.* 1970, 13, 265-272.

Woodworth, R.S., The accuracy of voluntary movements. *Psychological Monographs,* 1899, 3 (2, Whole No. 13).

Zelaznik, H.N., Hawkins, B. & Kisselburgh L., Rapid visual feedback processing in single-aiming movements. *Journal of Motor Behavior, 1983, 15, 217*-236.