Bulletin of the Psychonomic Society
1990, 28 (2), 158-160

Short-term memory for spatial location in goal-directed locomotion

DIGBY ELLIOTT, RUTH JONES, and SUSAN GRAY
McMaster University, Hamilton, Ontario, Canada

A blind walking study was conducted to examine the nature of the representation that subjects use to guide goal-directed locomotion. Subjects walked blindfolded to targets 4, 8, and 12 m away, either immediately after visual occlusion or following a 2-sec or 30-sec no-vision delay. On half of the trials, subjects were cued as to target prior to visual occlusion; on the other trials, the specific target was identified after visual occlusion, just prior to walking. Although consistency in target acquisition was influenced by both distance and delay, prior knowledge as to target had no impact on error. These results suggest that subjects remember/forget the general spatial layout of the task environment as opposed to a specific target location.

In the last several years, there have been a number of studies designed to examine intermittent visual pickup and goal-directed locomotion (Assaiante, Marchand, & Amblard, 1989; Corlett, Patla, & Williams, 1985; Elliott, 1986, 1987; Thomson, 1983). Typically, in these experiments a particular visual target is identified as the goal, and subjects close their eyes and walk to the target. By manipulating the time between visual occlusion and walking, Thomson (1983) was able to vary time to target (without vision) independently of the distance walked. In a series of studies in which he also varied walking speed, Thomson (1983) found that if subjects were able to reach the target area within 8 sec of visual occlusion, their accuracy and consistency approximated conditions in which full vision was available. On the basis of these findings, he proposed that a visual representation of the movement environment, useful for the control of locomotion, persists for an 8-sec period, but deteriorates rapidly thereafter.

Although several studies have failed to replicate the 8-sec-delay effect (Elliott, 1986, 1987; Steenhuis & Goodale, 1988), Steenhuis and Goodale (1988) have reported that the consistency of distance estimation deteriorates if subjects have vision occluded 30 sec before they are permitted to walk. In contrast to Thomson (1983), Steenhuis and Goodale (1988) propose that a less precise, more slowly decaying representation may be used to guide locomotion when direct visual contact with the environment is prevented.

The purpose of this study was to more closely examine the nature of this longer, less precise representation. In previous studies, subjects have always known before visual occlusion the target goal for that trial. This situation makes it possible for subjects to encode a specific target location prior to walking or to use a representation of the larger movement environment to control their movement. By manipulating information about the target for a trial, as well as target distance and walking delay, we have attempted to determine what type of information subjects remember.

This research was funded by the Natural Sciences and Engineering Research Council of Canada. Correspondence may be sent to Digby Elliott, Motor Behaviour Laboratory, School of Physical Education, McMaster University, Hamilton, Ontario L8S 4K1, Canada.

METHOD

Subjects

Ten young adults from the McMaster University community served as subjects (4 males and 6 females). All subjects had normal or corrected-to-normal vision.

Apparatus and Procedure

The experiment was conducted in a large activity room. The start position and five targets were defined by intersecting strips of masking tape on the floor. The targets were 4, 6, 8, 10, and 12 m from the start position. As in other work (Elliott, 1987), the 6- and 10-m targets were used only for preexperiment practice.

A small cassette player, harnessed to the subject, generated white noise in order to prevent the use of auditory cues to guide locomotion. An opaque mask with a headstrap was used to occlude vision.

Prior to the experiment, the subject walked three times to the 6- and 10-m targets. While standing on the start position with the mask on the forehead above the eyes, the subject was informed of the target for that trial. When the subject was ready, he/she pulled the mask down over his/her eyes and began walking. The subject was encouraged to walk at a normal rate and stop when he/she thought that the large toe on the right foot was directly over the target. For the practice trials, the subject was allowed to lift the mask when he/she had finished walking, thus receiving feedback about walking error.

Following practice, each subject completed 90 experimental trials. Thirty trials were collected at each of the three experimental targets (4, 8, and 12 m). On some trials, the subject pulled down the mask and began walking to the target immediately; on other trials, walking delays of 2 and 30 sec were imposed. For these trials, a tap on the shoulder provided the signal to begin walking. Of primary interest in this experiment was whether or not the particular target for the trial was verbally identified before visual occlusion or after visual occlusion, just prior to walking (i.e., concurrent with tap on the shoulder). Thus, the design involved a factorial arrangement of three target distances (4, 8, and 12 m), three delays (0, 2, and 30 sec), and two information conditions (cued before occlusion, cued after occlusion). There were five trials for each condition, and a separate random order was used for each subject.

As in other work (Elliott, 1986, 1987; Steenhuis & Goodale, 1988; Thomson, 1983), during the experimental trials, the subjects received no feedback about their walking performance. Thus, when a subject stopped walking, one experimenter marked and measured movement error, while a second experimenter led the subject back to the start position for the next trial.

For each trial, the experimenter measured the time between visual occlusion and target acquisition (i.e., delay plus walking time), as well as signed error in the direction of the movement. These signed-error scores were used to calculate constant error (mean algebraic error) and variable error (the standard deviation of the signed errors) for each subject for each condition. Constant and variable error provide information about movement bias and variability, respectively.

RESULTS

A 3 (distance) × 3 (delay) × 2 (information) × 10 (subjects) repeated measures analysis of variance was conducted for time to target (delay plus walking time) and constant and variable error in the direction of the locomotion.

The time-to-target analysis yielded main effects for distance [$F(2,18) = 138.6, p < .001$], delay [$F(2,18) = 40,330.0, p < .001$], and information [$F(1,9) = 9.2, p < .05$]. There were no interactions. As expected, the subjects required more time to reach more distant targets, and, of course, the delay had the intended impact (see Table 1). Of greater interest was the finding that, on average, it took the subjects more time to acquire the target in situations in which they were informed of the target just before walking (18.4 sec) than in conditions in which the target was cued prior to visual occlusion (18.2 sec). Because the delay was experimenter controlled, this difference reflects a slightly longer walking time.

The constant-error analysis yielded only a main effect for distance [$F(2,18) = 4.6, p < .05$]. The 4- and 8-m target errors reflect slight overshooting and undershooting, respectively (4 m = 5.1 cm, 8 m = −4.4 cm). For 12 m, the subjects stopped short of the target to a considerably greater extent (−24.5 cm). This pattern of constant error is often referred to as the range, or context, effect and is characteristic of a wide variety of motor tasks (Pepper & Herman, 1970).

The variable-error analysis revealed main effects for distance [$F(2,18) = 88.0, p < .001$] and delay [$F(2,18) = 13.5, p < .001$]. There was no overall influence of information ($p > .10$) or any interactions ($p > .20$). As in previous experiments (e.g., Elliott, 1986, 1987), variability in target acquisition increased with the distance walked (4 m = 18.0 cm, 8 m = 43.0 cm, 12 m = 75.1 cm). The target distance effect accounted for almost half of the overall variance in the variable-error analysis ($w^2 = 0.489$). Post hoc analysis (Tukey a, $p = .05$) of the delay effect indicated more variable error in the 30-sec-delay condition (53.5 cm) than in the 0-sec (40.0 cm) or 2-sec (42.7 cm) conditions. The latter two conditions did not differ from each other. Thus, this experiment replicates the recent findings of Steenhuis and Goodale (1988).

DISCUSSION

Steenhuis and Goodale (1988) have suggested that a slowly decaying representation of the movement environment may be used to guide goal-directed locomotion when direct visual contact with the environment is prevented. The purpose of this experiment was to determine if subjects encode and remember the general environmental layout, a specific target location, and/or a movement plan to acquire that specific target location. Since, in this study, distance-estimation consistency was unaffected by whether or not the subjects were informed as to target location prior to visual occlusion, our results support the former hypothesis. That is, it would appear that subjects use some sort of visual short-term memory of the whole environmental layout to guide movement when vision is occluded. In contrast to the suggestions of Thomson (1983), this representation does not deteriorate abruptly at 8 sec (i.e., 0-sec-delay vs. 2-sec-delay situations), but loses accuracy gradually over a longer period of time.

Since, in this experiment, the shortest period of time without vision was 4.5 sec, our results do not preclude the possibility that a very brief representation of the visual environment may be used to guide movement. In fact, recent work by Assaiante et al. (1989) with stroboscopic lighting suggests that brief static snapshots of the visual environment may be sufficient for relatively precise locomotion, as long as several snapshots are provided each second. Their findings are consistent with the results of manual aiming studies from our laboratory (Elliott, 1988; Elliott & Jaeger, 1988; Elliott & Madalena, 1987) and suggest that a very rapidly decaying, sensory memory system (Sperling, 1960) may

Table 1
Time to Target (T; in sec), Constant Error (CE; in cm), and Variable Error (VE; in cm) as a Function of Distance, Delay, and Information

	Distance								
	4 m			8 m			12 m		
Information	T	CE	VE	T	CE	VE	T	CE	VE
0-sec Delay									
Before Occlusion	4.5	4.6	14.5	7.2	−8.6	34.0	10.4	−24.4	54.8
After Occlusion	4.6	4.9	15.6	7.6	−2.9	43.5	10.5	−9.9	77.6
2-sec Delay									
Before Occlusion	6.7	3.1	16.2	9.5	−4.3	31.6	12.6	−33.6	74.7
After Occlusion	7.0	8.3	19.3	9.8	−4.3	43.6	12.7	−30.7	70.5
30-sec Delay									
Before Occlusion	34.6	3.1	19.3	37.6	−14.6	53.7	40.5	−14.2	82.5
After Occlusion	34.7	6.8	23.3	37.7	8.1	51.8	40.9	−33.9	90.3

be functional for movement control. This type of representation, along with a more durable, less precise representation (Steenhuis & Goodale, 1988), may have a role to play in the control of locomotion. Given this situation, the optimal frequency for intermittent visual pickup will depend primarily on the precision requirement of the movement task under consideration.

REFERENCES

Assaiante, C., Marchand, H. R., & Amblard, B. (1989). Discrete visual samples may control locomotor equilibrium and foot positioning in man. *Journal of Motor Behavior*, **21**, 72-91.

Corlett, J. T., Patla, A. E., & Williams, J. G. (1985). Locomotor estimation of distance after visual scanning by children and adults. *Perception*, **14**, 257-263.

Elliott, D. (1986). Continuous visual information may be important after all: A failure to replicate Thomson (1983). *Journal of Experimental Psychology: Human Perception & Performance*, **12**, 388-391.

Elliott, D. (1987). The influence of walking speed and prior practice on locomotor distance estimation. *Journal of Motor Behavior*, **19**, 476-485.

Elliott, D. (1988). The influence of visual target and limb information on manual aiming. *Canadian Journal of Psychology*, **42**, 57-68.

Elliott, D., & Jaeger, M. (1988). Practice and the visual control of manual aiming movements. *Journal of Human Movement Studies*, **14**, 279-291.

Elliott, D., & Madalena, J. (1987). The influence of premovement visual information on manual aiming. *Quarterly Journal of Experimental Psychology*, **39A**, 541-559.

Pepper, R. L., & Herman, L. M. (1970). Decay and interference effects in short-term retention of a discrete motor act. *Journal of Experimental Psychology*, **83** (Monograph Supplement 2).

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs*, **74** (Whole No. 11).

Steenhuis, R. E., & Goodale, M. A. (1988). The effects of time and distance on accuracy of target-directed locomotion: Does an accurate short-term memory for spatial location exist? *Journal of Motor Behavior*, **20**, 399-415.

Thomson, J. A. (1983). Is continuous visual monitoring necessary in visually guided locomotion? *Journal of Experimental Psychology: Human Perception & Performance*, **9**, 427-443.

(Manuscript received July 29, 1989.)