The Influence of Uncertainty and Premovement Visual Information on Manual Aiming

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ABSTRACT Target-aiming studies in which premovement visual information is manipulated suggest that when vision is occluded, a brief visual representation of the target environment may be used to guide movement. The purpose of this work was to determine if the internal representation contains information about the whole movement environment or just specific information about the position of a single target goal. Two experiments were conducted in which we manipulated both target uncertainty and the visual information available before and during a target-aiming movement. Radial error differences between visual conditions and the independence of the vision and uncertainty manipulations support the hypothesis that subjects form a representation of the overall movement environment.

During the last several years, there have been a number of attempts to determine if intermittent visual sampling is sufficient for the precise control of target-directed locomotion (Elliott, 1986, 1987; Laurent & Thomson, 1988; Thomson, 1983) and manual aiming (Elliott, 1988; Elliott & Madalena, 1987). Although findings in the walking studies have been equivocal (Elliott, 1986, 1987; Steenhuis & Goodale, 1988; Thomson, 1986), manual aiming experiments conducted in our laboratory (Elliott, 1988, 1990; Elliott & Jaeger, 1988; Elliott & Madalena, 1987) suggest that a brief visual representation of the movement environment can, in some cases, substitute for direct visual contact with the environment.

In our manual aiming studies subjects have been required to move a stylus from a home position to targets a short distance away (e.g., 25-35 cm) in a specified movement time. The major variable of interest has been the visual condition under which

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the movement is performed. In an initial experiment (Elliott & Madalena, 1987, Exp. 1), we manipulated vision by leaving the room lights on, turning the room lights off upon movement initiation, or turning the room lights off 2, 5 or 10 s prior to movement initiation. As other experiments (Elliott & Allard, 1985; Keele & Posner, 1968) have demonstrated, subjects were more accurate in the lights-on condition than the lights-off-upon-movement initiation condition when the movement times were long (400-500 ms), but this advantage diminished when subjects were required to move to the target more rapidly (200-300 ms). Of greater interest was the impact of the target-pointing delay. Compared with the lights-off-upon-movement initiation condition, there was a huge deterioration in movement accuracy if subjects were required to sit in the dark prior to movement initiation. Following the logic that has been used in locomotion studies (Thomson, 1983), we suggested “that some sort of representation of the environment, useful for the visual control of movement, persists for a brief period of time (< 2 s) after visual occlusion” (Elliott & Madalena, 1987, p. 547). Stated differently, intermittent visual sampling may be sufficient for reasonably precise motor control as long as the samples are acquired fairly frequently.

In subsequent experiments we have provided (Elliott & Madalena, 1987, Exp. 3) and manipulated (Elliott, 1988) visual target information in order to establish that the representation used to guide pointing is visual as opposed to motor (e.g., a specific motor programme that can only be held in readiness for so long). Presumably the representation contains three-dimensional information about the position of the target relative to the body, but at this point we still haven’t determined whether this information is coded retinotopically or with respect to the gravitational upright (see Elliott, 1990, for discussion). As well, while our studies to date indicate that the representation is visual or at least spatial, it is not clear whether subjects code information about the whole movement environment or just information about the spatial location of a specific target. This situation exists because, in our experiments to date, the subject has always been aware of the specific target position prior to visual occlusion. The purpose of the experiments reported here was to determine if the no-vision movement-delay effect can be obtained in a situation in which the specific target for a trial is not known before vision is eliminated.

EXPERIMENT 1

While in our other work (Elliott, 1988; Elliott & Jaeger, 1988; Elliott & Madalena, 1987) the initiation of target-pointing movements has been self-paced, in this experiment we adopted a reaction time paradigm. Upon an auditory signal subjects were required to make a rapid movement to a target either to the right or left of the midline. In a choice reaction time situation, the signal specified the target for that trial, whereas in other conditions, subjects were told in advance which target would be signalled. The pointing was done either with full vision, with the lights being extinguished upon movement initiation, with the lights being extinguished at the same time as the reaction time signal, or with the lights being extinguished 2 s prior to the reaction time signal. Thus, in the simple reaction time situation, subjects always had the opportunity to encode a specific target location prior to the elimination of
vision, while in the two-choice situation, two positions had to be remembered. Of interest is whether or not prior knowledge of target location has an impact on movement accuracy in those situations in which direct visual contact with the environment is prevented over the course of the movement.

Method

Subjects: Four male and six female undergraduate students participated in the experiment for course credit. All subjects were right-handed and had normal or corrected-to-normal vision.

Apparatus: The target-pointing apparatus was situated on a table top in front of the seated subject. It consisted of a microswitch that served as a home position located 25 cm from a pressure-sensitive target surface (20 × 28 cm). Sheets of white paper were secured to the target surface. On the paper were two small targets 15° to the left and the right of an imaginary line drawn through the home position from the subject’s midline. The targets were defined by the intersection of two perpendicular lines.

The subject’s task in this experiment was to make a rapid movement with a stylus from the home position to one of the two targets. The signal to initiate the movement was a low frequency tone for the left target and a high frequency tone for the right target. The onset of the tone started a digital timer that stopped when the stylus left the home position (reaction time). Movement of the stylus from the home position started a second timer that stopped with impact of the stylus on the pressure-sensitive target surface, providing the experimenter with a measure of movement time. As well, the stylus left a small hole in the target paper which was used to measure movement error.

The only source of light in the room was 12 three-watt neon bulbs (rapid decay) suspended 1 m above the target surface. The equipment arrangement allowed the lights to remain on over the course of a movement, to be extinguished on movement initiation or tone onset, or to be extinguished by the experimenter 2 s prior to tone onset. In the last three situations the lights came back on when the stylus touched the target surface.

Procedure: Prior to the experiment subjects were given 30 practice trials. Twenty of the trials were conducted with subjects having prior knowledge of the tone (target) for the trial. Although the subjects prepared to move for each trial, the tone actually occurred only 10 times (i.e., Donders’ C with 50% catch trials). The other 10 practice trials were performed under choice reaction time conditions with each of the two targets signalled five times. The primary purpose of the practice was to familiarize the subjects with the tone-target pairing. As with the experimental trials, subjects were requested to move as quickly and accurately as possible.

The experiment consisted of a total of 192 pointing movements in blocks of 12 trials in which half the movements were to the left target and the other half to the right target. In the simple reaction time situation the target was identified before the trial, and the tone, when it occurred (50% catch trials), simply signalled the subject to initiate the movement. In choice reaction time trial blocks the tone actually identified the target. For both situations, target order within a block was randomized separately for each subject.

As well as the simple-choice manipulation, target-pointing was done under four vision conditions. In the full-vision condition there was an auditory warning signal followed by a 2-s silent foreperiod, after which the low or high frequency tone sounded. In one of the no-vision conditions the sequence of events was the same except that the lights were extinguished upon movement initiation preventing direct visual contact during the movement. In a second no-vision condition the lights were extinguished coincidentally with the reaction tone, thus occluding vision during the movement and during the reaction time interval. In the no-vision-delay condition subjects indicated to the experimenter when they were prepared, and the experimenter pushed a button that extinguished the lights and started the 2-s foreperiod. Thus vision was eliminated during the movement, during the reaction time interval, and for the full 2-s foreperiod prior to the pointing signal. In all no-vision situations the lights came back on at the completion of the movement.
TABLE 1
Mean Reaction and Movement Times (ms) in Experiment 1

<table>
<thead>
<tr>
<th>Response</th>
<th>Target</th>
<th>Lights On</th>
<th>Off Initiation</th>
<th>Off Tone</th>
<th>2s Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td></td>
<td>RT</td>
<td>MT</td>
<td>RT</td>
<td>MT</td>
</tr>
<tr>
<td>Simple</td>
<td>Right</td>
<td>253</td>
<td>252</td>
<td>267</td>
<td>244</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>269</td>
<td>260</td>
<td>283</td>
<td>251</td>
</tr>
<tr>
<td>Choice</td>
<td>Right</td>
<td>313</td>
<td>269</td>
<td>308</td>
<td>246</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>353</td>
<td>286</td>
<td>349</td>
<td>268</td>
</tr>
</tbody>
</table>

Each subject performed two 12-trial blocks for each of the reaction time (simple, choice) by vision conditions. A different random block order was used for each subject.

Results

The three dependent variables of interest in this study were reaction time, movement time, and radial error. These measures were analyzed in separate two response type (simple, choice) by visual condition (vision, lights-off upon initiation, lights-off upon signal, lights-off 2 s prior to signal) by target (left, right) repeated measures analyses of variance. The results of these analyses are discussed in turn.

Reaction Time: The reaction time analysis (see Table 1) yielded main effects for both response type, \( F(1, 9) = 43.1, p < .001 \), and target, \( F(1, 9) = 34.3, p < .001 \), as well as a response type by target interaction, \( F(1, 9) = 8.8, p < .05 \). As expected, subjects responded more quickly in the Donders' C reaction time situation (265 ms) than in the choice situation (336 ms). Presumably this was because subjects were not required to make a decision about the target in the former situation. Alternatively, the Donders' C reaction time situation allowed some preprogramming of the response, which was not possible in the choice reaction time conditions.

The influence of target surprised us. Overall, subjects responded to the right target (289 ms) more quickly than the left target (312 ms). This situation was more pronounced in choice reaction time conditions (choice-right = 320 ms, choice-left = 351 ms) than in simple reaction time conditions (simple-right = 258 ms, simple-left = 273 ms). While based on the main effect, one might speculate that right-handed movements in right space can be prepared more quickly than movements in left space, the interaction with response type suggests that right-left differences may have more to do with the alerting properties of the high and low frequency tone. This possibility was examined in Experiment 2.

Movement Time: The movement time analysis (see Table 1) revealed main effects for response type, \( F(1, 9) = 17.4, p < .01 \), visual condition, \( F(3, 27) = 4.8, p < .05 \), and target, \( F(1, 9) = 41.6, p < .001 \), as well as a response type by target interaction, \( F(1, 9) = 11.4, p < .01 \). Overall, subjects moved more quickly in the simple situation (249 ms) than in the choice situation (269 ms) and more quickly to the right target (252 ms) than the left target (265 ms). As with reaction time, the right target (high tone) advantage was more pronounced in choice (right = 258 ms, left = 277 ms) than in simple (right = 245 ms, left = 253 ms) reaction time conditions.
Once again, the reason for the target/tone effects are examined more fully in Experiment 2.

Of greater interest was the influence of visual condition on movement time. Post hoc analysis (Tukey a, p — .05) of the vision effect revealed that subjects moved more slowly in the full-vision condition (267 ms) than in the no-vision-upon movement initiation condition (252 ms). The three no-vision conditions did not differ from each other (lights-off upon signal = 259 ms, 2-s delay = 256 ms). This finding is similar to results published elsewhere (Elliott & Madalena, 1987; Jeannerod, 1984) and indicates that when vision is available subjects use it to guide their movements.

Radial Error: The radial error analysis revealed only main effects for response type, $F(1, 9) = 6.8, p < .05$, and visual condition, $F(3, 27) = 97.3, p < .001$. There was no response type by visual condition interaction. Overall, subjects were more accurate in the simple reaction time situation (12.8 mm) than in the two-choice situation (13.5 mm). Post hoc analysis (Tukey a, $p = .05$) of the visual condition effect indicated that all four conditions were different from each other. As is evident in Figure 1, while subjects perform best when they are in direct visual contact with the environment, there is a large deterioration in performance if they are required to sit in the dark for as little as 2 s prior to movement initiation. Moreover, the availability of vision during the reaction time period influences movement accuracy regardless of whether or not subjects were precued as to the specific target for that trial. These visual condition effects appear to be of major importance since they account for close to half the overall variance in the radial error ($\omega^2 = .492$).

**Discussion**

Of primary interest in this experiment was the independent influence of visual condition and uncertainty on movement accuracy. While subjects were slightly more accurate in the simple situation than the choice situation, uncertainty did not mediate
the relatively larger effects of vision. If subjects remember/forget only a specific target location, the availability of vision during the reaction time interval would be expected to have more impact on accuracy in the choice reaction time situation than in the simple reaction time situation. These results would be expected because in the simple situation a specific target location can be encoded before vision is eliminated, whereas in the choice reaction time situation two positions must be remembered.

Although the main effect for response type indicates that some prior preparation can be useful, it appears that a brief representation of the overall movement environment is useful for movement control regardless of target uncertainty. As in our earlier studies (Elliott, 1988; Elliott & Madalena, 1987), while aiming was most precise when vision was continually available, the removal of vision upon movement initiation presented fewer problems for subjects than when vision was eliminated earlier (i.e., 2 s delay or prior to the reaction time interval).

Surprisingly, even in the simple reaction time situations in which preprogramming is theoretically possible (Klapp, 1977), visual information provided during the reaction time interval is beneficial to precise movement control. This situation could exist for at least two reasons. First, it is possible that the exact force values for a motor programme must be specified just prior to movement initiation, perhaps because of their susceptibility to decay or interference (see Henry & Rogers, 1960; Sternberg, Monsell, Knoll, & Wright, 1978). Alternatively, it may be that exact force values need not be specified prior to movement since, even in the absence of direct visual contact with the environment, closed-loop control mechanisms are still in operation. For example, a ballpark movement may be adjusted on the basis of kinesthetic information about limb position and remembered information about the position of the target. Given this latter explanation, movement error might be a direct function of the strength of the target representation since the quality of limb information is the same in all no vision situations. Recall that when direct visual information is eliminated with the reaction time signal, the information contained in the representation has another quarter of a second to decay.

**EXPERIMENT 2**

While it is tempting to conclude, based on Experiment 1, that the movement uncertainty and the availability of visual information about the movement environment are independent, we decided a more robust manipulation of target uncertainty was in order. In Experiment 2, we adopted a cost-benefit (Posner, 1978) or reprogramming paradigm (Lee, Elliott, & Carnahan, 1987); that is, prior to a trial, a specific target (tone) was precued. On 80% of the trials the precue was valid and the appropriate signal occurred. However, on 20% of the trials the precue was invalid and the tone signalled the subject to move to the uncued target. The assumption of this paradigm is that the high probability of a valid cue will encourage subjects to prepare a movement in advance of the reaction time signal. On the invalid trials, then, subjects must abort the prepared motor programme and reprogramme. Thus in the 20% condition, the opportunity for advance planning is reduced to an even greater extent than it is in the two-choice reaction time situation.
Subjects: Six male and four female undergraduate students participated in the experiment for course credit. All subjects were right-handed and had normal or corrected-to-normal vision.

Apparatus and Procedure: The apparatus and experimental setup were the same as Experiment 1 except the high and low frequency tone could be paired with either the right or left target. This allowed us to examine the influence of tone and target independently.

The practice and basic procedures were the same as in Experiment 1 except that for five subjects the high tone signalled the right target and for the other five subjects it signalled the left target. Ten of the practice trials were performed under equal probability, two-choice conditions ($p = .50$), while 20 trials were conducted using the .80-.20 manipulation (i.e., 4 invalid trials randomly mixed with 16 valid trials).

A total of 400 experimental trials were conducted on 2 consecutive days. The visual manipulations were identical to Experiment 1, while reprogramming manipulation (.80-.20) replaced the Donders’ C simple reaction time procedure. Twelve blocks of trials (response type by visual condition) were conducted on each of the 2 days. A separate random block order was used for each subject each day. Four equal probability ($p = .50$) blocks consisted of 20 trials each. A separate random target order was determined for each subject. The eight reprogramming trial blocks (four cued right, four cued left) consisted of 15 trials each. Thus 3 invalid cues were randomly inserted into a series of 12 valid cues. As with the practice trials, the tone-target pairing was counterbalanced between subjects.

Results

Once again, reaction time, movement time, and radial error were the variables of interest. In this experiment specific tone-target pairing served as a between-subjects variable with half the subjects moving right with the high tone and half the subjects moving left with the high tone. Thus, the three dependent measures were analyzed in separate pairing group by probability (.20, .50, .80) by visual condition (vision, lights-off upon initiation, lights-off upon signal, lights-off 2 s prior to signal) by target (right, left) mixed analyses of variance.

Reaction Time: The reaction time analysis (see Table 2) yielded main effects only for visual condition, $F(3, 24) = 5.1, p < .01$, and probability, $F(2, 16) = 14.2, p < .001$. Overall, subjects responded more quickly (Tukey $a, p = .05$) in the full-vision condition (271 ms) than they did in the lights-off-upon-movement initiation condition (282 ms) and the 2-s delay condition (284 ms). The three no-vision
conditions did not differ from each other (lights-off upon tone = 277 ms). Presumably when subjects know that vision will be available, they spend less time in movement preparation because continuous visual control of the movement is possible (see movement time results).

Of greater interest were the probability results. While reaction times in the valid cue condition (.80 = 270 ms) were faster (Tukey a, p = .05) than in the neutral condition (.50 = 291 ms), contrary to expectations, the invalid cue condition also produced faster times (.20 = 274 ms) than the .50 control situation. These findings indicate that in the .80-.20 trial blocks subjects were responding to either tone and reorganizing inappropriate movements in flight. Once again, this strategy should result in relatively long movement times in .20 situations.

Movement Time: The movement time analysis (see Table 2) revealed main effects for probability, F(2, 16) = 8.6, p < .01, and target, F(1, 8) = 15.7, p < .01, as well as a group by target interaction, F(1, 8) = 25.3, p < .001. The probability finding was as expected. Specifically, subjects took longer to move to the target in the .20 situation (289 ms) than in the .50 (277 ms) and .80 (277 ms) situations (Tukey a, p = .05). Thus the cost associated with an invalid trial was reflected in MT as opposed to RT. Once again, this indicates that even the direction of the movement is reprogrammed while the limb is in flight.

The target effect was the result of an overall speed advantage when subjects were moving to the target on the right (277 ms, left = 285 ms). This is a standard finding (Fisk & Goodale, 1985; Roy & Elliott, 1989) which reflects the fact that right-hand movements can be made more rapidly in right space than in left space. The pairing group by target interaction indicates that the right-side advantage occurred only for subjects who had the high frequency tone signalling the right target (high tone right group: right target = 271 ms, left target = 289 ms; high tone left group: right target = 283 ms, left target = 281 ms). Thus, the right-side advantage is mediated by tone frequency. It would appear that the high frequency tone has some sort of alerting property that contributes to a lower MT, regardless of the spatial location of the target. From a theoretical point of view, we were happy to see that pairing group and target did not interact with vision condition or probability.

Radial Error: The radial error analysis yielded only a main effect for visual condition, F(3, 24) = 42.6, p < .001. As in Experiment 1, all visual conditions were different from each other (Tukey a, p = .05), and the visual condition effect accounted for a large proportion of radial error variance, $\omega^2 = .440$ (see Fig. 2). Once again there was no interaction involving visual condition and uncertainty.

Discussion

Once again, the purpose of this experiment was to determine if the opportunity for movement planning and/or encoding of a specific target location prior to the

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1Even in the invalid cue condition, subjects moved to the wrong target less than 5% of the time. All wrong target trials were eliminated from the analyses.

2The main effect for visual condition approached conventional levels of significance (p = .057). As anticipated, subjects tended to move most slowly when vision was available (vision = 288 ms, lights-off upon initiation = 274 ms, lights-off upon tone = 278 ms, 2 s-delay = 283 ms).
elimination of visual information improves an individual's rapid target-aiming performance. Of particular interest in this experiment was the 20% invalid cue condition, for which all motor programming (i.e., reprogramming) is assumed to occur after the movement imperative. Our hypothesis was that if subjects encode and remember a specific target location and/or a movement plan, then movement error will be large in any condition in which reprogramming must be done in the absence of vision (e.g., lights-off upon tone condition). If, on the other hand, subjects use a representation of the entire movement environment or at least two target positions to guide aiming, then movement error will depend on the stability of that representation over time and not target uncertainty. Our failure to find any influence for target (movement) probability, but large effects for visual condition, supports our suggestion, following Experiment 1, that subjects employ a representation of the larger movement environment. While this representation can be useful for movement control, it decays very rapidly (see also Elliott, 1988; Elliott & Madalena, 1987).

The absence of a reprogramming effect in this experiment was all the more surprising since RT and MT results indicate that, for invalid cue situations, subjects reorganized their movements during the actual movement (MT effect) and not during the RT interval. This finding suggests that even when visual feedback is eliminated and information about target position greatly reduced, subjects do not totally prepare their movements in advance. In fact, it would appear that subjects rely on whatever spatial information is available regardless of how degraded it may be. In making this point, we are not trying to resurrect the old centralist versus peripheralist argument (see Keele, 1968; Kelso & Stelmach, 1976). On the contrary, we have suggested elsewhere that planning a movement involves specifying how and when feedback and other available information will be used (Elliott & Allard, 1985; Elliott & Jaeger, 1988). In this experiment, the availability of information about the positions of the targets in the environment relative to the limb seems to be the performance limiting factor.
GENERAL DISCUSSION

The primary purpose of these experiments was to extend previous work (Elliott, 1988; Elliott & Jaeger, 1988; Elliott & Madalena, 1987) suggesting that a brief visual representation of the movement environment may be used to organize and guide aiming movements when continuous visual contact with the environment is prevented. Specifically, we hoped to determine whether the representation contains information about a specific target location or more general information about the layout of the movement environment. Since in both experiments target uncertainty failed to interact with the visual manipulations, our results support the latter point of view. Moreover, by eliminating the hypothesis that subjects remember/forget a specific target location, we also provide further evidence against the notion that a specific motor programme is structured while vision is available and executed later.

Surprisingly both experiments show very little influence of target uncertainty, and thus advance planning, on movement accuracy. Although in Experiment 1 subjects were slightly more accurate in the simple reaction time situation than when they were uncertain about the location of the target, even when the target was known in advance, subjects performed more accurately when vision was available during the RT interval. Movement preparation models that posit motor programming in advance of the movement imperative (e.g., Klapp's 1977 preprogramming) would certainly not predict this finding. Perhaps, as Henry (1980) has suggested, preprogramming is not possible. Alternatively, it may be that accuracy differences between vision and no vision during the reaction time interval may simply reflect an extra 250 ms of decay in the visual representation used to guide the limb to the target (Elliott, 1988, 1990; Elliott & Madalena, 1987). This latter explanation certainly fits with the finding that subjects acquired the target just as accurately in the invalid cue situations as they did in the valid situations (Exp. 2), even though adjustment appears to have been made, not before, but during the actual movement. The rapid deterioration in movement accuracy over the no-vision RT interval also agrees with suggestions we have made elsewhere that the representation may have some of the same characteristics traditionally associated with iconic memory (Neisser, 1967). With respect to the intermittent versus continuous visual sampling issue (e.g., Elliott, 1986; Thomson, 1983), it would appear that reasonably precise aiming may be possible with intermittent sampling, as long as those samples are taken frequently (see Assaiante, Marchand, & Amblard, 1989, for recent work on intermittent visual pickup and locomotion).

References


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