ROLE OF LANDMARK FOR SPATIAL MAPPING IN NON-RIGID ENVIRONMENTS

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ABSTRACT

Spatial orientation in colonoscopy is difficult. Previous studies have shown that knowledge of shape information is more useful than direction or location information. However, the mechanism of spatial mapping in a non-rigid environment is unknown. It was hypothesized that visual landmarks were used as the primary cue for spatial orientation, as in rigid environments, even when other conflicting cues were available. An experiment was conducted to examine the role of visual landmarks in spatial mapping in a non-rigid environment. Simulated colonoscopy procedures were performed in colon models representing a compressed colon and a colon with missing landmarks. Preliminary results indicated that time, and not visual landmarks, were used as the dominant cue for spatial mapping. This may explain the conflict experienced by endoscopists who are aware of the stretchable nature of the colon, combined with the unreliable landmarks. Therefore, a useful navigational aid might be developed to encourage the use of a different strategy for spatial mapping in situations where the spatial relationship between landmarks is not constant, as in the colon.

INTRODUCTION

In colonoscopy, a flexible endoscope is used to examine the inside of the colon for lesions. The endoscopist inserts the scope into the patient, and guides the flexible scope from the patient’s rectum to the caecum, based on the endoscopic view provided by the scope. Earlier research has shown that navigating through the colon is a difficult task that involves medical background, visuomotor coordination, and spatial cognition (Cao & Milgram, 2000; Cirocco & Rusin, 1993; Cotton & Williams, 1990; Sugarbaker, Vineyard, Peterson, 1976). Mechanically, the endoscopist has little control over the behavior of the shaft of the flexible endoscope within the elastic and floppy colon. Cognitively, the endoscopist has difficulty inferring the location of the endoscope within the colon, due to the ambiguous landmarks and non-rigid spatial structure of the environment. This can lead to disorientation, resulting in incomplete examinations, or the incorrect location of tumors and lesions. In another study of spatial orientation in colonoscopy, Cao (2001) showed that unlike in a rigid environment, shape information was more important than direction or location information for spatial orientation in a non-rigid environment. However, it is not known what role landmarks play in spatial cognition in a non-rigid environment.

This paper describes a follow-up experiment to the aforementioned studies on spatial orientation in colonoscopy (Cao & Milgram, 2000; Cao, 2000). The purpose of this study was to evaluate the usefulness of landmarks for spatial orientation in non-rigid endoscopic environments. If the primary cue for mapping an unfamiliar environment is based on landmarks, as it is in rigid environments, then it may provide insight into novel designs of navigational aids to support spatial orientation in colonoscopy. It was hypothesized that landmarks would be the primary cue used for spatial mapping in a non-rigid environment. Furthermore, landmarks would dominate over other cues, such as time and distance traveled, which may provide contradictory information regarding spatial orientation in a non-rigid environment. In order to test these hypotheses, an experiment was conducted to examine the performance of orientation in a
simulated colon, under conditions of contradicting spatial information.

METHODS

Subjects:

Twenty subjects (10 female and 10 male graduate and undergraduate students from Tufts University) participated in this experiment.

Apparatus:

Colon Model. Three physical non-rigid models were constructed to represent the colonic environment (Cao, 2001). The colon models were representative of the real colon environment in visual appearance and mechanical compliance as experienced through an endoscope. In addition, each colon model contained five colored targets that were strategically placed along the length of the colon. The control model was 80 cm long and contained all five of the colored targets, in the following order traveling from the rectum to the caecum: yellow, blue, pink, red and green (see Figure 1). The second colon model was 71 cm long and contained all five colored targets with the correct sequence but at variable intervals along the colon. The second condition represented a case of variable colon length between landmarks or a compressed colon. The third colon model was 80 cm long and contained only four colored targets (yellow, blue, red and green), with the pink target missing. This last condition represented a non-existent landmark in the colon.

Colon Map. A black and white paper drawing of the human colon was provided alongside the endoscopic image of the colon. The color names of the landmarks were clearly labeled on the map in black ink (see Figure 1).

Colonoscope. A 180 cm long Pentax colonoscope with an EPM-3300 video processor was used. The distance markers along the scope's exterior were obscured using electrical tape. The endoscopic image was displayed on a 68.6 cm television monitor that was placed 170 cm in front of the subject at eye level. In order to remove the difficulty of manipulating the two control dials on the handle of the scope while holding it with one hand, the handle of the scope was fixed on the surface of the table to the left of the colon. This allowed the left hand to easily manipulate the dials while the right hand advanced the scope into the colon.

![Figure 1: Map of colon presented to subjects during experiment.](image)

Task:

The task simulated a simplified procedure of colonoscopy. Subjects were asked to navigate the colonoscope from the beginning to the end of the colon model as quickly and as safely as possible. One practice trial was conducted with the control model in order for the subjects to become familiarized with the scope, as well as to begin to form a mental model of the colon. During the test trials, the subjects were asked to stop at a pre-determined location in the colon, the monitor was shut off, and the colon drawing was covered. Participants were then asked to indicate where they were in the colon, the color of the last landmark passed in the colon, and their confidence in their answers. Confidence rating was measured using a 5-point Likert scale.

Experimental Design:

Each subject performed 1 trial in each of the 3 conditions (control, compressed colon, missing landmark). The first condition was always the control condition. Order of the compressed colon and missing landmark conditions was counterbalanced.
Dependent Measures:

Five measures of performance were collected: localization, confidence rating of localization, recall of last landmark’s color, confidence rating of the color of the last target seen, and time to task completion. These measures combined to provide an indication of how landmarks were being used for spatial orientation in the navigation task. At the end of all experimental trials, the subjects were asked to complete a questionnaire for a subjective assessment of spatial awareness.

Analysis:

An analysis of variance was conducted using an alpha value of 0.05 on the following variables: location error, location confidence, time, and color recall confidence. We report only significant results in this paper.

RESULTS AND DISCUSSION

Because the distances traveled in the colons were different, the time to task completion was normalized. There was a statistically significant difference noted for the normalized task completion time ($F=5.66$, $df=2$, $p=0.006$). A post-hoc analysis showed that the difference was between the missing landmark condition and the two other conditions (see Figure 2). A significant difference was also observed in location confidence between conditions ($F=16.72$, $df=2$, $p<0.001$). Post-hoc analysis showed that the difference was between the control and the other two conditions. There was no difference found between the means of the compressed colon and missing landmark colon (see Figure 3).

Overall, subjects underestimated their distance traveled along the colon in the test conditions. This underestimation was an average of 16 cm for the compressed colon and 10 cm for the missing landmark condition. Localization error was more variable in the compressed condition. This seems to suggest that localization is not primarily landmark dependent, but also time dependent. Subjects seemed to have used time spent in travel over landmark detected to estimate the location or distance traveled in the compressed condition colon model (all landmarks present), whereas landmark was a more dominant cue in the missing landmark condition. The latter may have been due to the fact that subjects did not anticipate landmarks to be missing. Thus, not seeing the expected landmark, the conflict created by the time factor may have resulted in a larger error in localization.
condition, to 50% in the missing landmark condition (see Figure 4). Combined with results of localization errors, this result suggests that correct recall of landmarks passed did benefit spatial orientation, but not enough to overcome the effect of the time spent in travel. The confidence of recalling the last landmark also showed a significant effect (F=13.73, df=2, p<0.001).

Figure 4: Average landmark recall percent accuracy and confidence rating in different colon conditions.

When asked to rate their agreement with statements of which cues they used most to gain orientation during the task, color targets were noted as having the highest percent agreement of 42% (see Figure 5). Participants felt that the color target cues were most useful to orient themselves.

Figure 5: Percent of response to cue most used for orientation.

The data demonstrate the conflict between landmark information and time/distance information perceived by the subjects as the dominant cue for orientation. Under conditions of unanticipated inadequate landmark information, subjects used the landmarks to localize in the colon despite the inconsistency in distance or time information. When landmark information conflicted with time/distance information, subjects relied on time information.

These preliminary results suggest that a different strategy for spatial mapping should be used in a non-rigid environment. A navigational aid that encourages such a strategy could be designed to guide endoscopists during a colonoscopy procedure.

REFERENCES


