

# VISUAL SEARCH IN VIRTUAL DEPTH: UNIQUE EYE-MOVEMENT PATTERNS IN SEARCHING 2½-D SURFACES.

M. Wagner, E. Berliner, L. Leah Lewkowicz and T.V. Pappathomas\*

*Ariel University Center of Samaria, 40700 Ariel, Israel [wagnerm@ariel.ac.il](mailto:wagnerm@ariel.ac.il)*

*\* Thomas V. Pappathomas, Rutgers University, Lab Vision Research & Dept. Biomed. Engineering, Piscataway, NJ 08854 USA. [papathom@rci.rutgers.edu](mailto:papathom@rci.rutgers.edu)*

## Abstract

*We investigated eye movement patterns of eleven participants while performing visual conjunction search to compare 2D (fronto-parallel) with virtual depth surfaces (2½D - floor perspective). Binocular eye-movements were recorded (EyeLink-II) during choice reaction tasks. 2½D wall perspective stimuli were presented as control for perceiving upper 2½D elements as “far” versus flat upper 2D elements. Stimuli (24 or 42 distractors) were composed of identical shape and color element attributes. Repeated measure analysis revealed unique search patterns of 2½D versus 2D surfaces. We found that in “un-interfered search” (target absence) typically first initiated searching saccades of the 2½D surface tended to land at the perceived far region, while in 2D surfaces search began without up or down preference and ended with preference to the upper region. A similar profile of search pattern was found with target present in the 42 distractors condition, but not with 24 distractors. Reaction time was separated for “view period” (from key press to release) and “response period” (key release to choice reaction). “View period” RT’s revealed set-size and target presence effects but not surface type effect. This suggests that even though search patterns were influenced by surface type, cognitive decision processes remained unaffected. Our results suggest that 2½D conjunctive search patterns reflect common underlying mechanisms of vision for action in natural 3D environments.*

## Introduction

Visual search patterns of surfaces and objects reflect the “world components” perception. Gibson (Gibson 2002) suggested a sort of hierarchy of volumetric surfaces. The main surface, the ground, consists of surfaces at different distances and slants. Reading a book or visual scanning of an X-ray image on fronto-parallel surfaces involves specific scan-patterns, while perspective images depicted on a flat surface (2½D) are immediately perceived as volumetric, eliciting as we hypothesize special visual scan patterns, specified to search in depth. The eliciting potency of perspective (2½D) surfaces versus stereopsis was demonstrated by (Nakayama, He et al. 1995) showing disparity cues “overpowered” by perspective “Gestalts”. Wagner et. al. (2009) demonstrated changes in fixation vergence elicited by perceived depth of the Reverspective illusion, but no dissociation of vision and action was found in depth perception (Wagner et al. 2011). While visual search in 2D has been extensively studied, search in 3D and virtual depth remained a puzzling issue. We hypothesize that 2½D perspective surfaces elicit search processes in depth guided by “vision for action” mechanisms as described by Milner and Goodale (2008), resembling search patterns of natural stereo-vision scenes. We studied visual conjunctive search in two arrays of elements

composed of identical properties. One set viewed from above was perceived as a 2D fronto-parallel surface, the other array was elevated and viewed as volumetric elements composing a virtual depth 2½D subjective surface. We asked whether virtual depth stimuli elicit specified and distinctive visual search patterns compared with 2D surfaces, and whether such patterns could imply that vision for action processes underlie visual search patterns in depth.

## Methods

### *Participants*

Eleven Ariel University students (3 females, 8 males) volunteered to participate, and were screened by "binocular balance" vision tests: "Parallel testing infinity balance" (Shapiro J.I. 1995).

### *Stimuli*

A white "+" shaped target between green "+"s and white "O" shaped distractors comprised the 2D-fronto-parallel display surface. The corresponding 2½D perspective displays included similar shaded cued volumetric elements, arranged on subjective perspective surfaces as if viewed from an elevated viewpoint. Elements from "near" to "far" became smaller and denser. The 2½D perspective displays were tilted by 90° to the right and left comprising the "Wall" stimuli. Thus elements from center to right or left ("near" to "far") became smaller and denser. The 2D and 2½D elements were composed of identical shape and color element attributes.

### *Stimuli preparation*

An 8x8 ground plane grid served to arrange the stimuli elements. This grid was "elevated" to display a perspective surface by "extream3D" graphic software. The 2D stimuli elements, crosses and rings, which were identical in diameter (2.5°) were randomly arranged within the grid squares, providing the required jitter (spacing between items was approximately 3° or 7.5° for 42 or 24 distractors respectively), measured from the center of one item to the center of its nearest neighbor, with an additional random jitter of up to 0.5°.

The same 8x8 grid served to arrange the 24 and 42 distractors stimuli manipulating density. Target items were defined as located in one of four vertical levels (T1 – T4 squares) and right or left of the grid middle line. Five no-target stimuli displays differed in item arrangements.

### *Virtual depth stimuli*

The volumetric appearance of the 2½D items, rings and crosses, was enhanced by shadows. These items were attached to the perspective "elevated" 8x8 ground plane, keeping the identical arrangement attributes (scattering, jitter etc.). Item size was perceived as gradually decreasing with the perceived perspective "distance". The height of the largest 2½D objects displayed at the front grid squares was 2° with a width of 4.5°. The height of the smallest item at the back line was 0.3° and 0.7° in width. All stimuli surfaces intersected in one common center point. The areas of the far and near stimuli regions were: far region= 9000 pixels, near region =40000 pixels. The entire stimuli regions contained 49000 pixels.

### *Hue and gray levels*

The stimuli screen background was black (RGB=0). The RGB value of the bright circles was 170 (R+G+B). We then calibrated the green level of the crosses with a light-spot-meter in the darkened experiment room measuring in both stimuli item types a luminance level of 0.85cd/m<sup>2</sup>. The gradual shaded cues of the 2½D objects projected the identical mean luminance levels. This procedure assured a close to “isoluminant” brightness projection of the stimuli objects. BMP format stimuli images were displayed on a 260 x 410 mm monitor. (16 msec refresh rate, 3.47 pixels/mm resolution). Binocular eye-screen viewing distance was 50cm.

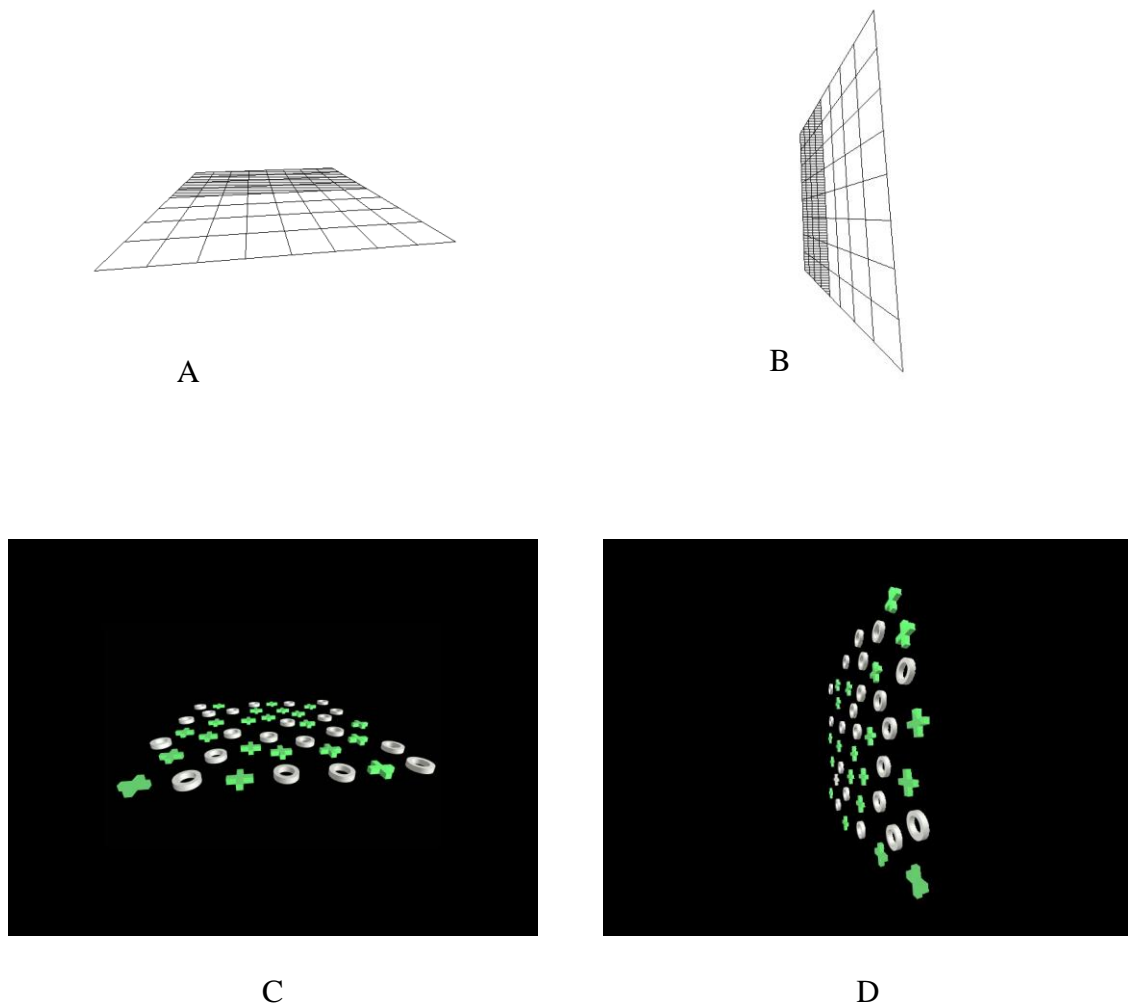


Fig. 1. Panels A and B show the basic 2½D floor and wall surface grids. “Far” region marked by stripes, served for stimuli preparation and analysis. Panels C and D show 2½D floor and “wall” surface example stimuli (42 distractors with “far” target).

### **Measures**

Reaction time was separated for “view period” from key press to release and “response period” key release to choice reaction. Participants were instructed to release the activating

key upon decision: target present or absent and press right or left response keys. Participants were asked to respond as fast as possible.

A probability ratio for a saccade to land in the far surface region (Saccade index) was computed for each subject and for each saccade in the initiated saccade sequence per trial. This ratio was the number of trials on which a certain saccade in the sequence landed at the "far" region by the total number of trials on which stimulus was delivered.

Each saccade was labeled according to its perceived landing area. In the 2½D surface: up, perceived far, was coded 1. Down (perceived near) was coded 0. In the "Wall" surface distant far-right or left was coded 1, and near right or left was coded 0. In the 2D stimuli: up was coded 1 and down was coded 0. The sum of that value for each saccade in the sequence of a trial was then divided by the number of times each trial was repeated giving the probability of a saccades' sequence landing on the far/up part of the 2½D surfaces in each trial.

## Results and Discussion

A 2 (# distractors) by 3 (far/near target and target absent) by 3 (surface type: 2D, 2½D, 2½D-'wall') separated repeated-measures ANOVA were performed on view periods (VP). And saccade number per trial. VP analysis revealed significant main effects of #distractors ( $F_{1,10}=339.962$   $p<.001$ ) and target distance ( $F_{2,20}=63.15.6$   $p<.001$ ). The following interactions were significant: #distractors with distance ( $F_{1,29, 12.8}=11$   $p<.04$ ), and distance with surface type ( $F_{4,40}=3.29.6$   $p<.02$ ).

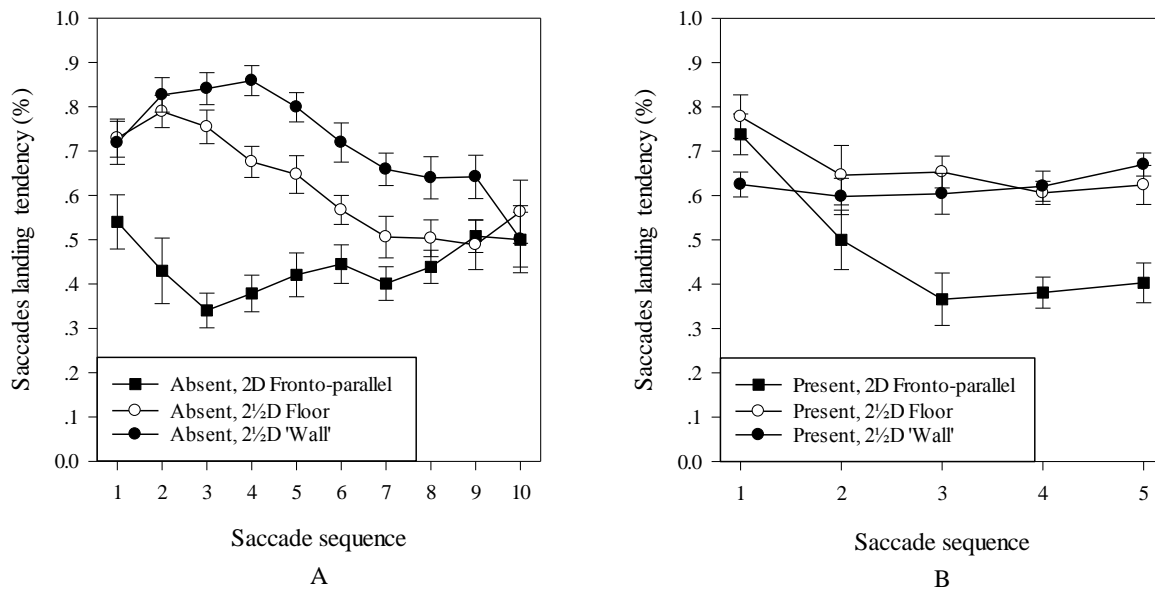
Analysis of # Saccades needed for target detection revealed significant main effects of #distractors ( $F_{1,10}=222.1$   $p<.001$ ) and target distance ( $F_{2,20}=63.7$   $p<.001$ ). The following interactions were significant: #distractors with distance ( $F_{2,20}=9.8$   $p<.001$ ), and distance with surface type ( $F_{4,40}=2.88$   $p<.03$ ).

Figures 2 A and B present the "Saccade landing tendency" (Saccade index) values of the initial searching saccades in the target absent and target present condition of the three search surfaces. In both conditions search in 2D surface and search in the 2½D surfaces reveal distinct search patterns. In both 2½D surfaces search begins and mainly remains in the surface far regions, while in the 2D surface search saccade landing probability spreads homogenously in almost all stimuli regions. Note that target was detected following about 5 saccades, while search went on for about 10 saccades in the target absent condition. Thus we needed to separate the analysis processes. Analysis included only the 42 distractors stimuli which showed the most stable results. A 10(Saccade Index) by 3(Step Type) repeated-measures ANOVA was separately performed for target absent and target present conditions.

Analysis revealed significant main effects of saccade index ( $F_{9,90}=5.733$ ,  $p<0.01$ ), and Surface type ( $F_{2,20}=152.130$ ,  $p<0.001$ ). Which was modified by a significant interaction ( $F_{18,180}=4.160$ ,  $p<0.01$ ). These results indicate that virtual depth influences visual search pattern by eliciting first saccades to land at the far surface region while 2D visual search pattern first saccades showed no stable preference to surface regions in which they land as is shown in figure 2.

Similar analysis procedure was performed for target present stimuli (near or far). An identical profile of search pattern was repeated i.e. significant main effects of Saccade index ( $F_{4,40}=7.851$   $p<.01$ ), Surface Type ( $F_{2,20}=14.958$   $p<.01$ ) and the significant interaction of Saccade Index with Surface Type ( $F_{8,80}=5.276$   $p<.01$ ) as shown in figure 2B.

Target presence effect on visual search pattern was expressed by target distance (far, near), which was found significant ( $F_{1,10}=128.598$   $p<.01$ ), but with no interaction at all with



surface type. This means that search in 2D and 2½D surfaces revealed a similar saccade index profile, but these profiles differed in level. Search in 2D showed a lower more homogenous profile level, while search in the 2½D surfaces revealed a higher saccade index profile level, indicating a search preference of the “far” regions.

Based on our results we conclude that the 2½D surfaces comprised of 42 distractors were immediately and robustly perceived as depth surfaces and were searched accordingly. Size constancy of the surface objects was instantaneously processed. Conversely 24 elements produced a weaker percept of a subjective 2½D surface, which explains our unstable results. We demonstrated a clear distinct saccadic search pattern of 2½D surfaces compared with 2D surface. 2½D surfaces were perceived and searched as depth stimuli, indicating a common underlying mechanism of vision for action in natural 3D environments.

Fig. 2. Mean probabilities of saccade to land in the “far” surface region as a function of searching saccades sequence and surfaces type in target present (Panel A) and target absent (Panel B) trials. Visual search pattern of uninterrupted search (target absent) initial saccades show high probability of beginning search at the far region of both 2½-D surfaces, inversely to the 2D fronto-parallel surface. The effect of Initial saccades show high probability of beginning search at the far region of all three surfaces, this tendency was farther maintained in the 2½-D surfaces, conversely to search pattern in the 2D fronto-parallel surface.

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