An Investigation of Visual Cues used to create and support Frames of Reference and Visual Search Tasks in Desktop Virtual Environments

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ABSTRACT

Visual depth cues are combined to produce the essential depth and dimensionality of Desktop Virtual Environments. This study discusses Desktop Virtual Environments in terms of the visual depth cues that create and support perception of frames of references and accomplishment of visual search tasks. This paper presents the results of an investigation that identifies the effects of the experimental stimuli positions and visual depth cues: luminance; texture; relative height; and motion parallax on precise depth judgements made within a Desktop Virtual Environment. Results indicate that the experimental stimuli positions significantly affect precise depth judgements, texture is only significantly effective for certain conditions and motion parallax, in line with previous results, is inconclusive to determine depth judgement accuracy for egocentrically viewed Desktop Virtual Environments. Results also show that exocentric views, incorporating relative height and motion parallax visual cues, are effective for precise depth judgements made in Desktop Virtual Environments. The results help us to understand the effects of certain visual depth cues to support the perception of frames of references and precise depth

judgements, suggesting that the visual depth cues employed to create frames of references in Desktop Virtual Environments may influence how effectively precise depth judgements are undertaken.

KEYWORDS: Desktop virtual environments, Depth perception, Visual search tasks, Frames of reference, Visual depth cues, Motion Parallax

1. INTRODUCTION

Desktop virtual environments (DVEs) are increasingly used to support a varied number of visual search tasks. Combinations of monocular visual cues are used to create the essential depth and dimensionality of these environments. DVEs can be distinguished from immersive virtual environments, which are created using binocular visual cues and perceived through stereoscopic vision. As the use of DVEs increases, so does the need to provide accurate and effective virtual representations (Wickens and Hollands 2000). For instance, Ruddle et al. (1998) argue that DVEs with lower visual fidelity may not provide sufficient visual cues to support effective task performance. This is particularly important for visual search tasks that involve precise depth judgements and are considered safety critical, such as applications within the medical, vehicle or aviation industries. Extensive research has been undertaken to investigate various factors of influence on depth perception such as differences of spatial tasks (Wanger et al. 1992), spatial layouts (Cutting and Vishton 1995, Ruddle et al. 1998) and the differences and the relative dominance of visual depth cues that combine to create the inherent illusion of depth. The implications of visual depth cue studies broadly relate to perceiving the real world and perceiving DVEs under specific contexts (Dosher et al. 1986, Surdick et al. 1997). However, research identifying visual depth cues within particular DVEs that support different visual search tasks, is limited (Hubona et al. 1999, Wickens 2000) even though recent studies have reflected the significance of task differences (Bradshaw et al. 2000).

This paper discusses the perception of DVEs by highlighting the implicit relationship between visual depth cues and the frames of reference and visual search tasks they create and support. For instance, visual depth cues that create and support tasks involving broad spatial layout perceptions in DVEs may be different to those supporting precise depth judgements that aim to control or facilitate specific user interaction or manipulation tasks. This range is emphasised by the influences of spatial layout discussed by Cutting and Vishton (1995). They classify spatial layout as three regions: personal; action and vista spaces. Personal space refers to the area immediately surrounding an individual's view of the environment; action space is just beyond that and is described as the region in which something can be thrown; and vista space refers to the furthest distances from an individual's frame of view and therefore relates to the outer region of a spatial layout being observed by an individual (Cutting and Vishton 1995, Cutting 1997). It is recognised that the effectiveness of visual depth cues vary according to the type of visual search task being undertaken and frame of reference employed within these regions.

The study reported in this paper discusses two experiments, which respectively explore the influences of the egocentric and exocentric frames of references when perceiving depth and undertaking precise depth judgements in DVEs. The first experiment examines the effects of experimental stimuli positions, texture (a relatively weaker depth cue) and motion parallax (a relatively dominant visual depth cue) on conducting precise depth judgements within a DVE that is viewed egocentrically. The second experiment examines the effects of relative height and motion parallax when conducting precise depth judgements with exocentric views in DVEs. For both experiments, precise depth judgements are undertaken within the 'personal' region of the desktop virtual environment spatial layout. Results are analysed and discussed to provide further understanding into the effects of visual depth cues and the implicit relationship between texture, relative height and motion parallax for egocentric and exocentric frames of reference when conducting a precise depth judgement task in DVE.

2. VISUAL SEARCH TASKS IN DESKTOP VIRTUAL ENVIRONMENTS

As the use of DVEs increases, so does the reliance on presenting virtual representations that can support precise depth judgements for visual search tasks. Extensive research has been undertaken within the aviation field in particular, since the challenge of representing air space accurately for pilots (Wickens and Hollands 2000) and understanding the operations within complex aircraft systems for engineers (Hubona et al. 1999) is considered of utmost importance. In these cases, research has acknowledged the inherent ambiguity of presenting the three dimensional environment on a two-dimensional display and has gone on to identify the specific visual cues or spatial display characteristics that impact on task performance. For instance, Hubona et al. (1997) found that controlling object motion affected perceptual accuracy with the time taken as a trade-off. It was suggested that further research was necessary to explore the effects of motion on other visual cues such as luminance, a visual depth cue that can provide information about the shape of an object (Ramachandran 1988).

Research has recognised the DVE as a 'spatial display' and a 'spatial instrument', supporting different visual search tasks, where the former presents clear and precise representations of space and the latter supports controlled user interactions (Eyles 1991). In either case, depth perception could impact on task performance and as such the findings of Hendrix and Barfield (1995) suggests that monocular and perspective cues are effective for depth judgement in azimuth but not altitude in DVEs. Their study did not take into account motion, which they accepted might be an influential factor for spatial perception. Research has found complex cue interactions when perceiving and undertaking different spatial tasks in the DVE context (Wanger et al. 1992, Hubona et al. 1999).

Recent studies have identified the relative importance of task differences and viewing distances on depth perception in the real world (Bradshaw 2000). Likewise, Wickens (2000) proposed that different tasks involving depth perception might be affected by different viewpoints of DVEs. Accordingly, research has indicated the need to investigate broader factors affecting perception of visual depth cues when conducting visual search tasks within DVEs, since these depth cues provide the essential and inherent dimensionality (Hubona et al. 1999).

3. INFLUENCE OF EGOCENTRIC AND EXOCENTRIC VIEWS ON VISUAL SEARCH TASKS IN A DVE

Recent studies have suggested that depth perception within DVEs may be effected by factors such as task differences, viewing distances and changing viewpoints (Wickens 2000). In particular, research has identified the egocentric and exocentric frames of reference. Howard (1991) describes these frames of reference and discusses them in terms of the types of tasks that may be most appropriate for each. For instance, he relates the egocentric task (which involves determining the position, orientation or motion of an object, or the proprioceptive task in which the object being judged is also part of the body) to the egocentric frame of reference. Many studies have used egocentric views for experimental depth judgement tasks (Surdick et al. 1997, Hubona et al. 1997, Westerman and Cribbin 1998). This is especially relevant when the DVE is considered a ‘spatial instrument’ that aims to support user interactions (Eyles 1991).

Howard (1991) discusses that the exocentric frame of reference supports tasks involving geographical directional judgements. This frame of reference has been largely discussed within the aviation field, particularly in terms of the type of visual search task that may be more suitably undertaken with this view (Olmos et al. 2000, Wickens and Hollands 2000). Likewise, Wickens and Hollands (2000) explain that the exocentric frame of reference is most suitable for *tasks involving understanding* and the egocentric frame of reference suits *tasks involving navigation*. It is important to look at each of these frames of reference in turn because they are fundamental to perceiving DVEs and this accordingly emphasises the need to understand how combinations of visual depth cues are employed to create them effectively.

Wickens (2000) argues that both types of frames of reference involve certain the perceptual ambiguities. For the exocentric view, there is a cost of ‘double ambiguity’ which refers to the observers inability to perceive the positions of other virtual objects as well their own, within the environment. For the egocentric view, Wickens (2000) describes the ‘keyhole’ effect, which refers to the inability of the observer to perceive the environment that is to the side or behind of a given virtual object. Wickens (2000) proposes that by interactively ‘panning’ the environment, such perceptual ambiguities may be resolved. This introduces the idea of examining the visual cues that inherently support the creation and perception of frames of reference in DVEs. For instance, it could be suggested that the ability to create a ‘pan’ view of an environment would involve the inherent use of motion parallax for supporting a view that employs a degree of relative height. Therefore, it is necessary to understand how motion parallax and relative height respectively support egocentric and exocentric views when conducting precise depth judgement tasks.

4. IMPACT OF VISUAL DEPTH CUES ON DEPTH JUDGEMENT

Combinations of visual cues create the illusion of depth and dimensionality that is essential for the presentation of desktop virtual environments. Individuals perceive these visual depth cue combinations to visualise the dimensionality and interactive features of the environment such as the frames of reference and type of spatial task being undertaken. Research has identified the relatively dominant and weaker visual cues and has attempted to relate findings to the most appropriate visual cue combination models (Wickens et al. 1989, Jacobs and Fine 1999). Broadly, results have shown that motion parallax is a dominant visual cue and relative brightness is, in contrast, very weak for depth perception on DVEs (Wickens et al. 1989). Surdick et al. (1997) found relative brightness reduced in effectiveness considerably as distances increased. Jacobs and Fine (1999) investigated cue combination strategies and concluded that visual cues were most effective when that particular cue was more informative in a given task. Further investigation of the egocentric view should reveal whether weaker cues, in terms of effectiveness for depth perception across distances, would be used for 'fine tunning' precise depth judgements within DVEs (Hubona et al. 1999).

According to research, the most dominant visual cue in a given scene would take precedence for depth perception (Landy et al. 1995). This has been emphasised for situations where visual depth cues are perceived in conflict and it is proposed that the dominant or least ambiguous visual depth cue be accordingly perceived (Dosher et al. 1986). The effective presentation of visual depth cues may impact on the frames of references employed and the accuracy of precise depth judgements undertaken. The impact of a dominant visual cue, motion parallax, has been investigated in respect of depth judgement (Hubona et al. 1997, Bradshaw et al. 2000). Hubona et al. (1997) found that for tasks involving the egocentric perception of computer generated objects, controlled object motion improved perceptual accuracy but time taken to complete this task increased. This suggests that observers spend time judging depth when the display is momentarily still. Bradshaw et al. (2000) present results indicating that the motion viewing condition had no effect on depth judgement tasks in the real world, which is accordingly discussed in terms of similar studies undertaken using simulated stimuli. This appears to suggest that although motion is a relatively dominant visual cue, it may not be entirely effective for egocentric views of precise depth judgements in DVEs. However, motion parallax when combined with relative height, may actually improve precise depth judgements. Wickens (2000) suggested that the ability to 'pan' the view of an environment might resolve the perceptual ambiguities that arise when perceiving DVEs. An exocentric view employs the use of relative height and when combined with horizontal motion parallax, could pr characteristic. This illustrates the explicit and essential use of visual cues to create and support frames of reference for DVEs.

5. HYPOTHESES

Five aspects of undertaking precise depth judgements in DVEs that are viewed egocentrically and exocentrically are emphasised through the discussion of five hypotheses in this section which form the basis for the experimental work reported in this paper. The first three hypotheses examine the impact of probe positioning, texture and motion for egocentric views. The fourth and fifth hypotheses examine the effects of relative height and motion parallax for exocentric views.

5.1 Impact of Probe Positioning on Precise Depth Judgements

Much empirical work has used egocentric views for depth judgement tasks (Surdick et al. 1997, Hubona et al. 1997, Westerman and Cribbin 1998). However, research is limited in respect to identifying the visual depth cues that effectively support DVEs in the context of spatial instruments presenting various spatial displays (Eyles 1991). Since many of these empirical depth judgement tasks involve matching the depths of a *target* probe to a *reference* probe, the initial positioning of these probes, as experimental stimuli, may have an impact on depth judgement as much as the particular visual depth cues that are being investigated. For instance, if the z-axis initialisp oashi et ai do, n voefr yt hcel otsaer gteot positions of the reference probe, visual cue effectiveness may vary according to the respective depth judgements being made. Surdick et al. (1997) found that relative brightness, relative height and relative size decreased in effectiveness with an increase in viewing distance. They also concluded that relative brightness was the least effective of depth cues within their results. Hendrix and Barfield (1995) similarly found from their results that the addition of shadows only slightly improved depth perception after the addition of texture. This suggests that initial probe positions would have an impact of visual cue effectiveness and the following hypothesis is examined for the single visual cues: luminance; texture; relative height and; motion parallax:

H1 Depth judgement accuracy is affected by the initial positions of the probes.

5.2 Effect of Texture on Precise Depth Judgements in Different Visual Cue Conditions

For egocentric views of DVEs requiring precise depth judgements, research has indicated that certain visual depth cues may vary in their effectiveness (Surdick et al. 1997). Westerman and Cribbin (1998) found that there was no difference between texture and luminance which were both considered as providing qualitatively similar depth information (Landy et al. 1995). However texture has been identified as a visual cue that can also provide spatial orientation (Cutting and Millard 1984, Wanger et al. 1992). In addition to this, Nagata (1991) illustrated that texture was slightly more effective across viewing distances than luminance. It is therefore proposed that although texture is a relatively weak visual depth cue, it may still support precise depth judgements for smaller distances where the dominant visual cues may be inaccurate. To examine the effectiveness of texture when combined with single cue conditions: (i) luminance; (ii) relative height and; (iii) motion parallax, the following hypothesis is tested:

H2: The presence of texture increases depth judgement accuracy for egocentric views.

5.3 Effect of Motion Parallax on Precise Depth Judgement for Egocentric Views

Wanger et al. (1992) found that motion did not have a significant effect when positioning probes within a DVE that was viewed egocentrically. They believed that the motion confused participants and this effected their ability to perceive the cue accurately. However, it could also be suggested that participants did not need such a dominant cue for the egocentric view of the virtual objects. For instance, Bradshaw et al. (2000) found that motion did not have any effect on the depth matching tasks that were undertaken in the real world and Delucia (1991) found that motion presented inaccurate distance perceptions of two virtual objects, if the ground intercept cue was not added to the objects. To examine the effectiveness of motion parallax for depth judgement accuracy, when added to visual cue conditions: (i) luminance; (ii) texture; (iii) relative height; (iv) luminance and texture; (v) luminance, texture and height, in DVEs viewed egocentrically, the following hypothesis is tested:

H3: The presence of motion parallax decreases depth judgement accuracy for egocentric views.

5.4 Effect of Relative Height on Precise Depth Judgements for Exocentric Views.

Relative height is fundamental to creating exocentric views within desktop virtual environments. Although research has investigated the effectiveness of relative height for depth perception in DVEs (Surdick et al. 1997), it has not explicitly examined its relation to creating and supporting the exocentric frame of reference. Instead, extensive research within the aviation field has investigated the relationship between appropriate frames of references for different visual search tasks. For instance, Wickens and Hollands (2000) proposed that the exocentric view is effective for visual search tasks that involve understanding the spatial environment. Olmos et al. (2000) agreed that the exocentric view might be more appropriate when undertaking spatial awareness, aviation tasks. This appears to imply that relative height is effective for depth judgements made across spatial layouts in DVEs which is in contrast to the findings of Surdick et al. (1997) suggesting that the effectiveness of relative height dissipates as distance increases. Therefore to examine whether relative height is effective for depth judgements in DVEs, the following hypothesis is tested:

H4: Depth judgement accuracy significantly improves with relative height for exocentric views.

5.5 Effects of Motion Parallax on Precise Depth Judgements for Exocentric Views

Wickens (2000) described the 'line of sight' perceptual ambiguity when perceiving depth in DVEs, with an exocentric view. The line of sight ambiguity was described as the difficulty for an individual to accurately judge the locations of themselves and other virtual objects within a DVE. The ability to 'pan' the view of an environment was offered as a possible resolution for perceptual ambiguities (Wickens 2000). Technically, a pan view would employ horizontal motion parallax suggesting that adding motion parallax to a view created by relative height, might improve depth judgement accuracy. The following hypothesis is tested to examine the effects of motion parallax when combined with cue conditions consisting of relative height:

H5: Depth judgement accuracy significantly improves with motion parallax for exocentric views.

6. EXPERIMENTAL METHODOLOGY

Two experiments were undertaken to explore the perception and effects of visual cues on perceiving depth in DVEs. The first experiment was designed to examine the first three hypotheses and the second experiment examined the effect of relative height and motion parallax on the exocentric view on perceiving different cue conditions. As illustrated in figure 1, both of the experiments employed two virtual probes, which defined the nature of the experimental task. Participants performed an experimental task that involved matching the z probes. This was an interactive task that focussed on measuring participant's depth perception ability and has commonly been used in previous depth matching experiments (Delucia 1991, Westerman and Cribbin 1998). Two grey probes of varying sizes were presented against a red background. The probes were randomly separate same y-axis positions respect to their initial positions whereby the differed interactive, target probe was either in front of, very close to, or behind the static, reference probe.

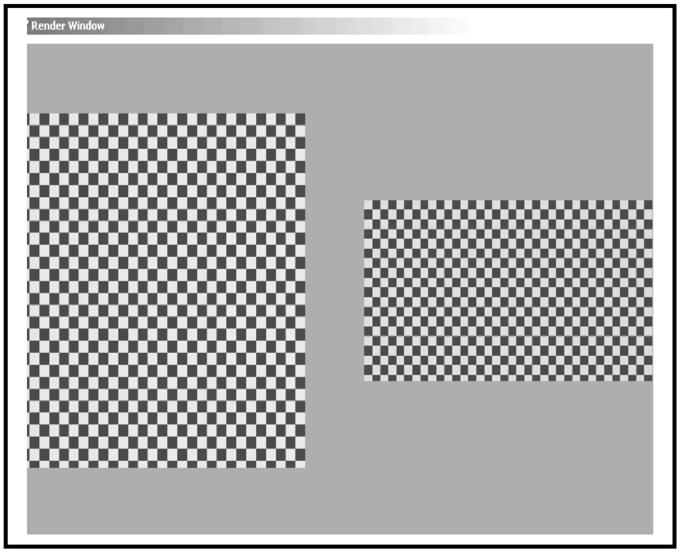

Figure 1: Illustration of experimental stimuli.

Participants were required to match the z-axi space bar to record the measurement and were accordingly presented with the next trial. Luminance was illustrated by positioning a virtual light source near the participant which meant that as the probe was moved closer towards to the participant, it became lighter. Participants assessed the relative brightness of the probes in order to judge their respective depths. Texture was applied as a checkerboard bitmap to the probes. As the interactive, target probe was moved closer towards the participant, the checkerboard pattern increased in size. Relative height was illustrated by the target probe appearing to rise higher as it was moved backwards from the participant and descend as it was moved closer towards the participant. Both the probes swaying illustrated motion parallax, and as the participant moved the target probe forward, the swaying movement increased accordingly. The DVE graphics, for both experiments, were created using Wild Tangent software and the graphics were presented using Viglen P3 400 hardware.

7. EXPERIMENT 1

The first experiment aimed to explore the effects of single and combinations of visual cues when perceiving depth in DVEs. In particular, the focus of this experiment was on three hypotheses, H1 to H3. The first hypothesis examined the effects of probe positioning for varying visual cue conditions, the second examined the effects of texture and the third examined the effects of motion parallax, both on conducting precise depth judgements, with egocentric views in DVEs.

7.1 Method

32 participants (16 male and 16 female) volunteered from the first year undergraduate and masters student population of Brunel University, UK. The experiment was a repeated measures design and all participants completed sixteen conditions consisting firstly of the four cues in isolation, then six combinations of the cues in pairs, then four conditions of the cues in combinations of three and finally a combination with all four cues together. Each condition comprised of 20 trials. However, for the purpose of testing H1 to H3, only certain conditions were analysed. The first set investigated the impact of probe positioning under four conditions: (1) with and without luminance; (2) with and without texture; (3) with and without height; and (4) with and without motion. The second set investigated the effect of texture on conducting precise depth judgements in three conditions: (1) with and without luminance; (2) with and without height; and (3) with and without motion. The third set investigated the effect of motion when perceiving three conditions: (1) with and without luminance; (2) with and without texture; (3) with and without a combination of luminance and texture. The depende
axis error of distance between the two probes.

7.2 Results and Analysis

The dependent measure was the mean (absolute) error of distance between the two probes. Five further dependent measures were ctrlmean, singlemean, doublemean, triplemean and combinationmean, which were calculated by averaging the performance of: the control condition; single cues; double cues; triple cues and all-cue combination, respectively. Data for the repeated measures ANOVA failed to meet the assumption of sphericity ($p < 0.01$) and therefore the Huynh-Feldt was used instead. The analysis indicated that there was a significant difference between the five means $F(4, 124) = 76.725$; $p < 0.01$. Figure 2 clearly illustrates the improvement of depth judgement as qualitatively different cues are added to a combination, particularly as the control condition does not support depth judgement accuracy.

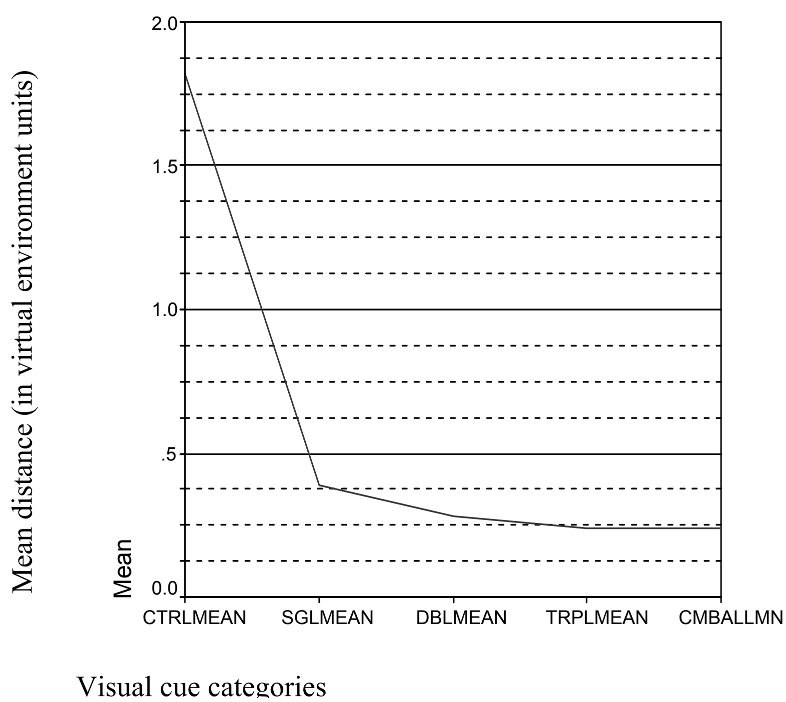

Figure 2: Difference between depth judgement accuracy of five visual cue categories.

For H1, there was a significant main effect for the three initial positions with and without luminance $F(2, 62) = 13.057$; $p < 0.001$. There was also a significant main effect with adding luminance $F(1, 31) = 82.83$; $p < 0.001$ and a significant interaction effect between the initial positions and adding luminance $F(2, 62) = 8.376$; $p < 0.05$. There was a significant main effect for the three initial positions with and without texture $F(2, 62) = 12.202$; $p < 0.001$. Main effects analysis was also significant for the addition of texture $F(1, 31) = 57.066$; $p < 0.001$ and the interaction effect was significant $F(2, 62) = 6.618$; $p < 0.05$. The analysis for main effects also showed that initial positions $F(2, 62) = 12.22$; $p < 0.001$ and the addition of relative height $F(1, 31) = 66.67$; $p < 0.001$ were significant. The interaction effect for initial positions and height was also significant $F(2, 62) = 6.853$; $p < 0.05$. Main effects for the initial positions in the motion parallax condition was significant $F(2, 62) = 16.58$; $p < 0.001$, as was the addition of motion cue $F(1, 31) = 56.21$: $p < 0.001$, and the interaction between the two $F(2, 62) = 4.04$; $p < 0.05$. In all single cue conditions, results indicated that initial positions were significantly different. This is represented by figure 3 which shows that depth judgement accuracy was most effective for all four single cues, when the target probe was initially positioned ‘very close to’ the reference probe. The single cues were also, broadly more effective when the target probe was initially positioned behind the reference probe, rather than positioned ahead. Therefore results show that depth judgement accuracy is effected by the initial positions of the probes for the visual cue conditions: (i) luminance; (ii) texture; (iii) relative height and; (iv) motion parallax, supporting H1.

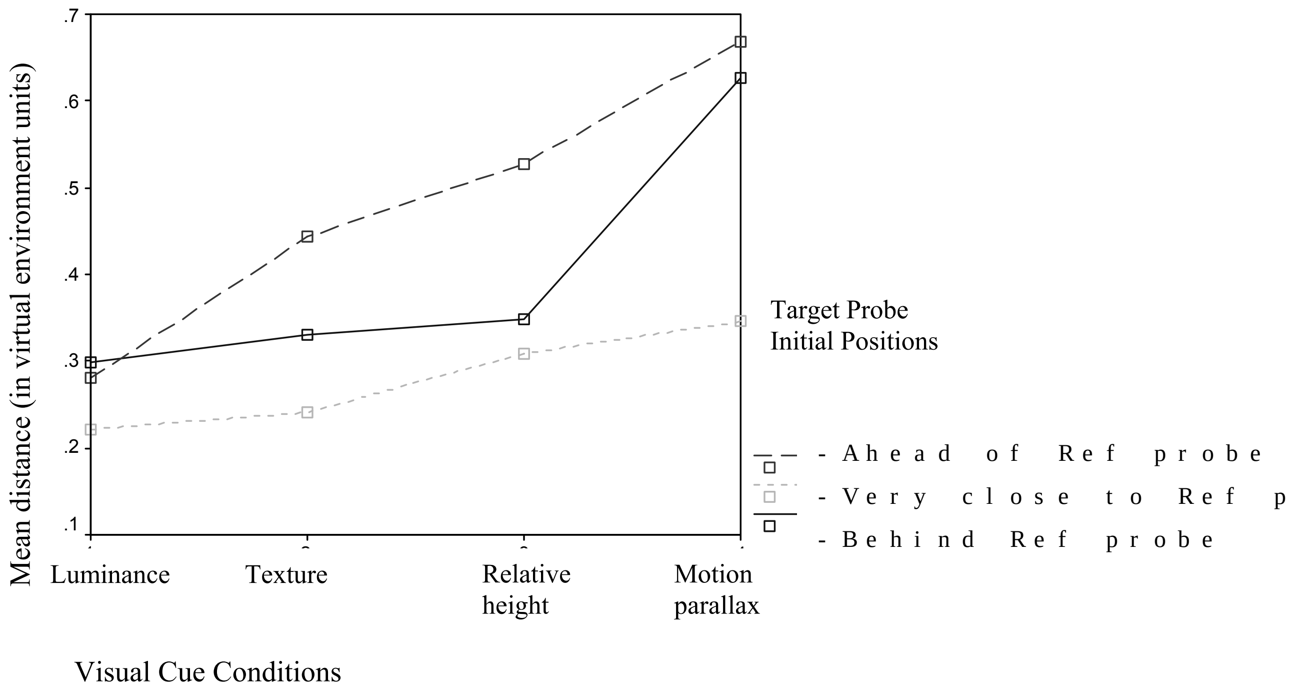

Figure 3: Impact of initial probe positions on depth judgment accuracy for single visual cue conditions.

H2 examines the effects of adding texture to different cue conditions. ANOVA main effects indicate that there were no significant main effects for the luminance condition or for the height condition. However, there is significant main effects for the motion parallax condition $F(1, 31) = 8.447$; $p < 0.05$. For the combined cue condition of luminance, height and motion parallax, there were no significant main effects. Therefore results supported the H2, only for the motion parallax condition.

For H3, repeated measures ANOVA was used to test the effect of adding motion to single cues; luminance, texture and a combination of luminance and texture. There were no significant main effects for motion parallax added to the three cue conditions respectively. This suggests that the results were inconclusive to determine the effectiveness of motion parallax for the visual cue conditions: (i) luminance; (ii) texture and; (iii) luminance and texture.

8. EXPERIMENT 2

The second experiment examined two hypotheses, H4 and H5. The fourth hypothesis of this study examined the whether relative height increased depth judgement accuracy in DVEs. The aim was to see whether exocentric views, which are created using relative height, were more effective than egocentric views, with no relative height. The fifth hypothesis examined whether motion parallax increased depth judgement accuracy for an exocentric view. The aim was to explore the effects of a panning view which was proposed as a method for resolving the perceptual ambiguities associated with viewing depth in a DVE context.

8.1 Method

20 participants (8 male and 12 female) volunteered from the first year undergraduate and masters student population of Brunel University, UK. The experiment was a repeated measures design and all participants completed three visual cue condition which were: (1) luminance only; (2) texture only and (3) combined luminance and texture. To examine H4, two levels of frame of reference were manipulated which was relative height (present, not present) and to examine H5, two levels of motion parallax were manipulated (present, not present). Participants were required to complete 12 trials per condition. The dependent measure was the z-axi distance between the two probes.

8.2 Results and Analysis

The dependent measure was the mean (absolute) error of distance between the two probes. In certain cases, data for the repeated measures ANOVA failed to meet the assumption of sphericity ($p < 0.01$) and therefore the Huynh-Feldt values were used, instead. Table 1 shows the means, standard deviations and significance values for the three visual cue conditions, with and without relative height.

Visual Cue Conditions	Without Relative Height Mean (sd)	With Relative Height Mean (sd)	Significance F-value (p-value)
(1) Luminance only:	0.5785 (0.8879)	0.3346 (0.2965)	$F(1,219) = 16.069$ ($p < 0.001$)
(2) Texture only:	0.9719 (1.5120)	0.5230 (0.5122)	$F(1,219) = 18.624$ ($p < 0.001$)
(3) Luminance & Texture:	0.4354 (0.4358)	0.4763 (0.7966)	$F(1,219) = 0.446$ ($p > 0.05$)

Table 1: Means, standard deviations (sd) and significance values for three visual cue conditions.

The analysis indicated that there was a significant main effect for the luminance only condition, with and without relative height, $F(1,219) = 16.069$; $p < 0.001$. The effects of luminance with and without relative height is illustrated by the box plot graph in Figure 4. This clearly shows the smaller mean and standard deviation values for the three visual cue conditions with relative height, suggesting that depth accuracy increases with relative height. There was significance main effects for the three visual cue conditions with and without relative height $F(2, 218) = 21.960$; $p < 0.001$. This suggests that the differences between the results of the three visual cue conditions are significant proposing that relative height is significantly effective for depth judgement accuracy, supporting H4.

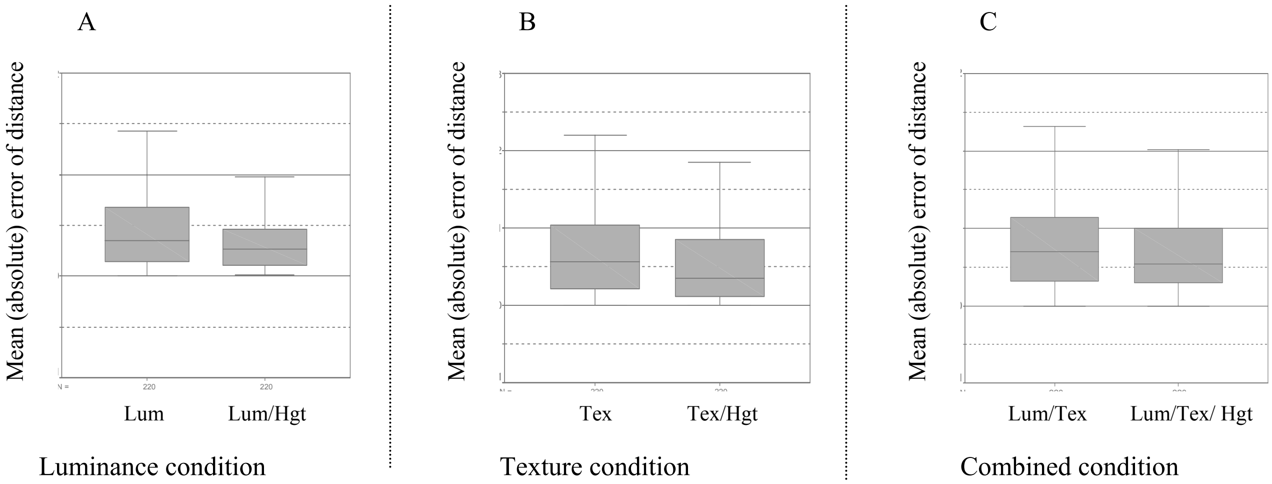

Figure 4: Box plot graphs to illustrate effects of relative height for the three visual cue conditions. (Mean error of distance in virtual environment units).

H5 examines whether adding motion parallax to visual cue conditions consisting of relative height, increases depth judgement accuracy. This hypothesis relates to the pan view characteristic, which employs the horizontal motion parallax to resolve line of sight ambiguities. Results of this study found that H3 was supported implying that motion parallax was ineffective for the egocentric view. H5 investigates this visual cue condition for the exocentric view.

Visual Cue Conditions: [Luminance (Lum), Texture (Tex), Relative Height (Hgt)]	Without Motion Parallax Mean (sd)	With Motion Parallax Mean (sd)	Significance F-value (p-value)
(1) Lum & Hgt:	0.3346 (0.2965)	0.3782 (0.4318)	F(1,219) = 1.763 (p > 0.05)
(2) Tex & Hgt:	0.5230 (0.5122)	0.4114 (0.4313)	F(1,219) = 7.277 (p < 0.01)
(3) Lum, Tex & Hgt :	0.4763 (0.7966)	0.3385 (0.3845)	F(1,219) = 6.893 (p < 0.01)

Table 2: Means, standard deviations (sd) and significance values for three visual cue conditions.

Repeated measures ANOVA showed that there was significant main effects for the impact of motion parallax on two conditions: texture and relative height F(1,219) = 7.277; p < 0.01 and luminance, texture and relative height F(1, 219) = 6.893; p < 0.01. Figure 5 shows box plot graphs which illustrates the effect of motion parallax on visual cue conditions that consist of relative height. Box plots graphs B and C show that motion parallax increases depth judgement accuracy for the two respective visual cue conditions as mean and standard deviation values decrease when motion parallax is added which is supported by the means and standard deviation values presented in table 2. However, box plot graph A illustrates that motion parallax does not significantly effect the luminance and relative height visual cue condition. Therefore results support H5 for certain conditions. Motion parallax is effective for the combined cue condition of relative height with texture and the combined cue condition of luminance, texture and relative height.

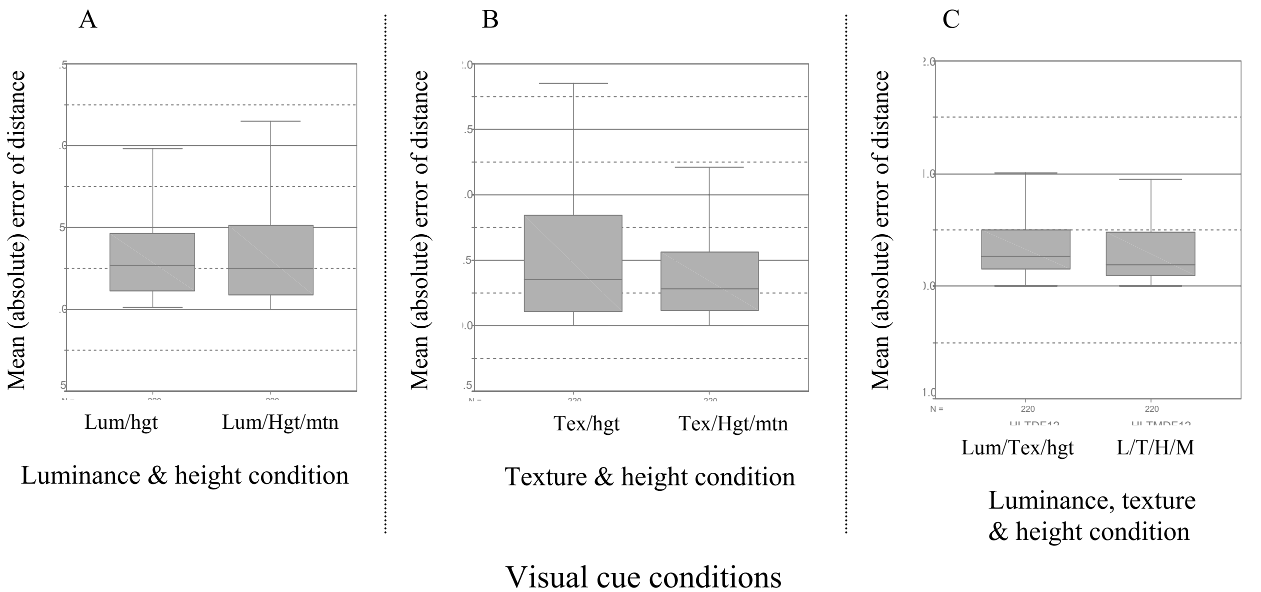

Figure 5: Box plot graphs illustrating the effects of motion parallax on cue conditions consisting of relative height. (Mean error of distance in virtual environment units).

9. DISCUSSION

Results from this study seem to suggest that, for egocentric views of precise depth judgements made within DVEs, the initial positioning of probes has a significant effect on the effectiveness of the four single visual cues whereby texture and relative height were more effective when the initial position of the target probe was behind the reference probe. Results also showed that texture only improves depth judgement when motion parallax is present and results for motion parallax were inconclusive.

Since motion parallax had been acknowledged as a dominant visual cue (Wickens et al. 1989), this study attempted to determine the effect it had on precise depth judgements when viewing probes within DVEs, egocentrically and exocentrically. Previous studies had concluded that motion parallax did not make a significant difference, however their results did not distinguish between egocentric and exocentric views (Wanger et al. 1992). Certain studies have used the egocentric view for the depth matching tasks (Hendrix and Barfield 1995, Westerman and Cribbin 1998). Results in this study have provided inconclusive results as to the effectiveness of motion parallax for the egocentric frame of reference. The results of previous studies have either been inconclusive (Wanger et al. 1992) or found motion parallax to be ineffective (Delucia 1991, Bradshaw et al. 2000). This suggests that either participants were confused by the implemented speed of motion parallax in this experiment or that static displays may be more effective for precise depth judgements that are made in DVEs that are egocentrically viewed (see table 3). Hubona et al. (1997) found that controlled motion was more effective and the results of this study may partially support that idea since continuous motion was used for the experimental task. Further experimental investigations would be required to determine the effectiveness of motion parallax.

Visual Cues:	**Egocentric View**		**Exocentric View**	
Relative Height	Not Present	Not Present	Present	Present
Motion Parallax	Not Present	Present	Not Present	Present
Luminance	Effective	Not significant	Effective	Not Significant
Texture	Effective	Not significant	Effective	Effective
Luminance and Texture	Effective	Not significant	Not Effective	Effective

Table 3: Effectiveness of visual depth cue conditions for egocentric and exocentric views.

Results and analysis for experiment 2 of this investigation showed that precise depth judgement accuracy increased when relative height was added to only the single cue conditions; (i) luminance and (ii) texture. Table 3 describes the effectiveness of luminance and texture visual depth cue conditions for egocentric and exocentric views that are created by the presence and absence of relative height and motion parallax, respectively. When motion parallax was added to the visual cue combinations consisting of relative height, depth judgement accuracy appeared to increase for two visual cue conditions only: (i) texture and relative height and (ii) luminance, texture and relative height (see table 3). Results also showed that relative height was not effective when added to the combined cue condition of luminance and texture however, when motion parallax was added to this combination of three cues, depth judgment accuracy increased (see table 3). This seems to suggest that the 'pan' view effect, which employs motion parallax, is effective when a sufficient number of visual depth cues are available in a given scene (illustrated by figure 2). Therefore, whilst existing research has acknowledged the dominance of motion parallax for depth perception (Wickens et al. 1989), the results of this study suggests that this cue may be more effective for depth judgment accuracy in DVEs when combined with other visual depth cues.

Wickens (2000) conducted a study that investigated the visual perceptiveness of a DVE, which was viewed egocentrically and exocentrically. He concluded that due to the limitations of both types of views, visual search tasks in the context of flight simulation would benefit from having more than one view being presented simultaneously. It may however be possible to identify visual search tasks in terms of the varying depth judgements they involve. It may then be possible to define the characteristics that would support the visual search tasks, in terms of: ideal display views; prospective level of interaction; required amount of motion; and most effective combination of visual depth cues. The salient feature of DVEs is that it is an interactive virtual environment and therefore views can be manipulated to perceive varying amounts of detail, at any given time.

This study concentrated on precise depth judgements made within DVEs that were viewed egocentrically and exocentrically. This was in an attempt to recognise the relation between visual depth cues to provide the appropriate illusion of depth necessary to create and support frames of references and precise depth judgements. Further investigations would reveal whether controlled motion improves precise depth judgements for egocentric views and whether texture, or other weaker visual cues, provides detail for virtual distances that may be lost through motion parallax.

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