# Performance of a path tracing task using stereo and motion based depth cues



*DOI:*
10.1109/QOMEX.2010.5516268

*Document status and date:*
Published: 01/01/2010

*Document Version:*
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

# PERFORMANCE OF A PATH TRACING TASK USING STEREOSCOPIC AND MOTION BASED DEPTH CUES

*Maurice H.P.H. van Beurden, Andre Kuijsters & Wijnand A. IJsselsteijn*

**Human-Technology Interaction Group**
**Department of Industrial Engineering & Innovation Sciences**
**Eindhoven University of Technology**

## ABSTRACT

Stereoscopic displays have a number of properties that could be advantageous in the field of medical diagnosis. The aim of the current study is to get a better understanding of the relative importance of motion based depth cues (object motion, movement parallax) and stereoscopic disparity on the performance of a path tracing task, representative of angiographic visualizations. To date, these cues have not frequently been combined in a single study that would allow a direct comparison of their effects. In this paper, we report on an experiment where we measured the effectiveness of motion-based cues and stereoscopic disparity in terms of completion time, number of errors, perceived workload and perceived discomfort. Results revealed that both object motion and movement parallax enhanced performance in terms of number of correct answers. However, object motion was superior to motion parallax on self-report of mental workload and visual comfort. Stereoscopic disparity significantly decreased completion times when combined with object motion or movement parallax. On accuracy, no effect of stereo was found.

***Index Terms—***Performance, perception, 3D, Object motion, Movement parallax

## 1. INTRODUCTION

At what appears to be a turning point in the public acceptance and commercial viability of stereoscopic 3D entertainment, the application of stereoscopic displays for professional markets show a much more gradual, yet durable acceptance. The acceptance is driven by certain niche applications, such as molecular visualization, computer aided design, remote operation, geological exploration, and volumetric data visualization. One application area that has not yet embraced stereoscopic displays to its full potential is the field of medical imaging. This area can potentially benefit from stereoscopic displays through, for example, improved understanding of complex (spatial) structures and increased detection of abnormalities, both of which can augment the process of medical diagnosis.

Nowadays many radiological images are visualized in 3D perspective, presented on 2D monitors. A range of static monocular depth cues (shading, texture, occlusion, relative size, etc) and/or motion (e.g., rotating the volume using a mouse) give the physician a better understanding of the presented volume. The 3D perspective visualization and the ability to rotate the volume provide the physician already with a strong depth percept. The addition of binocular disparity can potentially enhance the perception of spatial structures in medical volumes, although its practical application is still limited to a number of specialist areas, such as minimally invasive surgery [1]. Well-known advantages of stereoscopic vision include improved relative depth judgment, ability to concentrate on objects located at different depth levels, and better judgment of surface curvature. In the current paper, we aim to empirically explore the potential of stereoscopic disparity on performance in a tracking task. We compare stereo with two types of motion-based depth cues: object motion (OM) and movement parallax (MP). Movement parallax is defined as the change in image perspective corresponding to the movements of the user's head, whereas in OM the perspective view can be changed by observing a rotating image or actively manipulating the orientation of the image with an interaction device like a mouse. Both OM and MP are strong information sources on spatial layout and depth structure. Although temporally separated, successive views of an environment (i.e., MP, and OM) mathematically provide the same information to the visual system as spatially separated (stereoscopic) views [2]. Their effectiveness in terms of task performance can nevertheless be different. We aim to investigate the informational potency of OM, MP, and stereoscopic disparity, and to empirically investigate whether stereo has an added value above and beyond these monoscopic motion cues.

One of the medical imaging domains that potentially stand to benefit most from the use of stereoscopic displays is angiography. In angiography it is frequently difficult to understand the spatial arrangements of blood vessels and to perceive the direction of curvatures, as illustrated in Figure 1 (left panel). A task that is representative for reading angiograms is a path tracing task as shown in Figure 1 (right panel). Following one line within a complicated arrangement of lines in a path tracing task requires a correct understanding of the spatial arrangements of the lines. Various studies used this type of task to measure the relative performance of stereo, OM and/or MP [3],[4]. A comparable task is the node connection task, where participants have to indicate if a particular node is connected to another node. Other tasks that also require spatial understanding of the scenes are rod positioning tasks [5] and object recognition [6].

### 1.1 Motion based depth cues and stereo

A number of studies investigate the effectiveness of motion based depth cues, stereo and a combination between motion and stereo on the performance on a variety of tasks.

| Study | Task | N | Conditions | | | | Rank order: Best performance on top | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | OM | MP | Stereo | Stereo + motion | Completion time | Accuracy (% correct) | |
| [3] Sollenberger et al. (1993) | Path tracing task | 16 | √ | n/a | √ | √ | n/a | (Stereo + OM) | Users had 12 seconds to complete the task |
| | 1 difficulty level | | | | | | | OM | |
| | | | | | | | | Stereo | |
| | | | | | | | | No cues | |
| [4] Naepflin et al. (2001) | Path tracing task | 20 | n/a | √ | √ | √ | Stereo | (Stereo + MP) and MP | Difficulty levels were determined after the experiment |
| | 3 difficulty levels | | | | | | Stereo +MP | Stereo | |
| | | | | | | | MP | | |
| [5] Faubert (2001) | Rod positioning task | 5 | n/a | √ | √ | √ | n/a | (Stereo + MP) and MP | Accuracy was expressed in positioning error |
| | 1 difficulty level | | | | | | | Stereo | |
| | | | | | | | | No cues | |
| [6] Hubona et al. (1997) | Mental rotation task | 31 | √ | n/a | n/a | √ | Stereo +OM | (Stereo +OM) | Motion was devided into controlled and uncontrolled motion |
| | 1 difficulty level | | | | | | OM | OM | |
| | | | | | | | | | |
| [7] Ware et al. (1993) | Node connection task. | 11 | √ | √ | √ | √ | Stereo and (Stereo + motion) and No cues | (Stereo + motion) | OM condition is split into controlled and uncontrolled OM |
| | 1 difficulty level | | | | | | | OM and MP | |
| | | | | | | | OM and MP | Stereo | |
| | | | | | | | | No cues | |
| [8] Ware et al. (2008) | Node connection task. | 14 | √ | n/a | √ | √ | Stereo | (Stereo + OM) | The graphs were shown for 5s |
| | 4 difficulty levels | | | | | | (Stereo + OM) and OM | OM and Stereo | |
| | | | | | | | No cues | No cues | |

*Table 1: Overview of studies investigating the effectiveness of object motion (OM), movement parallax (MP) and stereo for spatial tasks.*

An overview of the studies is listed in Table 1. In this table we compare the studies on different aspects: nature of the task, number of participants, conditions used in the experiment, measured performance and some additional remarks. The different studies show that the number of errors and completion time are the highest for a static monocular presentation. Adding either motion or stereoscopic cues, increases performance compared to a static monocular presentation [3],[5],[7],[8]. As illustrated in table 1, only one study used both OM and MP in the same experiment [7], whereas other studies investigated performance effects of either OM [3],[6],[8] or MP [4],[5] in isolation. It is worth noting that two types of OM can be identified; controlled (using a mouse to rotate an object) and uncontrolled (the object rotates at a constant speed). In contrast to OM, MP is always controlled, i.e. the content changes according to the position of the user's head position. Literature shows that controlled OM results in slightly longer completion times, yet with higher accuracy [6],[7]. As shown in Table 1, using stereo is most effective in terms of decreasing completion time, followed by a combination between stereo and motion. Completion times increase when using motion without the addition of stereo [4],[6],[7]. Accuracy is lower for the conditions using OM without stereo, accuracy increases when stereo is added to OM. [3],[5],[7],[8]. However, for MP the addition of stereo reveals similar results as the MP condition without stereo [4],[5].

The variations in performance advantages of OM, MP and stereo across the different studies may be the result of differences in methodology used in the studies. First, different tasks were used across the experiments (node connection task, rod poisoning, mental rotation and path tracing task). However even between studies using a similar task the effectiveness of the various depth cues differ slightly [7],[8]. Secondly, the use of a time limit which was imposed in two of the experiments reviewed here [2],[8] might be the cause of differences in results. Third, the complexity of the task also influences the effectiveness of the various depth cues. Both Ware et al [8] and Naepflin et al. [4] used different task complexities in their experiment. Ware et al [8] showed that for an easy task the completion time was similar between static stereo and when stereo is combined with motion. Further, motion is as accurate as a combination of motion and stereo when the task complexity decreases. Naepflin et al. [4] revealed that when a task becomes more complex, the degradation in the number of errors was larger in the stereo condition than in the condition with motion. In this study however, difficulty level was determined after the experiment, by ranking the percentage of correct answers into three difficulty levels. Finally, the quality of the stereoscopic images presented on the display may also explain why stereo is not always as effective as motion. All these arguments or a combination of them are potential explanations for the different findings in the effectiveness of motion, stereo and a combination between those cues. Since the different studies use different experimental designs, tasks and conditions, a direct comparison of the results between the various studies is difficult, in particular for a comparison between MP and OM. The current study serves to make such a direct comparison possible.

## 1.2 Rationale of the current study

As mentioned previously, in angiography it is often difficult to correctly perceive the direction and curvatures of blood vessels. Adding OM, MP or stereo, is likely to increase the spatial understanding of complex anatomical structures. Stereoscopic displays are currently not yet widely adopted in the medical discipline, because the added value has not yet been convincingly demonstrated [1]. The added value can be either a more accurate and/or a more efficient (faster) diagnosis, increasing quality of care and cost-effectiveness.

From the studies we reviewed in this paper, only one study we are aware of used both MP and OM in one study [7]. Although this study did not reveal a difference between OM and MP, the experiments using either OM or MP reveal a different ranking between the conditions [4],[8]. Thus, the results from previous studies cannot be regarded as conclusive in terms of comparing the effectiveness and efficiency of OM, MP, stereo and combinations between these cues. In the current study, we deploy these depth cues in one experiment, using 2 levels of complexity. We deployed a path tracing task, which can be regarded as an abstract representation of angiographic images (Figure 1). During a medical diagnosis, information overload is often seen as factor that negatively influences performance. Using a visualization mode that decreases the cognitive load allows the physician to process more information during a diagnosis which will increase performance. Therefore, not only completion time and percentage correct answers are used to access performance, also perceived workload is measured using the NASA Task Load Index [9]. Moreover, visual discomfort, potentially associated with the stereoscopic presentation of the stimuli, can decrease the performance of a task as well. Thus, self-report of visual discomfort was included in the experiment.

## 2. METHOD

### 2.1 Participants

In this experiment twenty participants took part in this experiment (14 male, 6 female), with an age between 19 and 33 years, all with normal to corrected-to-normal vision. All participants had stereo vision better than 40 seconds of arc, tested with the Randot® stereotest. Participants were either students or employees at the Eindhoven University of Technology, the Netherlands. Students were compensated with 7,50 Euro for their participation.

### 2.2 Stimuli

The task consisted of four lines randomly crossing each other. Each line had the same amount of line segments and the same length. The task started from the bottom of the screen up to one of the 4 endpoints (a, b, c, or d). With this task we were able to test to what extent participants correctly perceive the spatial arrangement of the complicated arrangement of lines.  The difficulty level of the task was varied by changing the number of line segments of all four lines. An increased number of line segments represented an increased difficulty level of the task. The difficulty levels were selected based on a pilot study in which six difficulty levels were tested. In the main experiment two difficulty levels were used containing 20 (easy) and 24 (hard) line segments. For each task a unique set of 4 lines was computed using Matlab. The maximum disparity used in this experiment was 10 min of arc. For OM the participants used a mouse to rotate the object. For MP, the orientation of the object was calculated according to the user's head position. For both OM and MP the rotation was fixed to the vertical axis only.

### 2.3 Setting and Apparatus

The experiment was carried out at the 3D/e lab of the Human-Technology Interaction group at Eindhoven University of Technology. The stimuli of the task were displayed on a Heinrich Hertz Free2C autostereoscopic 3D Display, with a resolution of 1200  x 1600. The stereoview on this display was created using a moving lenticular which steers the exit pupils to the user's current eye position. The eye position s measured with a stereo video head tracking device mounted on top of the display.

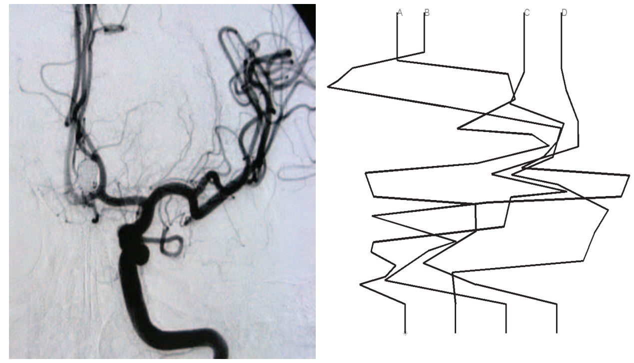

*Figure 1: In the left image an example of an angiographic image which shows the complexity of the blood vessels when presented in 2D. The right image illustrates the stimuli used in the experiment.*

In the current experiment, participants were seated approximately 65 cm in front of the display.

### 2.4 Measures

For each individual task we measured the time to complete the task and whether the answer was correct. For the analysis we averaged completion time over the four tasks and calculated the percentage correct answers for each condition. Perceived workload was measured using the NASA Task Load Index [9]. Additionally, visual discomfort was addressed with the question: "Did you experience any visual complaints." on a twenty points scale ranging from 'very low' to 'very high'.

### 2.5 Procedure

On arrival at the 3D/e lab, participants were tested for their stereo acuity using the Randot® stereotest. After the stereo test, participants were seated in front of the display and received written instructions explaining the procedure. Participants were instructed to perform the task as fast and accurately as possible. Before the start of the experiment, participants performed four training sessions to make sure they understood the procedure. After each condition, participants filled in the NASA-TLX workload questionnaire and the question regarding visual discomfort. The experiment took approximate 40 minutes.

## 3. RESULTS

The results of this experiment are analysed using a repeated measure ANOVA with completion time, percentage correct answers, workload and visual discomfort as dependent variables. We did not have a full factorial design, because OM and MP could not be used simultaneously. Therefore, for the analysis, the dataset was divided into two separate datasets, one with OM and one with MP. The results of the experiment are plotted in Figure 2.

### 3.1 Object motion

First, we will analyze the influence of difficulty level, OM, stereo and their interactions on the performance of the path tracing task. For the analysis we used a repeated measure ANOVA with 2 difficulty levels (20, 24), 2 Stereo levels (On, Off), and 2 Object Motion levels (On, Off) as fixed factors, and percentage correct, completion time, perceived workload, and perceived discomfort as dependent variables. First, the results of accuracy and completion time will be discussed, followed by the results of perceived workload and perceived discomfort.

#### *3.1.1 Accuracy and completion time*

The results of the ANOVA revealed that for a difficult task, users spent more time completing the task ($F(1,19) = 54.7$, $p<0.001$, $\eta^2=0,74$) and made more errors in the difficult task compared to the easy task ($F(1,19) = 3.67$, $p=0.07$, $\eta^2 =0,16$). This result was however only marginally significant. Adding stereo did not result in a significant increase or decrease of either completion time or percentage correct answers. Adding OM resulted in a significantly longer completion time ($F(1,19) = 11.76$, $p=0.003$, $\eta^2=0.38$). On the other hand, the percentage correct answers increased as well ($F(1,19) = 24.37$, $p<0.001$, $\eta^2=0,56$). An interaction effect between stereo and OM was found for completion time ($F(1,19) = 14.86$, $p=0.001$, $\eta^2=0,44$). As shown in Figure 2, adding Stereo to OM decreased completion time whereas completion times slightly increased when stereo was added to the static condition. The results also revealed a significant interaction between difficulty level and OM for both completion time ($F(1,19) = 20,57$, $p<0.001$, $\eta^2=0,52$) and percentage correct answers ($F(1,19) = 5,94$, $p=0.025$, $\eta^2=0,28$). For completion time this interaction revealed that for a difficult task completion time increased more when motion was present than in the conditions without motion. For percentage correct answers, there was a decrease in accuracy for the condition with Motion Parallax when the task became more difficult, whereas in the static conditions the performance remained similar over the two difficulty levels.

#### *3.1.2 Perceived workload and discomfort*

In addition to completion time and percentage correct answers, we also asked participants to reflect on their perceived workload and discomfort after performing the path tracing task. The results revealed that perceived workload was significantly higher in the difficult conditions ($F(1,19) = 69.9$, $p<0.001$, $\eta^2=0,79$). In the conditions with OM, perceived workload was significantly lower compared to the conditions without OM ($F(1,19) = 11.65$, $p=0.003$, $\eta^2=0,38$). Perceived discomfort was also significantly lower for the conditions with OM compared to the conditions without OM ($F(1,19) = 6.44$, $p=0.02$, $\eta^2=0,25$). Furthermore, there was a marginally significant interaction between Stereo and OM in terms of discomfort. Results revealed that the addition of OM to the stereo condition revealed a lower level of perceived discomfort compared to the condition with only stereo.

### 3.2 Movement parallax

In this paragraph we will analyze the influence of difficulty, MP, stereo, and their interaction on the performance of the path tracing task. As with object motion, we used a repeated measure ANOVA with 2 difficulty levels (20, 24), 2 Stereo levels (On, Off), and 2 Movement parallax levels (On, Off) as fixed factors, and with percentage correct, completion time, perceived workload, and perceived discomfort as dependent variables. Here, we also discuss accuracy and completion time first, followed by the results of perceived workload and perceived discomfort.

#### *3.2.1 Accuracy and completion time*

The results of the ANOVA revealed that for difficult tasks completion time was longer than for easy tasks ($F(1,19) = 42.59$, $p<0.001$, $\eta^2=0,69$), however the percentage correct answers were not significantly different between the two difficulty levels. A marginally significant effect of stereo was found; adding stereo decreased completion time ($F(1,19) = 4.22$, $p=0.054$, $\eta^2=0,1$). MP significantly increases completion time ($F(1,19) = 15.04$, $p<0.001$, $\eta^2=0,44$) and percentage correct answers ($F(1,19) = 19.73$, $p<0.001$, $\eta^2=0,51$). A significant interaction between Stereo and MP has been found in terms of completion time ($F(1,19) = 19.9$, $p<0.001$, $\eta^2=0,512$), indicating that the effect of stereo is different in the MP condition compared to the static condition. More specifically, in the conditions with MP the addition of stereo decreased completion time, whereas in the static condition, the addition of stereo resulted in longer completion times. The results also revealed a significant interaction between difficulty level and stereo in terms of completion time ($F(1,19) = 10,60$, $p=0.004$, $\eta^2=0,36$). This interaction showed that for the stereo conditions the difference between the two difficulty levels was smaller than for the conditions without stereo. Also an interaction between difficulty level and MP was found in terms of completion time ($F(1,19) = 6,94$, $p=0.016$, $\eta^2=0,27$). This interaction revealed, similar to OM, that for a difficult task the increase in completion time was larger for conditions with MP compared to conditions without MP.

#### *3.2.2 Perceived workload and discomfort*

Perceived workload was significantly higher in the difficult conditions ($F(1,19) = 50.18$, $p<0.001$, $\eta^2=0,72$). Adding MP decreased perceived workload ($F(1,19) = 4.04$ $p=0.059$, $\eta^2=0,18$), however this result was only marginally significant. The results further revealed a significant interaction between stereo and MP, indicating that the effect of MP is different between the stereo and the non stereo condition. More specifically, perceived workload was lower when stereo and MP were combined compared to the condition with only stereo, whereas in the monoscopic condition, the addition of MP did not decrease the perceived workload. The results did not reveal a main effect of stereo and MP for perceived discomfort, however there was an significant interaction between stereo and MP ($F(1,19) = 5,12$, $p=0.036$, $\eta^2=0,21$). Adding stereo to MP, decreases perceived discomfort ($F(1,19) = 4.3$, $p=0.053$, $\eta^2=0,18$). Without MP, the addition of stereo increases perceived discomfort.

### 3.3 Movement parallax versus Object motion

A paired samples t-test was conducted to compare the performance of MP and OM. The results revealed no significant difference between MP and OM in terms of completion time and percentage correct. However there was a significant main effect between OM ($M=6.39$, $SD=2.18$) and MP ($M=7.1$, $SD=2.44$) in terms of perceived workload ($t(19)= -2.41$, $p=0.026$). Figure 2 illustrates that this main effect is mainly caused by the condition without stereo, showing a higher perceived workload for MP compared to OM. Also in terms of perceived discomfort, OM ($M=4,52$, $SD=4.37$) revealed a significant lower score than MP ($M=5.41$, $SD=4.44$), ($t(18)=-2.16$, $p=0.045$). The results above imply that OM is associated with lower perceived workload and perceived discomfort than MP.

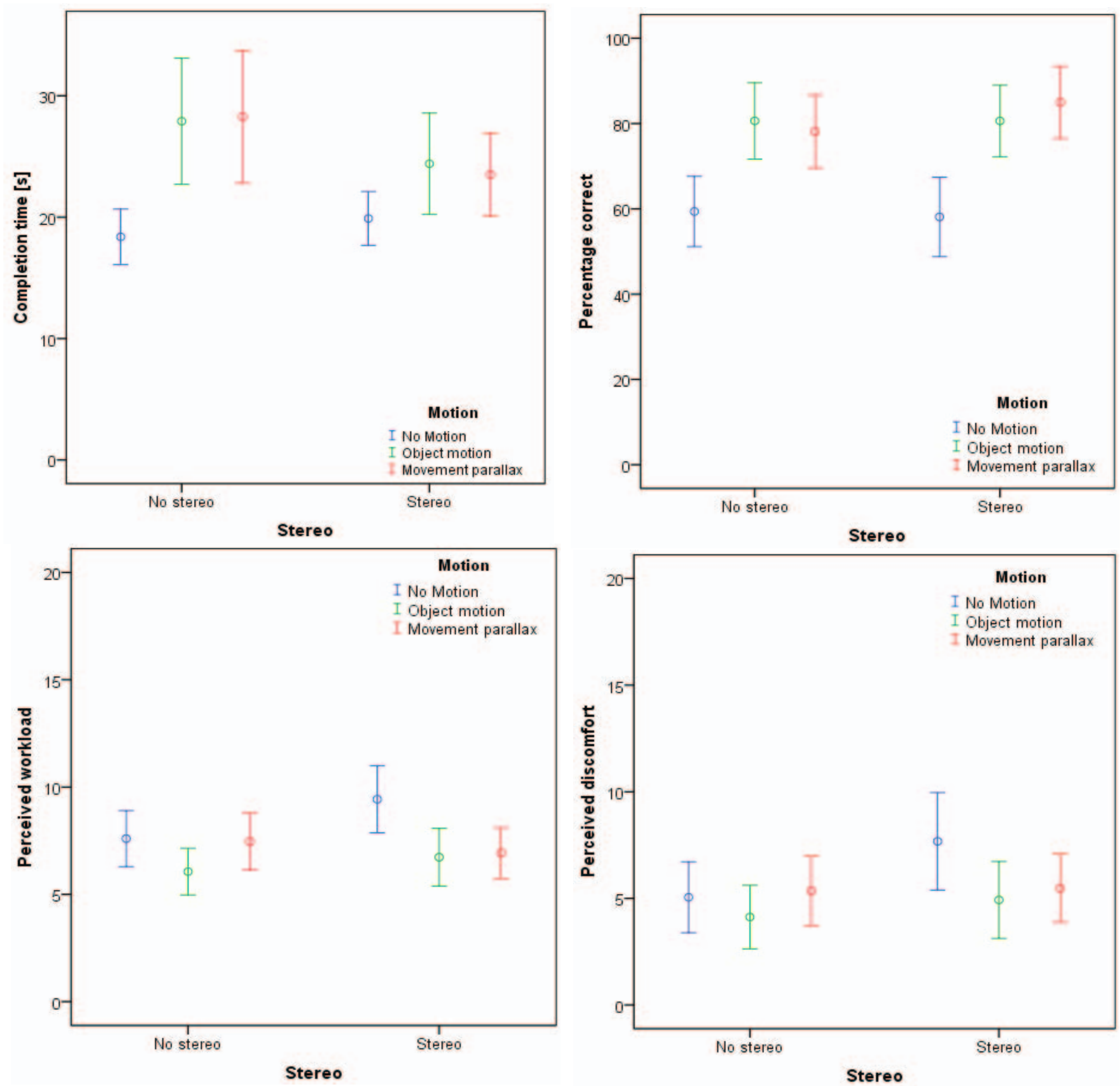


*Figure 2 Results of the experiment for completion time, percentage correct answers, perceived workload and perceived discomfort as function of no stereo and stereo. The clustered lines represents the conditions with no motion, object motion and movement parallax.*

## 4. GENERAL DISCUSSION

In this paper we investigate the informational potency of OM, MP, and stereoscopic disparity, and empirically investigate whether stereo has an added value above and beyond these monoscopic motion cues. We studied this using a path tracing task with two difficulty levels. Results showed that stereo without motion did not increase accuracy (e.g. percentage correct answers), however completion time slightly increased. This result is not in line with previous research reporting that stereo improves the percentage correct answers [3],[7] and decreases completion time [7]. An explanation might be that the disparity levels chosen in this experiment were too low (10 min/arc). Another explanation is the complexity of the task. For the conditions without OM or MP, the results did not reveal a difference between the two difficulty levels, whereas in conditions where the user was able to rotate the image, the results did reveal a main effect of difficulty. This suggests that the chosen task difficulties were too complex when the user was not able to rotate the image, suggesting a ceiling effect.

Compared to the static conditions the percentage correct answers increased when OM or MP were used. Participants also spent more time to complete the task. This is in line with the majority of studies, that also showed that motion increases accuracy, but is also associated to longer completion times than static stereo. When stereo is added to either OM or MP completion time decreased, although the percentage correct answers remained similar, i.e. participants worked faster without an increase in the error percentage. For MP, this result is in line with the study performed by Naeplin et al [4]. However for OM, previous studies suggests that a combination of OM and stereo result in a higher accuracy compared to OM without stereo [3],[7],[8]. In the current study we find a similar trend for both OM and MP. Although trends were similar in terms of percentage correct and completion time, perceived workload differed significantly between OM and MP. In the condition without stereo, OM revealed a lower level of perceived workload than MP. As shown in Figure 2, the static stereo condition revealed the highest level of workload, which significantly decreased with the addition of OM and MP. The results of perceived discomfort are similar to the results found for workload. As shown in Figure 2, perceived discomfort significantly decreased when adding motion to the static stereo condition. This might suggest that when an object is moving, using either OM or MP, stereo leads to less discomfort compared to the static conditions. An explanation can be that when an object is rotating the eye is fixating less towards a fixed point in the image, thereby potentially ameliorating the accommodation/vergence conflict. However, more research is needed into this topic, also with a more extended set of questions, and potentially a set of objective, optometric indicators of the visual state of the participants. The decrease in workload might also be due to a lower level of discomfort, as an increase in discomfort could make it potentially harder to concentrate on the task and therefore could increase cognitive load. Thus, decreasing visual discomfort makes it more comfortable to perform the task, and therefore the subjective assessment of workload decreases.

Although not directly reflected in terms of completion time and error percentage, results on perceived workload suggest that on a monoscopic display, OM is a more effective cue than MP. Presenting OM and MP on a stereoscopic display, significantly decreases completion time compared to a presentation on a monoscopic display. Stereoscopic displays are often associated with increasing levels of discomfort, however we did not find an increase in perceived workload or perceived discomfort when stereo was combined with either OM or MP. This supports the contention that the use of stereoscopic displays in medical imaging, in particular for tasks such as those performed in angiography, the combination of stereo and user-controlled object motion may yield the most optimal results, both in terms of objective performance (accuracy, efficiency) as well as subjective parameters (workload, visual comfort).

## 5. ACKNOWLEDGEMENT

Support from the EC HELIUM3D project is gratefully acknowledged (https://www.helium3d.eu).

## 6. REFERENCES

[1] M.H.P.H. van Beurden, G. van Hoey, H. Hatzakis, and W.A IJsselsteijn, Stereoscopic displays in medical domains: a review of perception and performance effects, Human Vision and Electronic Imaging XIV, *Proceedings of the SPIE*, 7240, pp. 72400A-72400A-15, 2009.

[2] B. Rogers, and M. Graham, "Similarities between motion parallax and stereopsis in human depth perception, *Vision Research*, 22, pp. 261-270, 1982.

[3] R. L. Sollenberg, and P. Milgram, "Effects of stereoscopic and rotational displays in a three-dimensional path-tracing task," *Human Factors, 35*, 483-499, 1993.

[4] U. Naepflin, and M. Menozzi, "Can movement parallax compensate lacking stereopsis in spatial explorative search tasks?," *Displays, 22,* pp. 157-164, 2001.

[5] J. Faubert, "Motion parallax, stereoscopy, and the perception of depth: Practical and theoretical issues," Three-dimensional video and display: devices and systems, *Proceedings of SPIE*, CR76, pp. 168-191, 2001.

[6] G. S. Hubona, G. W. Shirah, and D. G. Fout, "The effects of motion and stereopsis on three-dimensional visualization," International *Journal of Human-Computer Studies, 47*, pp. 609-627, 1997.

[7] C. Ware, D. Hui, and G. Franck, "Visualizing object oriented software in three dimensions," Proceedings of the 1993 conference of the Centre for Advanced Studies on Collaborative research: software engineering, Toronto, Ontario, Canada, pp. 612-620, 1993.

[8] C. Ware, and P. Mitchell, "Visualizing graphs in three dimensions," Proceedings of the 2nd symposium on Applied perception in graphics and visualization, Association for Computing Machinery, pp. 51 – 58, 2008.

[9] S.H. Hart, and L.E. Staveland, "Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research." In P. Hancock and N. Meshkati (Eds.), Human mental workload, Amsterdam, The Netherlands: Elsevier, pp. 139-183, 1988.