# Consequence of Two-handed Manipulation on Speed, Precision and Perception on Spatial Input Task in 3D Modelling Applications


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**Abstract:** We developed a free form deformation application for an immersive environment in which users can interact freely using data gloves. To ensure better comfort and performances, we added the possibility of bi-manual interaction in our environment. To investigate the actual gain obtained by this interaction technique we designed an experimental protocol based on spatial input tasks. In our experiment, we asked our subjects to use only the dominant hand to achieve the different tasks or, on the contrary, to use both hands. Comparison of users' performances – i-e, time and precision – shows that, without proper training, executing a task using two hands can be more time consuming than using one hand. In fact, the degree of symmetry of the tasks performed with each hand seem to have a significant impact on whether or not users take advantage of bi-manual possibilities. Our results also show that bi-manual interaction can introduce proprioceptive cues that can be of help to achieve more precision in the placement or selection only when proper visual information are missing. In this study, we also wanted to investigate if bi-manual interaction can help users in their perception of the task. Even if there aren't statistically significant, our results shows that using symmetric bi-manual interaction, proprioception cues can improve user's perception.



**Key Words:** User Interfaces, Virtual Reality, Bi-manual Interaction
**Category:** H.5, H.5.1, H.5.2


## 1 Introduction

With numerous recent advances in computer graphics technology, Virtual Reality (VR) and 3D interactions are often presented as a major step toward real direct and intuitive manipulation. Indeed, users can be immersed in a Virtual Environment (VE) in which they can interact using everyday actions and commands. For example, using their bare hand, users can manipulate – i.e. grab, move, rotate, warp, etc. – virtual objects as they would in the real world. VR by introducing stereoscopic displays immerse users in 3D virtual environments.

Adding the third dimension seems to have improved users' perception and understanding of his surrounding environment. Thanks to this improvement many scientific's visualization applications in immersive virtual environments (IVE) have emerged, improving complex phenomenon understanding.

However, the introduction of a third dimension in a graphical environment has necessitated the development of new interaction techniques that can't be described by theoretical models. For example, an adaptation of Fitt's law [Fitts & Peterson, 1964] to 3D VE hasn't yet been proposed. As a matter of fact, interaction's situations users may experience in VE are quite different from what they usually would in desktop environment. At the present time it seems that the main application fields are visualization and virtual scene exploration. Such applications try to exploit feeling of immersion brought by such environments to enhance users understanding of the virtual scene explored [Christou *et al.*, 2006]. In fact, interaction isn't efficient enough to offer users rapid and precise actions in the virtual environment. This lack is even more important in applications where precision and speed is overriding.

We developed a free form deformation application called *OMM* that allows a user to perform simple 3D modelling tasks in IVE using data gloves. Our objective with this application is to provide a set of intuitive and efficient interaction techniques to realize simple modelling tasks. Relying on previous studies, showing the potential manual and cognitive benefits obtained from bi-manual interaction [Leganchuk *et al.*, 1998], we developed several bi-manual interaction techniques for modelling tasks. In this paper we propose a preliminary survey investigating the benefits of some basic bi-manual interaction techniques in IVE for 3D input. Our study aims at investigating whether bi-manual interaction can be used as a significant improvement towards effective and convenient spatial input in IVE, and how they influence users' performance, comfort and perception.

## 2 3D modelling applications and bi-manual interaction in VE

Since VE's emergence, different ways have been explored to try to improve users' interaction. One of the first idea was to use specific interaction devices so called *props* to achieve specific tasks. This solution was explored by *Grossman et al.* who designed *ShapeTape* [Grossman *et al.*, 2002]. *ShapeTape* is a plastic shaft including sensors providing users with a set specific interaction techniques to create or edit curves and surfaces. A more recent way of trying to give users more precision during interaction is to introduce missing sensory motor channels. Force feedback devices has been considered has a major step towards more efficient interaction in virtual environment. 3D modelling applications exploiting such devices has widely increased these last few years [Nijholt *et al.*, 2005, Bordegoni & Cugini, 2006, H. *et al.*, 2007]. Using force feedback devices seems to be a promising way since it can ensure user precision during interaction in many cases [Tavakkoli Attar *et al.*, 2005]. Force feedback can be used to provide users with more informations about the virtual scene, e.g. by allowing users to touch and feel surfaces. But force feedback can also be used to help user controlling his gesture during interaction [Keefe *et al.*, 2007]. *Keefe et al.* proposed a bi-manual interaction technique using a magnetic tracker and Phantom$^{\mathrm{TM}}$device to sketch 3D shapes directly in 3D VE.

The introduction of props in 3D modelling applications seems not appropriated. In fact, providing users with a specific interaction device for each of the large number of tasks involved in 3D modelling context appear to be awkward. That's why we decided to use bi-manual interaction to try to give users more control during modelling tasks. Bi-manual interaction has been identified as a promising way of giving users more direct and natural interaction with virtual worlds. In order to design 3D models, specific bi-manual techniques was designed to create appropriate 2D profiles using projection planes [Grossman *et al.*, 2001]. In addition, bi-manual interaction introduces *proprioception* in the environment. Proprioception is the sense of the relative position of neighbouring parts of the body. Using a persons' sense of position and orientation of his body and limbs can be exploited as an additional sensory-motor channel that provides useful information to the user [Mine *et al.*, 1997].

The justification of research interest in bi-manual interactions seems obvious. We spontaneously use bi-manual interactions to ensure efficiency, precision, comfort in the realization of everyday tasks. Thereby, bi-manual interactions techniques are becoming more and more present in 2D applications, and have been exploited to lead to intuitive interactions modalities in IVE (e.g. over the shoulder deletion and two hands flying [Mine *et al.*, 1997], two-handed selection techniques for volumetric data [Ulinski *et al.*, 2007]).

The *Kinematic Chain Theory* [Guiard, 1987] provides a theoretical framework to describe bi-manual techniques. In *symmetrical tasks* the two hands perform the same action (e.g. when performing two deformations at the same time). In *asymmetrical tasks* each hand performs a different action (e.g. when positionning and orientating the object using one hand and warping the object using the other hand). In that case the non dominant hand usually sets the frame of reference for the action of the dominant hand. Our interaction modality, manipulating objects using non dominant hand while deforming with dominant hand, is based on these principles : we hope the user will use the non dominant hand as a reference frame to correct dominant hand gesture [Bagesteiro *et al.*, 2006] and make precise manipulations on an object.

As well, using one's bare hands to achieve a task can bring gains in motor efficiency and lower cognitive load. In bi-manual interaction motor efficiency is mainly due to *parallelism* i.e. the simultaneous execution of the two tasks assigned to each hand. According to *Buxton and Myers*, there's a correlation between degree of parallelism and performances [Buxton & Myers, 1986] : the results of their study show that it is possible to improve users performance by splitting the sub-tasks of compound continuous tasks between the two hands. This procedure leads in improvement of performances for both novices and experts users. Their study also show that when the two hands are used sequentially, each one making separate tasks, using both hands can avoid time consuming task switching, thus reducing task completion times.

However, these encouraging results must be taken with proper care considering the fact that the expected benefits may depend on the interaction device or input modalities, on the subtasks involved in the task and on the environment [Kunert *et al.*, 2007]. For example, a study realized on a docking task necessitating manipulation and navigation in an IVE showed no significant gain from bi-manual interaction [Huckauf *et al.*, 2005] while an experiment conducted to evaluate the effectiveness of bi-manual interaction techniques in the VLEGO environment showed that two-handed cooperative manipulation led to shorter completion times and lower error rates [Kiyokawa *et al.*, 1997].

## 3 *OMM*: a 3D Modelling application

### 3.1 Manipulation paradigm

Direct deformation applications in IVE (i.e. manipulating three dimensional forms freely in a 3D environment, allowing designers to grab and deform free formed surfaces at any point of the surface) were considered has an important breakthrough towards more efficient and intuitive design interfaces [Yamashita & Fukui, 1993].

As a matter of fact, in these environments, users can experience an unmediated direct manipulation situation [Shneiderman, 1992]. Assuming that the actions are performed directly on the objects by the user with his/her bare hands, the environments do not necessitate to act through artefacts such as display control points, widgets, icons, etc... In that extent it shortens the *distance* (between one's thoughts and the physical requirements of the system under use) and increases the *engagement* (the feeling that one is directly manipulating the objects of interest) [Hutchins *et al.*, 1985].

### 3.2 The Odd Mesh Maker application

Our protocol implementation is based on *Odd Mesh Maker*, a deformation application based on the *Twister* deformation model [Llamas *et al.*, 2003], in which users can freely perform deformation on 3D objects using their hands.

To control the application, the user is provided with a fix menu. Using this menu, they can load or save an object, define the current application mode (moving, scaling or warping), modify the object's drawing parameters and deformation parameters. Moving, scaling and warping an object can be performed using unimanual gestures. Because of warping task's high complexity, we decided to introduce a two handed deformation modality. The two hands can be used simultaneously (bottom right image of figure 2) or alternatively to manipulate or warp an object.

Every deformation is defined by a *deformation volume* and a *deformation function*. The deformation volume is a spherical zone of influence around the deformation hand. If the deformation volume intersects the object, every vertices laying inside the volume will be moved by the deformation. In *OMM*, deformation volume is spherical and can vary in radius. The deformation function is a function $f : \Re \longmapsto \Re, f(x) = y$ with $y \in \Re \cap [0, 1]$, which defines how vertices laying inside the deformation volume will be affected by the deformation. When $f = 0$, it means *not affected by the deformation*, and when $f = 1$ it means *fully affected by the deformation* (see figure 1). This parameters can be modified using the menu.

The user uses a data glove to interact with the environment, position the starting point of the deformation gesture and control the deformation shape (see figure 2).

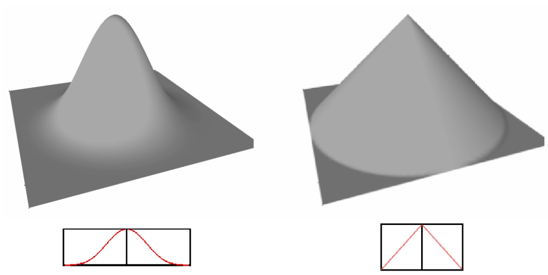

Figure 1: Deformations examples with same deformation volume but different deformation functions.

Our objective with this application is to develop an environment that proposes 3D modelling tools that will not require ad hoc devices to interact. In that purpose we developed a wide range of tools that allows a user to rotate, translate, replace, add... objects with the sole use of the data gloves as an interaction device. Since these tools are still under an evaluation process, we will not present them further here.

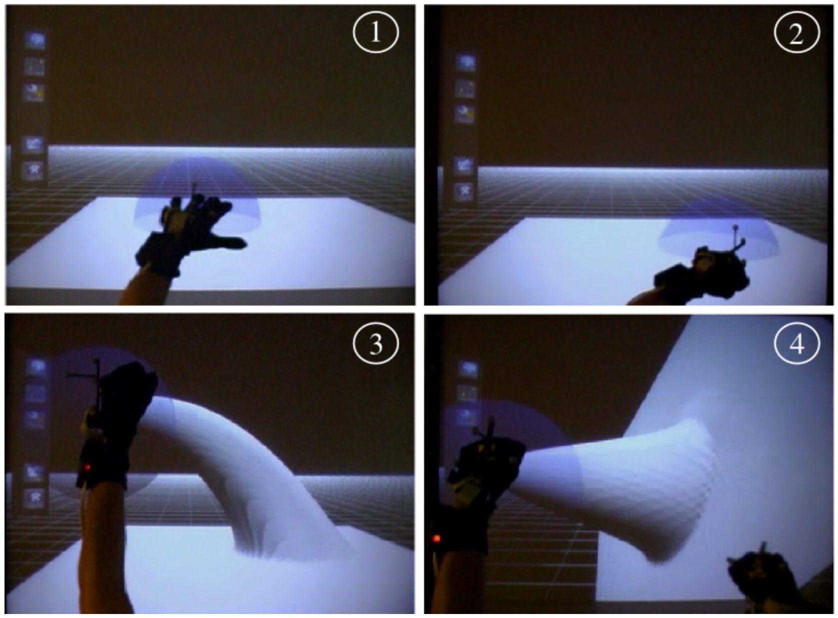


Figure 2: An influence sphere is attached to the users' dominant hand. The deformation area is defined by the intersection of the selection sphere and the surface.

## 4 Design study

This study aims at investigating whether using bi-manual interaction can improve performance and perception in spatial input tasks, and how proprioception can be exploited to enhance users control over the task. In this section, we present our experimental setup and the hypothesis we investigated.

### 4.1 Subjects

We selected 8 subjects with no prior experience with IVE. They were divided into two groups : group 1 achieved the two tasks using only the dominant hand, group 2 had to use both hands. We first presented the FFD application and hardware device to the subjects. We then allowed them to use it freely for a few minutes period. During this training session, they were allowed to use both unimanual or bi-manual interaction to perform a deformation.

### 4.2 Apparatus

Experiments was conducted on a Barco Consul, a semi-immersive Virtual Reality environment using stereoscopic display  resolution 1400x1050, refreshed at

100Hz – and CrystalEyes CE-2 glasses. Images were generated using two HP Workstation XW8000 – one for each screen – fit out with a 3Ghz Quad Xeon and a NVIDIA Quadro FX 3000. Head and hands tracking is ensured by the ART tracking system and magnetic trackers. Users used 5DT Data Gloves to interact with the virtual reality environment. Every result are rounded to centimetre because of tracking system's precision.

### 4.3 Tasks

Subjects were asked to achieve two different tasks, each task was repeated sixteen times.

In the first task, the *designation task*, the subject had to interact with a cube placed at a random position in the workspace always at arms length. One at a time, each of the four corners belonging to the face in front of the user was highlighted by a red colouring. The user was required to grab – or designate – highlighted corner as precisely as possible, and make a deformation to validate designation. During this session, the dominant hand of the user was surrounded with a coloured sphere representing the deformation area. This sphere was here to help the user perceive the volume of the cube that would be influenced by the deformation. The user perfectly grabbed the corner when the center of the sphere attached to the user's hand perfectly matched with it. In the first condition the user could only use the dominant hand to grasp the corner, while in the second condition, the user could manipulate (move and orientate) the object with the non-dominant hand while the dominant hand would grab the highlighted corner. We hypothesized that the use of the non dominant hand would bring higher comfort and efficiency in this designation task, leading to shorter completion times and higher accuracy. The accuracy was measured using the Euclidean distance between corner and center position.

In the second task, the *docking task*, two spheres were presented in the user's workspace. A red coloured sphere represented a fix target, and a white coloured sphere was to be manipulated by the user. The two spheres were randomly positioned. The user had to grasp the white sphere, and put it in the target. To make a perfect match the two centers had to coincide. In the first condition, the user had to grasp and put the sphere using the dominant hand, in the second condition, the user had to grasp the target sphere using the non dominant hand before grasping the white sphere using the dominant hand. The precision is measured by the Euclidean distance between the two spheres' centers. For this task, we did not expected shorter completion times assuming that the subjects had to realize two separate tasks : grab the target and then grab and drop the moveable sphere. However, we hypothesized higher accuracy for the bi-manual condition, assuming that the second hand would allow the subject to exploit proprioception has an additional information to perform the task.

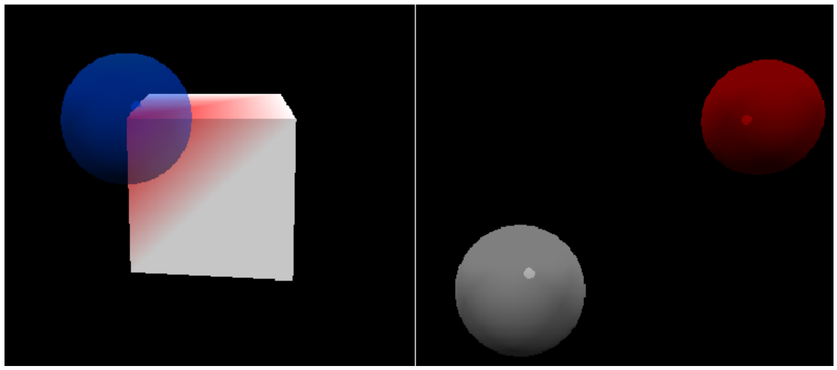

Figure 3: On the left the *designation task* with the user's sphere in blue, on the right the *docking task*

For each repetition of each task, users were required to evaluate their performance in terms of precision by rating it. Rate was given verbally by a number between 1, subject thinks they missed the target, and 10, subjects thinks they perfectly matched the target.

## 5 Results

### 5.1 Completion times

Regarding task completion times in the designation task, while we expected group 2 to be faster than group 1, results show the opposite. For the first task, subjects of group 1 took an average time of 11.39s to designate a vertex while group 2 took on average 14.05s. This result is statistically significant (p= 0,02). For the second task subjects of group 1 took an average time of 16.50s to move the sphere towards the target while group 2 took on average 15.02s (this result was not statistically significant). These time values include : the preliminary evaluation of the situation by the user, the realization of the task and the validation of the action.

We expected bi-manual interaction to prove faster than unimanual interaction for task one, taking into account that it seems to be a more natural way of interacting with objects. As a matter of fact, holding an object with one hand while performing an operation on the object with another is a day to day activity. However our results, with completion times increased by 2.66s for group 2 in comparison of group 1, show that it may not be so intuitive to realize such a manipulation in IVE. Previous studies showed that the degree of parallelization is dependent of the conceptual integration of both subtasks into a single one [Owen *et al.*, 2005]. This result tends to show that the positioning – using the non dominant hand – and the designation task – using the dominant hand – weren't conceptually integrated as a unique task , which, we hypothesized, would have led to shorter realization times.

Concerning task 2, we hypothesised shorter completion times for the unimanual situation. This expectation mainly comes from the necessity of performing one supplementary action in the bi-manual situation (grabbing the target), and assuming that this action could not be integrated to the main task at hand (positioning the sphere) : the subjects first had to grab the target before turning their attention to the moveable sphere. However, results show that the bi-manual condition leads to shorter completion times for the overall measures, with completion times increased by 1.48s for group 1 in comparison of group 2. Regarding placement times (the time to displace the sphere, after grabbing the two objects) group 2 is faster than group 1 with a mean difference of 3.54s ($t = 7.40$s vs $t = 10.94$s; this result is statistically significant, with $p = 0.006$). This important differences can explain why group 2 was faster than group 1 : the time spent for grabbing the target was regained during the docking phase were the bi-manual modality proved to be more efficient. It is surprising that such a gain was not observed during task 1. We think that this may be because in that case the two subtasks performed by each hand can easily be integrated in a unique conceptual objective – make the two spheres closer –, while in task one, each subtask had its own semantic : orientate and designate.

From this second result we can assume that bi-manual interaction can lead to shorter completion times for fully integrated task. However, the first result tend to show that bi-manual interaction, although intuitive with real objects, is not fully exploited in IVE. It may be because users need a learning period to integrate both subtasks into one conceptual task (which is *make a deformation on a precise vertex*), since the proper use of bi-manual techniques for a combined operation may be more difficult to learn, as suggested by [Gribnau, 1999]. In our experiment the learning period consisted in manipulating a plan and a cube using one or two hands. Whereas this learning period wasn't limited, almost every subjects took only about 5 minutes to try the different modalities. It probably would have needed a longer learning period for users to fully exploit the whole potential of bi-manual interaction.

These results are consistent with previous works that led to some doubts about whether bi-manual interaction can lead to real improvements in the effectiveness of user interaction in IVEs [Hinckley *et al.*, 1998]. Whereas our result shows significant improvements in the second task, the comparison with the results of task 1 suggest that it strongly depends on the structure of the task. Thus, considering that bi-manual interaction is compelled to save time because each hand works in parallel may not always be an effective way to think about two-handed interface design. Bimanual interaction should be analysed further to know how we should structure to two-handed manipulations proposed to the final users.

### 5.2 Precisions

Regarding precision, our results shows no difference between group 1 and group 2 for task 1. The two groups have the same average performance of 0.07 m. Performances for task 2 (table 1) show that all distances of Group 2 are smaller than those of Group 1 and are statistically significant (except for X distance). These 2 results seem contradictory : for the 2 tasks, group 1 and 2 differ only in the use of bi-manual interaction, but results indicate a positive influence of the bi-manual modality in terms of precision only for task 2. We explain this result by whether or not the visual cues provided by the environment are sufficient to perform the task. In fact subjects experienced difficulties for task 2 linked to the data glove sensitivity for postural detection between open hand and close hand. These difficulties lead to some involuntary drifts of the displaced sphere. It seems that in that case, the non dominant hand presence as a reference was used to improve gesture control whereas in task one only visual information (sphere of influence) were exploited. In task 2 it seems that the subjects actually used proprioceptive information, probably because of the interferences' nature, which were linked to the proprioceptive information about hand position during the target release stage. The absence of use can also be linked to the distance between the two hands, which is more important for task 1, and the degree of integration of both subtasks.

| | Group 1 | Group 2 | T-Test |
|---|---|---|---|
| $Distance_{tot}$ | 0.058 | 0.012 | p=0.024 |
| $Distance_x$ | 0.016 | 0.0036 | p=0.14 |
| $Distance_y$ | 0.025 | 0.0067 | p=0.04 |
| $Distance_z$ | 0.040 | 0.0061 | p=0.03 |

Table 1: Docking task precisions measures : Euclidean distance, distance along each axis.

Moreover, the gain in precision is more important regarding depth axis. It seems that the subjects' tendency was to place objects at height of sight, leading to occlusion phenomenon that cancelled visual information about depth information. In this case, absence of visual cues is overcome using information from proprioception cues : the relative positions of each hand.

### 5.3 Subjective evaluations

In the present study, subjective measure is used to have a quantitative approximation of subjects' feeling of precision about interaction technique they used. In fact, the more important the rating, the more subjects considered having achieved precise interaction. Considering subjects' subjective evaluation, even if no results are statistically significant (because of the few subjects who passed the test) we can notice that subjects of group 1 rated their performances higher than subjects of group 2 for docking task, and the contrary for the designation task (see Table 2). For the designation task, even both groups performances were similar, subjects of group 2 thought they performed better than those of group 1.

| Task | Group 1 | Group 2 |
|---|---|---|
| Designation task | 7.41 | 8.38 |
| Docking task | 7.22 | 6.66 |

**Table 2:** Mean subjects' subjective evaluation.

Results we present about subjects' subjective evaluation point out the difficulties users may experience when trying to perceive precisely their actions in the VE. For docking task, subjects of group 2 performed better than those of group 1 but they rated their performances as less precise than subjects of group 1. Numerous of previous studies had tried to identify which factors influence users' perception of the VE [Alexander *et al.*, 2003, Interrante *et al.*, 2007]. Indeed, many heterogeneous visual cues like motion parallax, stereoscopic displays, objects' texture or shadows influence users' perception. In this study, we investigate whether or not the introduction of a new sensory-motor channel influences users' perception. We compare the correlation between subjects' subjective evaluation and objective measure for each task. The strength of the correlation is obtained by computing Bravais-Pearson correlation coefficient noted $r$. The correlation coefficient vary between -1 and 1. When $|r| \in [0.5, 1]$ the correlation is strong, when $|r| \in ]0.0, 0, 5]$ is weak and when $r = 0$ the correlation is null. Strong correlation means subjects were able to suitably evaluate their performances and therefore have a correct perception of their actions. Otherwise users had not an accurate perception of their own actions in the VE.

Considering designation task, in both groups subjects' subjective evaluations are weakly correlated with precision measures. But considering docking task, we can observe a weak correlation for subjects of group 1, while there's a strong correlation for subjects of group 2 (see Table 3). We hypothesize that the reasons

| Objective measure | Group 1 | Group 2 |
|---|---|---|
| Docking task euclidean distance | -0.49 | -0.43 |
| Designation task euclidean distance | -0.3 | -0.53 |

Table 3: Mean Pearson correlation coefficient between subjects' subjective evaluation and the different objective measures for each task.

of this phenomenon is the same as for precisions' result. Our environment was not provided with visual cues (like shadows) that could help the user to properly evaluate the task. The occlusion phenomenon caused by the interaction grow worse the perception of the task, thus conducing to this low correlation. In the second task, our results suggest that the subjects took advantage of the proprioceptive informations to achieve the task and, it seems, also to evaluate the result. It seems that combining visual cues and proprioceptive cues can be used to help subjects have a more precise perception of their actions in the VE. This observation can be a part of the explanation of the gains in precision observed for subjects of group 2 for docking task.

## 6 Conclusions and perspectives

Our results show that bi-manual interaction lead to better efficiency and comfort without the need for prior training only under a certain set of conditions. Concerning completion times, it seems that symmetrical tasks are performed quicker. Asymmetrical tasks, on the other hand, did not allow our subjects to take advantage of the bi-manual interaction condition. We think that maybe with further practice, subjects would have obtained better performances.

We also found that bi-manual interaction introduces proprioception that can be exploited when proper visual cues are missing. For task 1, the groups did not show any differences concerning precision. This, we think, because of the influence sphere we added in *OMM*. We think that the subjects, in that case, only relied on visual informations to perform the task at hand. Yet, proprioception cues seem to have been used when visual information was inappropriate (problems to control the release of the sphere in task 2) or missing (depth information in task 2). Proprioception cues are also used to help users have a better perception of their surrounding environment. During docking task, subjects using both hands were able to make more accurate evaluation of their own performance.

In a future study, we would like to further investigate those results. We will analyse the impact of proper training to exploit bi-manual interaction for asymmetrical tasks. We would also like to further evaluate the importance of proprioceptive cues to replace missing visual information. For example, we could intentionally create a lack of visual information, by avoiding the sphere around the subjects' hand in a designation task. We could also create a new task with an environment visually overloaded and see if bi-manual interaction helps.

We would also like to investigate the impact of bi-manual interaction on the possibility to ensure greater control and precision during the deformation gesture. In a desktop modelling application, users generally refer to several visual cues to control the task at hand. In an IVE, adding the same visual clues could lead to a visual overload that would hinder the activity of the user. We think that it is possible to exploit proprioception to replace certain visual information, thus allowing the user to actually realize the deformation planed without relying only on the visual capabilities of the environment.

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