1. **Introduction**

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This study aims to explore **the processing of visual stimuli in virtual reality**, depending on its location and the experienced user representation. User were either represented by virtual hands, virtual controllers, or with no representation based on keyboard inputs. Participants were instructed to perform a motor task while simultaneously detecting visual stimuli appearing at different locations of the 3D space.

The study investigated the role of the visual connection/disconnection of virtual hands on:

1. Embodiment
2. Motor Performance
3. Physiological Responses to a Threat

This study the three supported interaction methods were: a) hands, b) controllers, c) keyboard. Each interaction method corresponds to a different User Representation: a) virtual hands, b) virtual controllers, c) None (keyboard input).

In a dual task paradigm participants executed a **motor task**, while simultaneously detecting **visual stimuli** (red sphere).

When a red sphere appeared participants quickly pressed a pedal. The sphere appeared at 32 locations, across 4 distances, 2 central angles, 2 peripheral angles and 2 elevation angles. To ensure equal salience of stimuli at all distances, the sphere was resized to maintain a constant visual angle.

Before the dual-task condition, participants completed a single-task baseline trial. During this baseline trial, participants had the single task of detecting the red sphere. The **performance in detection** of visual stimuli was assessed depending on **Distance** and **User Representation**. Further, the sense of **embodiment** and **mental workload** were also evaluated.

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Main questions regarding the study.

* How is information in VR processed, when presented at different distances from the user and appearing in different areas of the user's field of view?
* Does the type of user representation (i.e., body, tools, or no visual representation) impact the detectability of visual stimuli in VR?
* What role do user representations (i.e., body, tools, or no visual representation) play, with respect to the subjective sense of embodiment and mental workload?

Until now it is not well understood how the detectability of information in VR is affected by its location in virtual space and its distance with respect to the user. Past studies have hypothesized that nearby visual information is processed more efficiently however, it is still not well understood whether these effects are transferable to immersive VR environments.

Hence, it is possible that the detection of visual content in an immersive 3D virtual environment is also differently modulated, depending on the type of user representation used to interact in VR.

**2.1 Detection of Visuo-Spatial Information**

In everyday life we need to detect and process a vast amount of information embedded in the environment, with various stimuli competing for our attentional resources.

Studies have shown that certain stimuli might be detected and processed more quickly, depending on their spatial location and how close they are to the user, as well as on other features, such as colour, luminance, and motion.

### 2.2 Virtual Representations of the User in VR

User representations are the crucial element of the interface that allows users to carry out actions in the virtual environment and can drastically differ in terms of their visual appearance, the input method used to control them, and the mapping of controls.

1. An alternative way of representing the user is through realistic avatars that are experienced from a first-person perspective
2. For example, users may be represented through virtual models of physical hand-held controllers.
3. interaction may also be enabled through direct keyboard or controller input

Fig. 1. - 
This study is based on a dual-task paradigm where participants have to quickly identify virtual targets (i.e., a glowing virtual cube) and simultaneously detect visual stimuli (i.e., a virtual red sphere appearing in different locations). Participants performed the task by touching the yellow cube with (A) Hands or (B) Controllers, or by pressing one of four respective keys on a (C) Keyboard. The red sphere needed to be detected simultaneously can be seen floating in mid-air in each of the images.


### 2.3 Experimental Design and Hypothesis

A total of 24 participants took part in the study. We designed a VR experience based on a dual-task paradigm: Users were instructed to quickly execute a motor task while simultaneously detecting visual information presented in different locations of the 3D space

**(Cube Task)** - In random order, one of the cubes turned yellow and participants were instructed to select the highlighted cube as quickly as possible; #number of hits

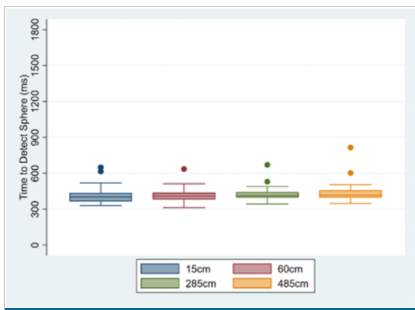
**(Sphere Task)** - we requested participants to pay attention the appearance of a red sphere and press a pedal with their right foot as soon as they detected it anywhere in the scene; #time taken to identify

***H1****:* When information is presented near to the user's body, it is more quickly detected (higher detection performance), compared to when information is presented further away in the virtual environment.

***H2****:* Representing the user by means of a virtual body leads to an enhanced sense of embodiment and decreased mental workload, compared to the use of a virtual tool (i.e., controllers) or a physical keyboard.

### 3.1 Statistical Analysis and Results

Generalized Linear Mixed Models (GLMM) were used to analyse the time taken to detect the red sphere during the baseline and the different experimental conditions. We used a gamma function to fit the distribution of the model to the reaction time data, since reaction times do not follow a normal distribution.   
  
 1st - For the baseline trial and for the actual experimental trials, we ran an additional GLMM, where **User Representation**, **Distance**, **Vertical Angles**, and **Horizontal Angles** were set as the independent variables and participants’ IDs were defined as random effects in the model.  
2nd- Equal to the above, however the factor **User Representation was not included**.

This additional analysis allowed us to evaluate the performance based on their location within the virtual environment, independently of how the user was virtually represented and of the input method used.

**In the baseline trial (single-task paradigm) no effect of Distance on detection of visual stimuli was observed.**

* *Boxplot showing the average detection time for visual stimuli by distance during the baseline trial.*

**3.2 Results**

**Visual Information Processing during Cube Task**

Overall, the number of undetected stimuli was very low. Per distance and across all conditions, the sphere appeared 1104 times, and averaging across all conditions participants only missed 2.08 percent stimuli at 15 cm distance, 1.81 percent at 60 cm, 5.43 percent at 285 cm, and 5.34 percent at 485 cm.

This means that in most trials’ participants were successful in detecting the sphere every time it appeared.

**Fig. 4. - 
Boxplot showing the response time to visual stimuli by distance from the user, with data aggregated for all three conditions (i.e., all user representations).
In the dual-task paradigm, spheres close to the user were detected significantly faster, independent of the User Representation**

* *Boxplot showing the response time to visual stimuli by distance from the user, with data aggregated for all three conditions (i.e., all user representations).*

**Motor Performance in the Cube Task**

Analysing participants’ performance in the Cube Task, a repeated measures ANOVA shows a main effect of Condition. Participants accomplished a significantly higher number of hits with virtual Hands and Controllers, compared to the Keyboard. No significant difference in number of hits was found between the Hands and Controllers

Fig. 5. - 
Average number of hits (cubes touched) in each experimental condition (User Representation).


**Motor performance was higher with a) Hand and b) Controllers, compared to c) Keyboard.**

* *Average number of hits (cubes touched) in each experimental condition (User Representation).*

### 3.3 VR Questionnaire

### 3.3.1 Body Ownership, Agency, and Self-Location

Tests reveal that reported body ownership and agency scores were significantly higher when interacting using virtual Hands compared to a Controllers and Keyboards.

Participants also reported higher body ownership for the virtual Hands compared to the Controllers

Fig. 6. - 
Boxplot with Likert scale ratings for Body Ownership, Agency, and Self-location items in each of the user representation conditions.


**The sense of embodiment was strongest with a) Hands, and weaker with b) Controllers and c) Keyboard.**

* *Boxplot with Likert scale ratings for Body Ownership, Agency, and Self-location items in each of the user representation conditions.*

**3.3.2 Control, Realism, and Effectiveness**

Participants reported a higher sense of **control** when using the Hands and Controllers, compared to the Keyboard. The Hands interaction was perceived as more **realistic** when compared to the Keyboard, with no differences between the Hands and the Controllers, or between the Controllers and Keyboard. For perceived **effectiveness** it was found that ratings were higher when participants interacted through the virtual Hands or the Controllers, compared to Keyboard input. Again, there were no differences in reported effectiveness when comparing the Hands and Controllers.

Fig. 7. - 
Boxplot with Likert scale ratings for Control, Realism, and Effectiveness items in each of the conditions.


* *Boxplot with Likert scale ratings for Control, Realism, and Effectiveness items in each of the conditions.*

### 3.4 NASA TLX

Participants also completed the NASA TLX which is a validated questionnaire for evaluating mental workload. It assesses six sub-scales: mental demand, physical demand, temporal demand, perceived performance, effort, and frustration. In this study we wanted to explore whether subjective workload could vary depending on the type of user representation used in the dual-task paradigm.

**Fig. 8. - 
Boxplot with results from the NASA TLX questionnaire, showing differences between the conditions.
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**Mental workload was lowest with a) Hands and perceived performance was best with a) Hands and b) Controllers.**

* *Boxplot with results from the NASA TLX questionnaire, showing differences between the conditions*

**SECTION 5**

## **Discussion**

The evidence from our study strongly supports our **first hypothesis (H1)**, since detection performance of visual information was significantly influenced by distance, with information presented near the user's physical body being more quickly detected. However, this effect occurred only in the dual-task paradigm. No such results were observed in the baseline control condition.

In relation to our **second hypothesis (H2)**, we found that users indeed reported a strong sense of embodiment and lower mental workload when interacting with virtual Hands, but to some extent this was also the case when using Controllers.

Finally, we also found that interacting through virtual Controllers positively **impacted motor performance**, analysed by the number of hits, compared to using a Keyboard. However, no such difference in motor performance was found between Controllers and Hands.

Our findings support the notion that when faced with more than one task in VR, the processing of nearby virtual objects is prioritized and these are detected more quickly, compared to virtual objects located further away. However, in these studies, stimuli presented very near to the participants were also perceived as more disruptive.

This suggests that in a simple VR scenario, placing virtual content in the background may still result in effective, although slower, detection.

Therefore, the detectability of visual stimuli within a VR scene might similarly be impacted by the type of virtual environment represented.

**SECTION 7**

## **Conclusion**

Our results indicate that while engaged in a motor task, performance in detecting visual stimuli is higher if the visual information is presented near the user's body. However, a different processing of near and far away visual stimuli does not occur when the user is not concurrently performing a motor task and only focuses on detecting the visual information.

Furthermore, we observed no difference in information processing when varying the type of user representations, with all user representations leading to similar processing of visual stimuli in a 3D immersive environment. The user representation did however impact motor performance, as well as the sense of embodiment, which are increased when having a body or tool representation.