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Evaluation of Visual and Vibro-Tactile Feedback Modalities on Interaction With a Virtual Cockpit

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ABSTRACT

Depth perception is important for the human eye to understand the surrounding environment. The feeling of touch is an example of sensory feedback that aids environmental depth perception in the real world, but is missing in most virtual applications. To replace this missing feedback, we investigate users' experience of three different types of visual and vibrotactile feedback methods in a human-in-the-loop experiment, while performing interactions in a virtual cockpit environment, wearing a vibrotactile vest. Our results indicate that receiving visual and vibrotactile feedback is preferred over receiving no feedback. Although vibrotactile feedback is not beneficial to everyone, users are predominantly positive about vibrotactile feedback. Vibrotactile feedback appears to be easier to interpret while being visually distracted. Additionally, object highlighting (visual) and receiving vibrations at the target location (vibrotactile), are the preferred methods as target confirmation. Changing the vibration intensity based on target distance, gives directional guidance that is generally appreciated.

KEYWORDS

Human-Computer Interaction, Virtual Reality, Haptics, Multitasking, Sensory Feedback

1 INTRODUCTION

Recent progress in the field of Extended-Reality (XR), which includes Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR), and the development of devices with increasing computing power, has made it possible to create more immersive and detailed virtual recreations of real-world devices, systems and environments [9]. Simulations in these virtual environments (VE), enable the experience of specific or complex situations, that would otherwise be very costly or impossible to recreate in real-life. Furthermore, simulating commonly occurring scenarios in the real world will become increasingly expensive when done often. Both common scenarios as well as more specific situations could be used in training, for example in airplane or helicopter pilot training. A digital twin of a cockpit can be created, with which a pilot is able to interact in a similar way as a real cockpit [4, 15]. With MR it is even possible to use a real, physical interface and virtually show its corresponding functionality [10, 27].

A contributing factor to creating a more realistic experience in virtual environments is the advancement of Head-Mounted Displays (HMD) [17] and hand-tracking technology. A hand-tracking device enables the user to use their own hands within VEs to have a more realistic-feeling interaction, with either virtual or physical objects. However, long existing problems in interaction with virtual objects in XR have a negative impact on the immersiveness, most evident in AR [8, 16]. An example where extensive research is being done to resolve these problems, is depth perception [1, 13, 22]. Depth perception is important for the human eye to understand what the environment entails [5]. Since VEs miss some sensory feedback that helps environmental depth perception in the real world, interaction with these environments may be experienced differently than with its physical counterpart. An example of sensory feedback that is fundamentally missing from virtual environments, is the sense of touch (tactile feedback). The perceptual aspects of touch, make the world feel real and it helps us in understanding and navigating our nearby surroundings [11]. It allows to complete commonly done activities, such as holding or moving objects. Difficulties with performing such activities become unequivocally clear, in studies that comprise individuals that lack sensations of touch [6]. Thus, if we again have a look at airplane pilot training, performing interactions in a virtual cockpit becomes inevitably different than in a real cockpit.

1.1 Research Topic and Relevance

In this study, we investigate the use of specific feedback cues in terms of interaction performance (how fast are interactions being completed, with and without feedback), but also how the feedback cues are experienced by users. More specifically, we want to study how visual and cutaneous vibrotactile feedback are experienced when performing interactions on a set of objects, and which of the feedback methods are preferred. As VE, a cockpit of a commercial airliner is used, where the user is able to manipulate and interact with multiple flight control instruments. We intent for our results to aid in understanding how different forms of feedback influence the experience of interacting with a VE. This knowledge could aid development of realistic training simulators. Following from this, the virtual instruments should notably resemble real counterparts.

Furthermore, training simulators often require the user to perform tasks concurrently, albeit in a passive manner. However, performing multiple tasks concurrently in a VE, is not very often touched upon. Some studies use verbal interactions to study focus of users while experiencing distractions [21], but the resulting effects on different types of interactions with the environment remain unclear. Furthermore, measurements are done to assess the mental workload in pilots within operational settings. There, it is found that, as the task demands increases, the perceived mental load increases and the task performance decreases [12]. Following from this, we also study the performance and how the feedback cues are experienced, when the user is distracted by a concurrent task.

2 BACKGROUND

In previous work, vibrotactile feedback is used to increase the immersion and (depth) perception of a virtual environment [24, 19]. Furthermore, a meta-analysis on visual-tactile feedback shows advantages such as reduced reaction times and improved performance scores, compared to visual-only feedback [3]. To simulate the feeling of touch in a VE, hand wearables, such as gloves, are used. Although progress is being made in the development of high fidelity hand wearables, for example the gloves shown in [26], they are still often found to be bulky or obstructing [7]. Besides providing feedback on the hands, receiving vibrotactile feedback on other body parts is studied. [20] investigates the use of vibrations on the wrist and temples in an object picking task. Results suggest that receiving suboptimal feedback is better than receiving no feedback at all [20]. Another study investigates different mappings of tactile feedback in a reaching task. It was found that two mappings work well, namely a mapping of distance to vibration intensity and distance to vibration position. It is suggested that the two mappings can be used on different body parts [25].

In our virtual setting, we investigate if and how the performance of interaction with the instruments change when a user performs a cognitive task while testing for the earlier proposed visual and vibratory cues. Moreover, we will investigate the positional and intensity mappings on the chest area. Not studied in [25], we are also interested in how the feedback methods are experienced by users and which they prefer to use, both in the conditions 'with distraction' and 'without distraction'.

3 METHODOLOGY

We conduct a user study to evaluate how visual and vibrotactile feedback modalities aid the user in interacting with control instruments in a virtual environment. The study has a within-subjects design.

3.1 Experimental Setup

We designed an experiment, where participants are asked to perform a sequence of tasks (interaction cycle) on different control instruments in the virtual cockpit. The VE is shown in Figure 1. The interaction cycle consists of pressing a button called 'Left engine button', indicated with 'A', pressing a button called 'Right engine button', indicated with 'B', and pulling the throttle handle backwards, indicated with 'C'. The participants start the cycle by clicking a start button on their left wrist. The interaction cycle is done multiple times, where each time there is a different feedback method, which indicates when your fingers are at the correct position to interact with either the buttons or handle. We designed three visual and three vibrotactile feedback methods, which are explained in detail in Section 3.4. Each participant performs all task sequences, thus with either a form of visual feedback or vibrotactile feedback or no feedback.

Furthermore, users are asked to perform the same interactions while also having to do a small distracting task. For this distracting task, the user is asked to name three airline companies, which are displayed on airplanes outside the cockpit, indicated with 'D' in the figure. When the participant has started doing the interactions, the planes are visible for five seconds, after which they disappear. All feedback methods are done both with and without the distracting task. For each participant, the order of the feedback methods together with the order of having a distracting task or not, is randomized to prevent order biases.

3.2 Participants

For this study, we had 32 voluntary participants, of which 24 were male and 8 were female. Their age ranged from 22 to 38 (mean 27.9, SD = 3.88). The participants were asked to indicate how much experience they have with games and with VR, since we are interested in how this changes the capability to interact with the tested feedback methods. The scores used are on a Likert scale from 1 (No previous usage) to 5 (Very frequent usage) and the results can be found in Figure 2.

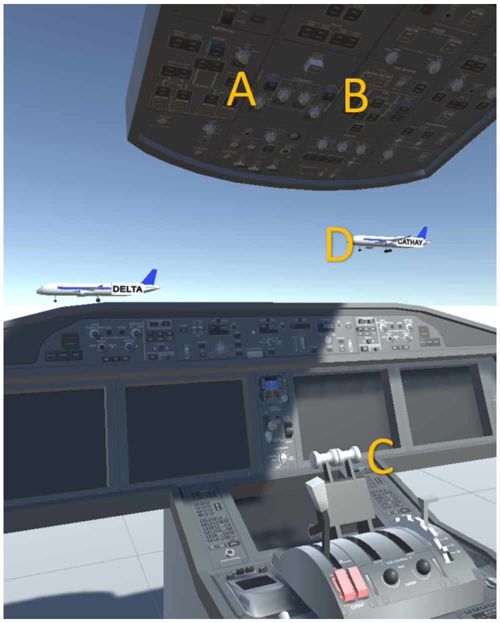

Figure 1: Virtual environment as used in the experiment. Users perform interactions with the objects indicated with A, B and C. The airplanes, indicated by D, are part of the distraction task.

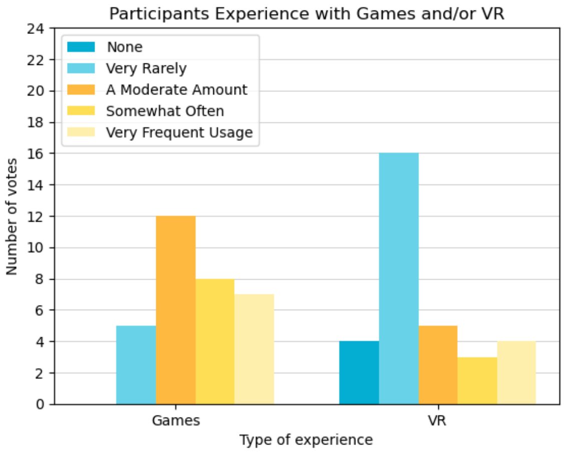

Figure 2: Participants indicated experience with Games (left) and VR (right), ranging from no usage to very frequent usage.

3.3 Apparatus

The VE is a recreation of the cockpit of a Boeing 787 commercial airliner. A select set of buttons and handles within the virtual cockpit is made interactive for this study. To view the VE, we use the Varjo XR-3 HMD[1]. The integrated Ultraleap hand-tracking functionality (Ultraleap Gemini v5) is used to interact with the environment. The HMD has a Field of View (FOV) of 115° horizontally and 90° vertically and a refresh rate of 90 Hz. The experiment is created in Unity. The visual feedback methods are created with Unity functions. The vibrotactile feedback methods are implemented using the bHaptics X40 TactSuit[2] and the bHaptics SDK made for

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[1] https://www.varjo.com/products/varjo-xr-3/

[2] https://www.bhaptics.com/tactsuit/tactsuit-x40

Unity. The TactSuit is a wearable vest that features 40 eccentric rotating mass (ERM) vibration motors that can provide feedback. The front and back side of the vest consist of five rows of four motors. The motors can vibrate individually or together in different configurations.

3.4 Methods

Overall, 7 different feedback conditions are studied, namely 1 baseline, 3 visual methods and 3 haptic methods. All methods are explained below:

(1) For the baseline, no feedback is added to guide the user.
(2) In the first visual feedback method, the instrument is highlighted by colouring the entire object, to indicate that the user is in close proximity of the instrument with their fingers. A bright green colour is used, to make sure it is clearly visible against the background. The user will need one finger (index finger) for a button press and two fingers (index and middle finger) to pull the handle backwards. Having to use two fingers to pull the handle, is chosen based on an expert pilot's suggestion.
(3) Secondly, the fingers are highlighted, when they are in close proximity to the object. Again, the index finger is used for a button press and the index and middle finger are used to pull the handle backwards. Furthermore, the same colour green is used.
(4) Lastly, both methods are combined. Thus when the user moves their fingers close enough to either the button or handle, both the instrument and corresponding fingers will be coloured (green for the instrument and blue for the fingers). Again, the index finger is used for the button and both index and middle finger are used for the handle).
(5) In the first haptic feedback method, the distance of the finger to the instrument is translated to intensity of the vibration. The top-right motor (front and back) will increase in vibration intensity, if the finger is moved closer to the instrument and if the finger is close enough to the instrument, the user will feel the most vibrations.
(6) Secondly, the distance of the finger to the instrument is translated to the position of the vibration. In the top row of motors on the vest (front and back), the vibration will start on the leftmost motor and if the finger is moved closer towards the instrument, the vibration will gradually shift to the motors on the right.
(7) Lastly, if the index finger is in the correct position to perform the interaction, the leftmost motor will start vibrating. If the middle finger is in the correct position to perform the interaction (only for the handle), the rightmost motor will start vibrating. The second row of motors is used.

3.5 Metrics

The completion times of all interaction cycles, are recorded. The start time is when the participant presses the 'Start' button on their wrist and the stop time is when the both buttons are pressed and the handle is pulled backwards completely. When the interaction cycle also contains the distraction, it is noted how many airline names are remembered correctly, and what the behaviour is of the participant when the airplanes appear. After the participants have completed all interaction cycles, they are asked to fill out a questionnaire. The questionnaire consists of the following questions:

- How much experience they have with games and VR respectively, on a Likert scale from 1 (no usage) to 5 (very frequent usage).
- Indicate a score on the 11-point MISC [2] en fill out a Motion Sickness Susceptibility Questionnaire (MSSQ-short) [14].

The following questions are asked twice, once for the interaction cycles without distraction and once for the interaction cycles with distraction.

- Which feedback modality they prefer (No feedback, Visual feedback, Vibrotactile feedback, No preference) and why.
- Which visual feedback method they prefer (No feedback, Highlighting fingers, Highlighting instrument, Highlighting both, No preference) and why.
- Which vibrotactile feedback method they prefer (No feedback, Change of vibration intensity, Change of vibration position, Vibration when in the correct spot, No preference) and why.

3.6 Procedure

For each participant in the experiment, the same procedure is followed. Firstly, written consent for participation is obtained. The data for this study is collected anonymously. Then, the participant is asked to fill out a Motion Sickness Susceptibility Questionnaire (MSSQ-short) and indicate a score on the 11-point MISC. The experiment leader explains the headset, the environment and how handtracking enables the participant to interact with the environment. The interaction cycle is introduced and an indication of the used feedback methods is given. Next, the participant has two minutes of training time in a similar virtual environment, to allow the participant to understand the hand-tracking functionality and to test out the interactions, namely the button press and pulling a handle. After this, the participant will commence with the interaction cycles, where the feedback methods (with and without distraction) are tested in randomized order. For each interaction cycle, the used feedback method is explained, such that the participant knows what to expect. On completion of all the interaction cycles, the participant is asked to fill out the subjective questionnaire on the feedback modalities and methods. Here the participant is again asked to indicate a score on the 11-point MISC. The participant is seated throughout the whole experiment. The full experiment duration for each participant will be approximately 30 minutes, of which approximately 15 minutes are needed to complete all the interaction cycles.

3.7 Hypotheses

In this study, we aim to research the degree of influence of visual and vibrotactile feedback on the interaction with virtual objects. Therefore, we want to compare the use of both feedback modalities to interactions without added feedback methods. We aim to verify the following hypotheses:

H1. Both the added visual and vibrotactile feedback modalities make for faster control inputs compared to control inputs without added feedback methods. The feedback modalities are also preferred over having no feedback added.
H2. Highlighting of fingertips and highlighting of the instrument are equally preferred.

Table 1: P-values of results for feedback method and modality preference questions.

Preference voting	Without distraction	With distraction
Modalities	<0.001	0.037
Visual methods	<0.001	0.001
Haptic methods	<0.001	0.005

H3. Users prefer the change in position and intensity of vibrations equally. Furthermore, they prefer them over the vibrations on the spot.

H4. When users are being distracted (having to remember airline company names while performing the interactions concurrently), the vibrotactile feedback methods will be preferred over the visual feedback methods. This is due to the feedback being experienced without having to look at the interaction itself.

4 RESULTS

The analysis of the user study is described in the following subsections. Firstly, participants' preference of feedback modalities and their preference of the visual and haptic feedback methods, is reported. Also, participants' preferences compared to their indicated game and VR experience, are reported. Furthermore, the duration to complete the interaction cycles, specifically for each feedback method, is discussed. Lastly, the average learning effect from cycle 1 to 14 is discussed.

In our study, although it is not our primary objective, we also accounted for cybersickness. Results of the MSSQ show an average score of 7.27 (SD = 8.48). This score is around the 30th percentile of motion sickness susceptibility of a normal population [14]. Participants were asked to indicate a score on the MISC scale before and after the experiment. Using a Wilcoxon signed-rank test, statistical significant results are found between the scores before and after the experiment, with a p-value of 0.015.

4.1 Preference of Feedback Modalities and Methods

4.1.1 Modalities. The participants preferences of feedback modalities are summarized in Figure 3. Results for interaction cycles both with and without distraction, are shown. When the participants experience no distraction, the visual feedback modality is clearly preferred (18 out of 32 votes). The haptic feedback modality is only preferred by roughly one-third (10 votes) of the participants. Furthermore, all participants preferred having feedback over receiving no feedback at all. When there is a distraction, the visual and haptic feedback modalities are almost equally preferred, with haptic feedback even receiving more votes than visual feedback. Interesting to note, is that there are 3 people that prefer no feedback. The results are tested for statistical significance using a Pearson chi-squared test, where we assess the likelihood the observed data distribution is found by chance. We find significant results for both the 'without distraction' and 'with distraction' conditions. The p-values are shown in Table 1 in the first row.

4.1.2 Visual Methods. For the participants preferences of visual feedback methods, the results are shown in Figure 4. In both conditions, without and with distraction, the method where the object is highlighted, is preferred. In the first condition, the object highlighting has more than double the votes compared to the method where both the object and finger are highlighted. Furthermore, these results are tested for statistical significance using a Pearson chi-squared test, where we assess the likelihood the observed data distribution is found by chance. For both conditions, we find significant results and the p-values are shown in Table 1 in the second row.

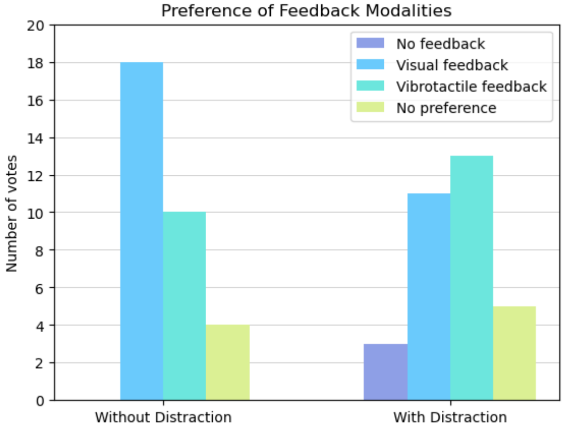


Figure 3: Participants preference of the feedback modalities. Preference is indicated for interaction cycles without (left) and with distraction (right).

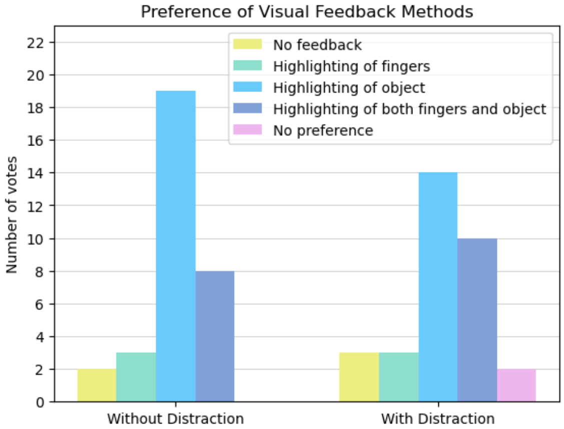


Figure 4: Participants preference of the visual feedback methods. Preference is indicated for interaction cycles without (left) and with distraction (right).

4.1.3 Haptic Methods. In Figure 5, the participants preferences of haptic feedback methods is shown. Two methods are clearly preferred the most, namely the change of vibration intensity and the vibration on the spot. Those methods score similarly in both the conditions, with and without distraction. It is again interesting to note, that in the condition with distraction, more people prefer no feedback at all. Furthermore, these results are tested for statistical significance using a Pearson chi-squared test, where we assess the likelihood the observed data distribution is found by chance. For both conditions, we find significant results and the p-values are shown in Table 1 in the third row.

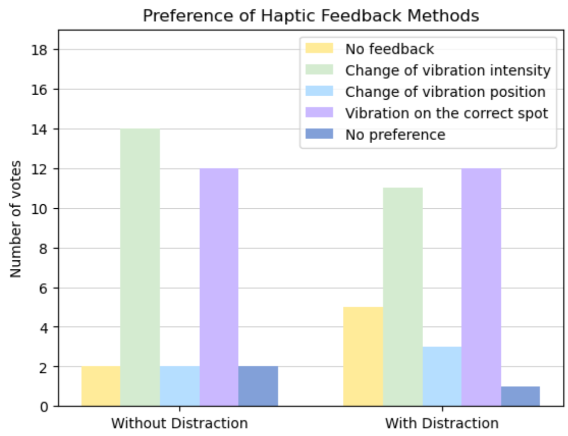


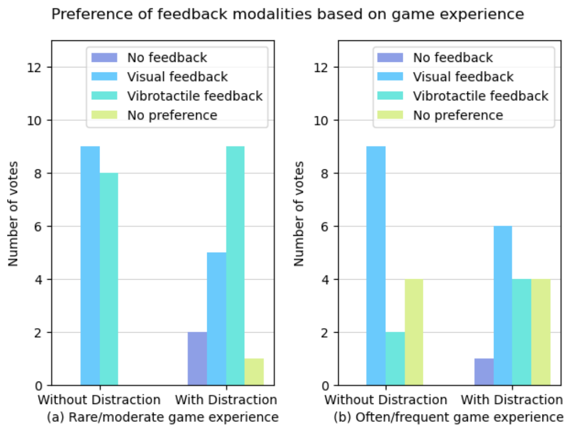
Figure 5: Participants preference of the haptic feedback methods. Preference is indicated for interaction cycles without (left) and with distraction (right).

4.2 Preference of Feedback Modalities/Methods Compared to Games/VR Experience

In this subsection, we investigate the preference for feedback modalities and feedback methods of participants, based on the amount of experience they have with games and VR. Participants' experience is collected via the questionnaire, of which the data is summarized in Figure 2. For both game and VR experience, we have grouped the participants in two categories. For VR experience, we have the category of none to rare experience, consisting of 20 out of 32 participants, and the category of moderate to very frequent experience, consisting of 12 out of 32 participants. For game experience, we have the category of rare to moderate experience, consisting of 17 participants, and the category of often to very frequent experience, consisting of 15 participants. The categories for game experience do not contain the option 'No experience', because none of the participants indicated having no game experience.

4.2.1 *Modalities.*

Participants' preference of the feedback modalities, grouped by their experience with games, is shown in Figure 6. The figure shows a multitude of votes for vibrotactile feedback by participants with rare/moderate game experience, compared to the votes by participants with often/very frequent game experience. For the 'without distraction' condition, there is a multiplication factor of 4, and for the 'with distraction' condition, there is a multiplication factor of more than 2. Furthermore, we find the vibrotactile feedback to be predominantly preferred over the visual feedback in the 'with distraction' condition, voted by participants with rare/moderate game experience. Similar results can be seen in Figure 3. We tested for statistical significance, using a Pearson chi-squared test, where we assess the likelihood the observed data distribution is found by chance. In Figure (a), we find significant results for both conditions with p-values of <0.001 and 0.027. In Figure (b), we find a significant result for the 'without distraction' condition, with a p-value of 0.008. We find no significant result for the 'with distraction' condition, with a p-value of 0.33. Additionally, the preference for feedback modalities, based on participants' VR experience, follows a similar distribution as in Figure 6.



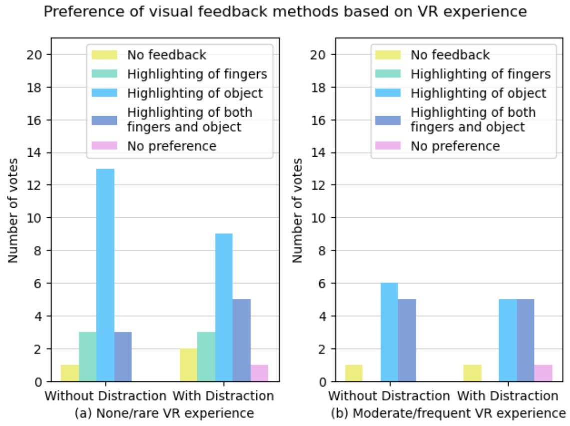
(a) Rare/moderate game experience

(b) Often/frequent game experience

Figure 6: Participants preference of the feedback modalities. Figure (a) shows the preference of participants with rare to moderate game experience, Figure (b) shows the preference of participants with often to very frequent game experience.

4.2.2 *Visual & Haptic Methods.*

The participants' preference of the visual feedback methods, grouped by their experience with VR, is shown in Figure 7. The participants with none or rare VR experience, have a clear preference for object highlighting in the 'without distraction' condition. In the 'with distraction' condition, the difference with other options is smaller, but still present. The participants with moderate to frequent VR experience vote equally for the feedback methods 'object highlighting' and 'both finger and object highlighting'. Furthermore, the feedback method 'finger highlighting' is never the preferred method, while this method received three votes from the participants with none/rare VR experience. All results in Figure 7 are statistically significant, following a Pearson chi-squared test, where we assess the likelihood the observed data distribution is found by chance. The condition 'with distraction' in both graphs has a p-value of 0.04 and the condition 'without distraction' has p-values of <0.001 and 0.007.



(a) None/rare VR experience

(b) Moderate/frequent VR experience

Figure 7: Participants preference of the visual feedback methods. Figure (a) shows the preference of participants with none to rare VR experience, Figure (b) shows the preference of participants with moderate to very frequent VR experience.

When we study the participants' preference for haptic feedback methods, based on their experience with games and VR, we find similar distributions to what can be seen in Figure 5. A noticeable difference, is that 86% of votes for the option 'No feedback' is from the group of participants with less game/VR experience.

4.3 Duration of Interaction cycles

Figure 8 and Figure 9, show the time needed by participants to complete interaction cycles. Boxes are shown for each feedback method, and without and with distracting task respectively. The boxes represent the average and quartiles of the data distribution, whereas the horizontal line is the median value in the data. At first sight, the boxes seem to have slightly different shapes and locations. However, when comparing the data of each of the feedback methods to one another, we only find that participants are significantly slower using the 'finger highlighting' method compared to the 'object and finger highlighting' method, following a Wilcoxon signed-rank test. This holds true for both the 'without distraction' condition, with a p-value of 0.01, and the 'with distraction' condition, with a p-value of 0.03. Furthermore, we investigate if the distracting task makes for slower results. Thus meaning whether the results in Figure 9 are significantly slower than the results in Figure 8. Using a Wilcoxon signed-rank test, we find significantly slower results for the 'with distraction' condition compared to the 'without distraction' condition, for four out of seven feedback methods. This is namely for Baseline, Object and Finger Highlighting, Vibration Intensity, and Vibration in Correct Spot. The results of the remaining three methods seem sensitively similar, but the results are not significantly different.

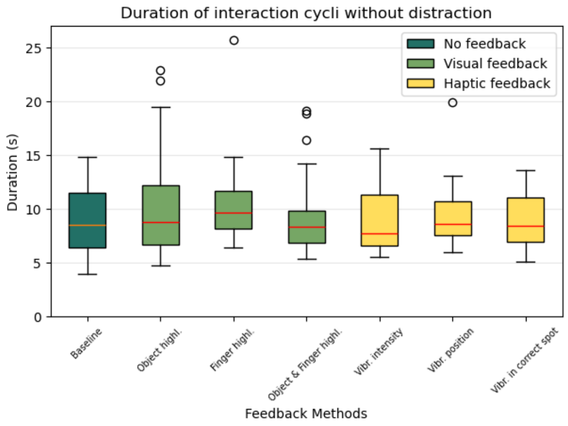


Figure 8: Time needed by participants to complete interaction cycles, shown for each feedback method. The interaction cycles were done without distraction.

4.4 Learning Effect During the Interaction cycles

To study if participants become faster in completing the interactions, we calculated the average time participants needed to complete interaction cycle 1 through 14. The results are shown in Figure 10. By comparing cycle 1 to 14, it can be seen that the average duration of the cycles decreased by roughly 30%. Additionally, we studied the average duration of interaction cycles when participants started with either visual feedback, haptic feedback or no feedback. We did not find that starting with either of the modalities, results in a significantly faster or slower learning effect. Furthermore, we investigated whether participants showed faster or slower learning effects based on their experience with games or VR. We find that participants with moderate to very frequent VR experience, are significantly faster in completing the cycles than participants with none to very rare VR experience, with a p-value of 0.01. When comparing participants with very rare or moderate game experience to participants with often or very frequent game experience, we find no significant difference with a p-value of 0.46.

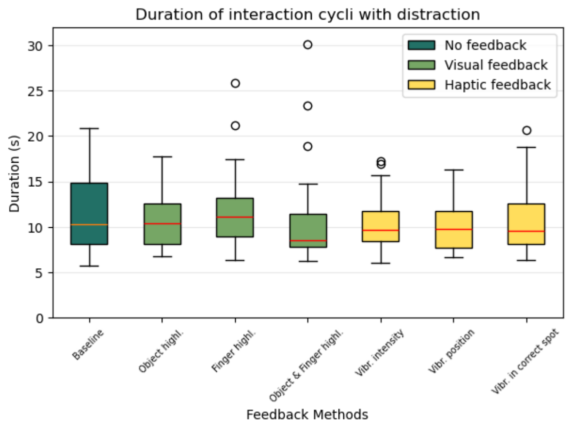


Figure 9: Time needed by participants to complete interaction cycles, shown for each feedback method. The interaction cycles were done with distraction.

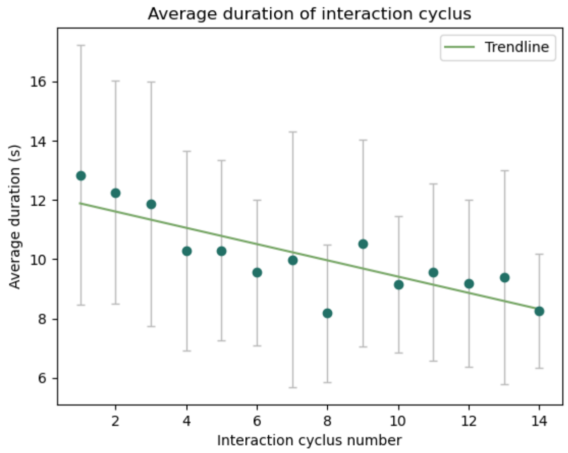


Figure 10: Average time needed by participants to complete each interaction cycle. The light gray bars above and below each data point, show the standard deviation.

5 DISCUSSION

Firstly, we discuss the preference of feedback modalities and methods, to answer our hypotheses. Our data of the preference of feedback modalities, shows significant results for both the 'without distraction' and 'with distraction' conditions. For the 'without distraction' condition, none of the participants prefer having no feedback. In the 'with distraction', three of the participants prefer having no feedback, namely because they feel both the visual and haptic feedback are distracting. Overall, comments by the participants, reveal that visual and haptic feedback give needed confirmation that an intended target is reached. Without any feedback, there is only an indication when you start interacting with an object. This partially confirms the first hypothesis, namely that both visual and haptic feedback modalities are preferred over having no feedback. The preference of having some sort of feedback rather than no feedback at all, coincides with conclusions from [20], which is discussed earlier in Section 2. For the 'with distraction' condition, the visual and haptic feedback modalities are roughly equally preferred. Haptic feedback even received more preferential votes. Based on participants' comments, a perceived benefit of the haptic feedback is that it can be interpreted besides being visually distracted. This confirms the fourth hypothesis, where we expect that users prefer the haptic feedback when they are being distracted during an interaction cycle. Participants were predominantly positive towards the haptic feedback methods. However, the haptic feedback methods are not yet beneficial to everyone. Five of the participants found the haptics to be distracting, and three participants find the visual feedback to be easier to comprehend. A possible reason, as is also mentioned by 2 participant, is that there are too many stimuli when haptic feedback is added. This might be because haptic feedback is not yet as commonly used in VR applications as visual feedback. Thus, using haptic feedback might require some learning to get used to the feeling and the application in feedback methods. Another possible reason, also mentioned by 1 participant, is that the haptic feedback is received on the chest, while receiving the feedback closer to the hands might feel more intuitive.

Figure 4 shows that our second hypothesis, which states that highlighting the fingers and highlighting the instrument are equally preferred, should be rejected. In both conditions, the option 'Highlighting of fingers' only received 3 votes, compared to 19 and 14 votes for the option 'Highlighting of object'. Furthermore, 5 participants state that highlighting fingers feels unnatural, weird or not intuitive. However, when this method is combined with highlighting the object, participants feel that it creates a sense of double confirmation. It firstly confirms you have arrived at the correct object, but also that the fingers are close enough to be able to interact with that object. We suggest that, whenever there is need to convey more information, the highlighting of fingers could be used as an additional cue. For simple confirmation, highlighting the object itself appears to be the most intuitive and easiest to understand.

Based on what was found in [25], discussed in Section 2, we expected the change in vibration position to be equally preferred and appreciated as the change in vibration intensity. Furthermore, we expected both methods to be preferred more than the vibrations solely when being in the correct spot, see the third hypothesis. The results in Figure 5, on the contrary, show that the change in vibration intensity and the vibration when in the correct spot, are roughly equally preferred and both methods received a multitude of votes compared to the change in vibration position. The change in vibration position is not the preferred method and that is partly because it is often found to be distracting, or not intuitive. Based on participants' comments and visual observations of the participants during the experiment, it can be argued that the change of vibration position was sometimes experienced as confusing because the meaning was unclear, even though beforehand it was explained what the cue meant. Based on two participants comments, they expected this method on the chest to point them in a general direction, either to the left or right, whenever they do not yet know at what location an interaction is required. Having explained where the interactable objects are, before the experiment started, the two participants felt this positional vibration change has an unexpected meaning. To summarize, the change in vibration position on the chest seems to be able to guide users towards a more general direction, rather than towards a precise input such as the buttons and handle, at least in short exposures such as this experiment. To explain the equal preference of vibrations on the spot and change of vibration intensity, there seems to be roughly two stances. Participants either like to receive a simple confirmation whenever they have reached their intended target, or they prefer the guidance that is provided by changing the vibration intensity. From this, we argue that when designing a VR application, people should be able to choose between the two options. It can be implied from participants' comments, that having guidance towards an intended target, is more appreciated by people that do not have experience with VR. However, the results we discuss in Section 4.2.2 do not reflect this, since we find similar preferential distributions as can be seen in Figure 5.

Our expectation in the first hypothesis, that the interaction cycles are done faster when visual or haptic feedback is enabled, cannot be endorsed by the results of our experiment. The results in Figure 8 and Figure 9, show slight changes in the position and size of the boxes. There is only a significant difference when we compare the 'Finger highlighting' method with the 'Finger & Object highlighting' method, both for the 'without distraction' and 'with distraction' condition. Arguably, a possible reason for the lack of difference between the conditions, is that the interactions the participants had to perform, are simple. The tasks require only one or two fingers, and single movements, either towards a button or backwards for the handle, are enough. Future experiments could therefore entail different types of interactions or tasks that need to be completed, ranging from easier tasks to more demanding ones. This might then establish whether any of the preferred methods also makes for a qualitative improvement of interactions.

Lastly, we found statistical significant results between the given scores on the MISC scale, before and after the experiment. However, the difference in scores, given before and after the experiment, is minor and is likely due to wearing the HMD [23]. Besides this, a recent study suggests a technique, using haptic feedback, to mitigate cybersickness, although why it is effective is still unclear [18]. Since roughly 15 minutes were needed to complete the interactions in our experiment, the effects of long-term exposure to our VE and the used feedback methods are unknown.

6 CONCLUSION AND FUTURE WORK

We have conducted a user study, where participants had to perform interactions in a virtual cockpit, with and without a concurrent task as distraction. During the interactions, the users received either no feedback, visual feedback or vibrotactile feedback. Our results show that people want to receive confirmation when performing interactions, whether that is visual or vibrotactile. Although it overall seems that visual feedback is still a simple and preferred form of feedback, when the users are being distracted, the vibrotactile feedback is the preferred method as it can be interpreted simultaneously. Thus, we suggest for developers of interactive applications to consider the use of vibrotactile feedback, as opposed to only using visual feedback, when multiple tasks have to be completed simultaneously or there are already multiple visual cues that clutter the interface. Moreover, our results show that people prefer feedback methods that convey a simple confirmation, but also feedback methods that convey a form of guidance. The methods 'object highlighting' and 'a vibration when the target location is reached' are the preferred methods that convey a simple confirmation and the preferred method that conveys a form of guidance, is 'translating the distance between hand and target location to vibration intensity'. Based on these results, we believe that there is no one-fits-all solution and as such, users of an interactive application should be able to choose the feedback method that works best for them.

Based on the results of our study, we discuss multiple recommendations for future work and experiments. Firstly, we suggest in Section 5 that some form of learning might be required, to make haptic feedback beneficial to more people. This suggestion follows from participants' comments, that the haptic feedback can be distracting or feel not intuitive. We suggest an experiment, where users are trained to use haptic feedback for varying periods of time. This can then show if the haptic feedback is less distracting, when users are more accustomed to the feeling or meaning. Secondly, we identify the easiness of the interactions in our experiment, as possible reason that we do not find significant differences between the time it takes to complete the interaction cycles. We suggest experiments with different types of interactions, as well as varying difficulties of interactions, as discussed in Section 5. Lastly, in terms of cybersickness, we are interested in the effects of long-term exposure to our feedback methods. We suggest an experiment where participants are exposed to visual and haptic feedback in a VE for different time lengths. Our results for 15 minutes exposure could then be used as a baseline. Besides this, experiments with longer exposure to the visual and haptic feedback might yield different results.

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