Passive Haptic Menus for Desk-Based and HMD-Projected Virtual Reality

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Abstract

In this work we evaluate the impact of passive haptic feedback on touch-based menus, given the constraints and possibilities of a seated, desk-based scenario in VR. Therefore, we compare a menu that once is placed on the surface of a desk and once mid-air on a surface in front of the user. The study design is completed by two conditions without passive haptic feedback. In the conducted user study ($n = 33$) we found effects of passive haptics (present vs- non-present) and menu alignment (desk vs. mid-air) on the task performance and subjective look & feel, however the race between the conditions was close. An overall winner was the mid-air menu with passive haptic feedback, which however raises hardware requirements.

Index Terms: Human-centered concepts [Human computer interaction (HCI)]: Interaction paradigms—Virtual reality; Human-centered concepts [Human computer interaction (HCI)]: Visualization—Empirical studies in visualization

1 Introduction

In Virtual Reality (VR) we often have to decide between a metaphorical (*natural*) interaction and a pragmatic one. An example is loading a data file by picking a file out of a virtual shelf against selecting it by a classic 2D file-browser. Unfortunately, this is not always an easy decision and we ourselves sometimes struggle between the first immersive solution and the second faster one, which however might break the illusion. Even in a productive setting, immersion and thus presence might have some impact on the overall productivity or performance, otherwise the Immersive Virtual Environment (IVE) might just be the wrong place for the activity. However, VR usually is not only about mimicking the real world as close as possible, rather than making it better or more productive. Therefore, control elements, such as menus, are sometimes just the right method to make functions, modes and data quickly accessible. Nevertheless, this does not mean that menus should be implemented in the same way as in a desktop application and at the end this is even not possible as, e.g., the positioning is not clear. There is just not this one obvious surface where the menu has to be placed on in VR, when compared to a desktop application. Thus, we took a standard plane hierarchical menu and tried to integrate it in the given IVE setting as good as possible. In our case this is a VR-supported (office) desk-based working scenario, as it is common for most data analysts and other professionals and recently has become more common [16, 17, 21, 23]. In this setting the office desk could serve as a possible surface to put the menu on and would support passive haptic feedback for free, when used with the bare hands. Another solution would be to put the menu, mid-air, just in front of the user, which is common in all kind of VR applications. The first solution might have some advantages over the second, e.g., to be accessible all the time, as well as being less tiring to use. To verify these expectations we evaluated a desk-aligned menu against a mid-air variant – both with and without passive haptic feedback – in a formal user study.

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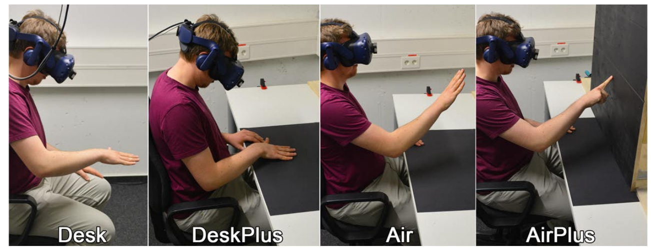

Figure 1: Experimental setting for the four different conditions, from left to right: *Desk* without a physical desk but the menu aligned with the virtual desk, *DeskPlus* with the menu aligned with a physical and virtual desk, *Air* at a physical desk but the menu aligned to the task and *AirPlus* at a physical desk, aligned to the task and aligned with wooden plate coated in black.

2 Related Work

Real world objects and surfaces are often utilized by augmented reality applications, such as shown by Weller and Newman et al. [14, 18] with the *DigitalDesk Calculator* or Xiao et al. [20] for touchable surfaces and further the precise detection of touch events. Nevertheless, virtual reality usually wants to overwrite the reality, while there is research showing that tangible interaction can increase user performance also in IVEs [9, 12, 13]. Therefore, often a lot of (technical) effort is done to stimulate cutaneous and/or kinesthetic receptors to re-include haptics into virtual reality [10, 11], where the Turkdeck [4] and VRHapticDrones [8] are expansive examples of prototypes for basic research. However, in some scenarios parts of reality can be reintegrated [23] or substituted [15] in VR, which provides the sensation of touch for free and the possibility to include further tangible interaction. This is described for desk-based scenarios by Zielasko et al. [23] and used by Sousa et al. [16] for widget interaction in a medical application. Filho et al. [17] served a very similar setting with a desk-based exploration of scatter plots, but without direct hand interaction and controllers instead. While the (desk) surface-based tangible control elements in the proposed works might be without an alternative, due to their practicability or just the given restrictions, it is still interesting to have a formal evaluation of it, which to the best of our knowledge, is not available for current hardware settings. Therefore, we evaluated four different menu configurations in the following, providing passive haptic feedback (present vs. non-present) crossed by the positioning of the menu (desk vs. mid-air).

3 Menu Implementation

For the study, a framework for a standard hierarchical menu was implemented in *C++*, based on an existing widget framework [5] (see Figure 3). In the course of this work, two types of menu elements were used, namely sub-menu elements and button elements. The first fold up a sub-menu to their right when selected, with an animation time of $.5s$, when opening, and $.35s$ on closing. A sub-menu is closed whenever another element is selected and this can be the extended sub-menu itself. The button element type just calls a callback, here it sets the characteristics of an object (see Section 4.3). Furthermore, the menu framework provides acoustical and visual feedback. For example, a menu item gets focused and is highlighted as soon as the input hand/fingers position is in front of it and closer than $5cm$.

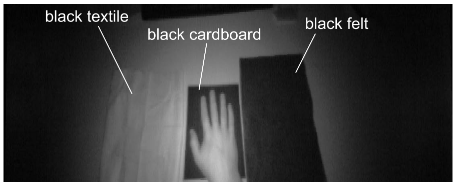

Figure 2: A Comparison of different materials and their contrast to a user's hand in the infrared light camera of the leap motion controller.

A selection is performed as soon as the distance falls below $1cm$ and is acoustically and visually confirmed. When this happens in a sub-menu, the sub-menu branch collapses.

4 Evaluation

In this section, a 2×2 study design is presented, which investigates the previous described hierarchical menu due to the influence of passive haptic feedback and the menu's position. Therefore, the condition (***DeskPlus***), i.e., the menu aligned with a virtual table providing passive haptics, is evaluated against a standard mid-air menu (***Air***), without passive haptics. To complete the two factors *haptic* and *alignment* two additional conditions were added. First, a desk-aligned menu without haptic feedback (***Desk***) and, second, a mid-air menu providing haptic feedback (***AirPlus***).

4.1 Apparatus

The experiment took place in front of a regular office desk ($0.71m$ height x $0.80m$ depth x $1.6m$ width) with the participant seated on a rotatable and tiltable office chair (see Figure 1). For the condition *Desk* (see Section 4.2), different to the three other conditions, the participant's chair was placed about one meter in front of the desk, such that the desk was not reachable. The IVE was projected using an HTC VIVE Pro and the headset was tracked with two tripod-mounted SteamVR Base Stations 2.0. Finally, the user's hands were tracked by a Leap Motion Controller running on firmware version 1.7.0, using version 4.0.0 of the Leap Motion SDK. The Controller was mounted to the Head-Mounted Display (HMD) and running in HMD optimized mode. The touch events on the surfaces were only detected using the position data provided by the Leap motion controller (c.f. [19]). During prior experiments, we noticed that the desk serves a bad contrast to the user's hands in the infrared light spectrum used by the controller. Since, the performance of the hand tracking device is not the main focus of this work, assuming an ongoing increase in precision and reliability anyways, we investigated some materials with respect to their infrared light reflection rate (see Figure 2) and at the end covered the interaction space of the desk with a thin, black cardboard (see Figure 1). In the background, there was always a black coated wooden wall, which in case of the *AirPlus* condition was placed closer to the user and then served as touchable surface (see Section 4.2 and Figure 1). We tested the system to be usable also without the special surface coating as well, but we wanted to provide the best possible tracking for all conditions with the given hardware to reduce possible biases.

4.2 Virtual Environment

In all conditions but *Desk*, the actual desk was substituted by a virtual equivalent. Condition *Desk* did not take place at a physical desk (see Section 4.1) and thus it was not a substitution, but still a virtual table was displayed to keep the IVE equal. Even when not utilized in the conditions *AirPlus* and *Air* , we assume that there is no negative impact of the desk on the task at all [24] and we think it makes sense to do so in a desk-based working scenario [21, 23]. Next to the desk, a menu was part of the virtual environment, which has a fixed position on the desk's surface and is always open in the condition *DeskPlus* and *Desk*. In conditions *AirPlus* and *Air* the menu is opened and closed with a gesture (see Figure 4) and its position is also fixed such that the line of sight to the virtual objects (see below) is not blocked. In the condition

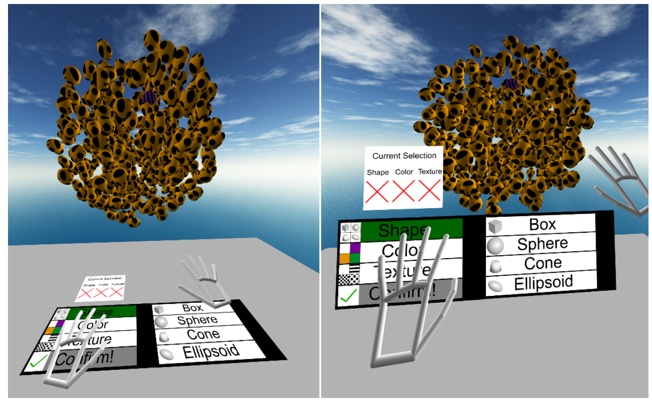

Figure 3: Depicted are the experimental settings of the IVE for the desk aligned conditions (left) and the task aligned conditions (right). In both cases there is the cloud of objects in the background and the menu opened, with the sub-menu *Shape* extended (as highlighted in green) and no selection made yet (see the 3 red crosses). The user is about to define a purple, striped sphere as the outlier object.

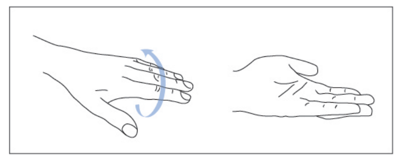

Figure 4: Gesture to open the menu in the two task-aligned conditions, *Air* and *AirPlus*. It was possible to close the menu with the reverse gesture for the case it might ever be in line of sight, which actually never happened.

AirPlus, the menu is additionally placed on the surface of a wooden board (see Section 4.1). For all conditions, but *Desk*, the precise height of the desk or position of the board were calibrated for any user. This procedure took a few seconds. Due to the tracking accuracy and drift of the Leap Motion controller this was necessary even if everything was stationary and thus in theory should have been calibrated just once and not per participant. The used hierarchical menu had a depth of two, where the first level contained the sub-menus shape, color and texture, and at fourth a button to confirm the task selection (see Section 4.3). Each of the corresponding sub-menus consisted out of four button elements. For the study, the menu elements' size was defined as $4.2cm \times 26cm$. This size was determined by iterative pretesting such that the elements' text label still were readable through an HMD and the menu was usable by novice users with their fingers only or their whole hand instead, considering the reliability of the used tracking hardware. To access the menu, the tracked hands were visualized in a simplified tube-based style (see Figure 3). Other than the virtual desk and the menu, only a cloud of objects, which is described in the following Section, was placed in front of the desk.

4.3 Task

To enhance external validity, we decided for a semi-realistic task including 3D objects and navigation. This also keeps artificial fatigue of interaction low. Otherwise, in pure menu interaction, people might for instance get exhausted faster when using the non haptic menu conditions, with their hands unsupported, compared to to any given realistic scenario. The task design was inspired by different previous studies on menu interaction [2, 6]. The first phase of each task, without direct menu interaction, was designed to cover approximately half of the time it took to solve a task and additionally also cover a significant part of the mental workload, as it would be in a real application, too. For every task there was a varying cloud of 499 identical and 1 different object in front of the participants (see Figure 3). To finish the task they first had to find the object that differs and then enter its object parameters (form, color and texture) via the menu. The center of the object cloud was placed approximately 3*m* in front of the participant. The objects had a size of about .1*m* in radius and together covered a radius of 2*m* around the center. The object clouds were randomly generated with the named parameters and then selected before the study. Every participant received the same object clouds in the same order but with permuted condition orders. To find the one object being different the participants had access to a simple travel metaphor. The metaphor was inspired by seated leaning [22], but was restricted to just one degree of freedom. The distance to the object cloud was kept constant and the participants were only able to orbit, together with the table, around the cloud by leaning to the left or respectively to the right. Once identified, the object parameters of the found object had to be entered and then confirmed via the menu either aligned to the table or in mid-air, depending on the current condition. Therefore, all objects were specified by three categories, which are mirrored to the menu's top level (see Figure 3). The first parameter was the object's shape, which either was a sphere, a cylinder, a cube or an ellipsoid. The second parameter was defined by the objects color, which either was white, orange, green or purple. Lastly, the third parameter described the objects texture, which either was none, striped, dotted or chequered. The current state of the chosen object parameter set was depicted above the menu (see Figure 3), always starting in an undefined state, which was marked with a red X. While using the menu to specify the object, it was still possible to orbit the object cloud, e.g., to double check the memories. Once the searched object was completely specified, the participant had to confirm the selection in the menu and the next cloud was displayed.

4.4 Procedure

The study procedure was structured as follows. First, the participants signed an informed consent outlining collection and usage of the study data. Second, they received a written study description, which explained the further procedure, the task and the interface. Then, the participants were asked to pseudonymously answer some questions, regarding demographics and an SSQ. In the following a first condition was assigned to them. All conditions were assigned in a balanced order. For each condition they performed a training phase, which was unrestricted in time and trials. Then, they solved 15 runs of the task (see Section 4.3). The practical part of each condition took about 8 minutes. Afterwards, they left the experimental setting and answered a SUS questionnaire and some Likert scaled items regarding the recently used menu condition (see Figure 7). This procedure was repeated for all remaining conditions. Finally, the participants answered a few general Likert scaled items (see Figure 8), an SSQ and were asked to rank the menu conditions with respect to given characteristics (see Table 2). The whole procedure took about 45-60 minutes.

4.5 Participants

33 subjects (5 female and 28 male, age $M = 25.5$ years, $SD = 4.7$) were recruited at the university campus and voluntarily participated in the study. All participants reported normal or corrected-to normal vision. Regarding their experience with 3DUIs, 14 participants reported a regular usage, 11 that they used a 3DUI at least once before and 8 never did so. The distribution was 30, 2, 1 for 3D video gaming and 16, 10, 7 for VR experience, respectively. An SSQ questionnaire measured an average score of 11.9 ($SD = 11.9$) before and 18.9 ($SD = 13.7$) after the experiment.

4.6 Hypotheses

We designed this study to compare desk-aligned menus with passive haptic feedback against standard mid-air menus, providing the factors haptics and alignment. Given these factors, we expect to observe the following effects. **(H1) Regarding the task performance (speed), we expect the *AirPlus* menu condition to perform the best**, because it should combine the advantages of both groups, alignment and haptics. In the case of alignment, the object cloud is visible

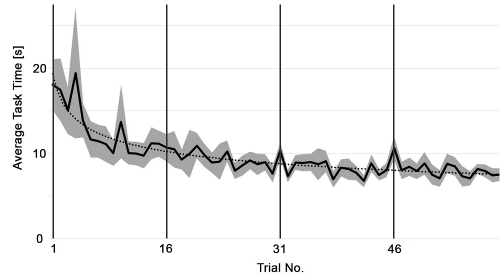

Figure 5: The average task completion time (and .95 confidence interval) plotted against the course of the whole experiment. A vertical line marks the start of a new condition. During the experiment the order of menu configurations was balanced, while the tasks had always the same order.

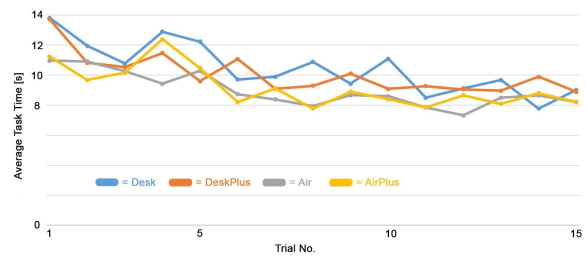

Figure 6: The average task completion time plotted against the course of each condition.

while using the menu. Therefore, **(H1.1) we expect that users have to look around less in the task-aligned conditions and thus are faster**. In the case of feedback, passive haptics should increase confidence, which should lead to the same effect. Additionally, we do not expect that the need to first open the menu adds significant time. **(H2) In consequence, we expect the *Desk* configuration to perform worst regarding task performance (speed)**, because it combines the disadvantages of both factors. Furthermore, the desk-aligned menus are the same size than their counterparts, but are viewed and accessed non-orthogonally, which de facto decreases the touchable surface. This can further add to a worse performance and can be measured separately. **(H3) Thus, we expect that the desk-aligned menus generate more miss-selections.** One of the main drivers to use passive haptic menus was the observation out of a pre-study, multiple expert evaluations and related work [3, 7, 21] that touch-based, unsupported mid-air menus, such as *Air*, tend to add a lot of physical strain with increasing time. Now, in this study the exposing time to every menu configuration is small, due to time limitations, and the tasks were designed in a careful manner, but still we expect to see **(H4) that the supported, i.e., passive haptic menu conditions are less exhausting to use than their counterparts.** Finally, **(H5) we expect the menus with passive haptic feedback to generate the better look & feel than their counterparts**. In summary, **(H6) we also expect the menus with passive haptic feedback to have the highest usability** and in further detail expect the following overall raking: *AirPlus* > *DeskPlus* > *Air* > *Desk*.

5 Results

The scaled measures were analyzed using a two-way repeated measures ANOVA. The ordered measures, e.g., participants were asked to rank the four conditions regarding different attributes, were analyzed using a Friedman test. For the post hoc analysis a Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied. Throughout the paper all results are reported at a significance level of .05 and non-significant trends at a level of .1.

	Task Time [s]	MenuInteraction Time [s]	Selections	FocusPer Selection	HeadMovement [°]	Traveled [°]	SUS
Desk	21.37 (7.95)	**10.53** (4.14)	7.77 (.81)	1.60 (.06)	**403.58** (120.64)	120.98 (65.57)	**78.75** (13.81)
DeskPlus	20.09 (6.63)	**10.10** (3.12)	8.06 (.78)	**1.84** (.07)	**377.06** (114.45)	113.68 (40.69)	83.44 (13.86)
Air	19.53 (6.77)	8.95 (2.72)	7.86 (1.5)	1.54 (.04)	295.50 (130.74)	118.91 (59.06)	86.41 (9.65)
AirPlus	20.34 (6.06)	9.45 (2.69)	7.76 (.53)	**1.84** (.06)	311.23 (115.45)	126.36 (58.09)	85.16 (10.68)

Table 1: **Core Measures**. The table shows the mean values (standard deviation) over all participants for the average time to solve a task, the time spent using the menu per task, the number of menu item selections (where the best possible is 7), the number of focus events per selection (where the best possible is 1.), the amount of head movement per task, the angle traveled around the object cloud per task und the SUS score. Highlighted values indicate statistical significant differences, but for details consult Section 5.1 and 5.2

5.1 Objective Measures

During the study, a collection of objective measures were recorded per participant and condition. The descriptives are summarized in Table 1. The first two were the average time to solve a task (*TaskTime*) and the average time spend with pure menu interaction per task (*MenuInteractionTime*). The statistical analysis revealed no main effects of haptic feedback on the *MenuInteractionTime*, $F(1,28) = .003, p = .959$, but a main effect of the menu alignment, $F(1,28) = 4.808, p = \mathbf{.037}$ as hypothesized in H1.1, and no interaction between the two factors, $F(1,28) = .777, p = .385$. However, there was no main effect of haptics ($F(1,28) = .030, p = .864$), nor alignment ($F(1,28) = .411, p = .527$) on the overall *TaskTimes* as well as no interaction between the two factors ($F(1,28) = .612, p = .441$). The temporal evolvement of the average time to solve a task over the course of the experiment, which was balanced in condition orders, is depicted in Figure 5 and separated by condition in Figure 6.

Then, to investigate the menu interaction, the average number of menu item selections (*Selections*) per task was recorded, with the assumption that difficulties caused by the menu configuration, such as miss-selecting a neighbored menu element, would show up in this measure, while all other types of errors should average out. Note that the variance added by the measurement itself is low, as the lowest number of selections for every task is the same, namely 7. The descriptives again are summarized in Table 1. The analysis determined that there is no main effect of haptics on the mean *Selections* ($F(1,28) = .209, p = .651$), nor a main effect of alignment ($F(1,28) = .504, p = .484$), and no interaction between the two factors ($F(1,28) = 2.272, p = .143$). To have an even deeper look into the interaction, with the different menu configurations we also logged the number of focus events per task. A focus event occurs while the user's hand approaches the menu item and triggers an optical highlighting when the element is just about to be selected. It can be a measure for false negative selections as well as difficulties with hitting the right menu element. For the analysis, we normalized this measures with the number of actual selections and further inspect the number of foci per selection (*FocusPerSelection*), which in best case is 1. In this case the analysis revealed a main effect of haptic feedback on the *FocusPerSelection* ($F(1,28) = 24.894, p < \mathbf{.001}$). Furthermore, there was no main effect of alignment ($F(1,28) = .259, p = .614$) and no interaction between the two factors ($F(1,28) = .612, p = .441$).

Finally, we logged the amount of head movement and the angle traveled around the object cloud with a sampling rate of $90Hz$. The first should be higher in the desk-based menu conditions, regarding H1.1, as they are not aligned to the task. The statistical analysis confirmed that alignment has a main effect on the amount on head movement ($F(1,28) = 35.136, p < \mathbf{.001}$), while there is no main effect of haptics ($F(1,28) = .136, p = .715$), and no interaction between the two factors ($F(1,28) = 1.559, p = .222$). Simultaneously, there was no main effect of haptics on the traveled distance found ($F(1,28) < 0.001, p = .994$), nor a main effect of alignment ($F(1,28) = .283, p = .599$), and there was no interaction between the two factors ($F(1,28) = .699, p = .410$).

5.2 System Usability Scale

For each condition, the participants were ask to fill out a System Usability Scale (SUS) regarding the menu configuration. The descriptives are summarized in Table 1. The analysis revealed an interaction between haptics and alignment ($F(1,31) = 4.619, p = \mathbf{.040}$) and no main effect of haptics ($F(1,31) = .728, p = .400$). There was also no main effect of alignment ($F(1,31) = 6.393, p = \mathbf{.017}$), as paired-sample t-tests revealed only one simple main effect between *Desk* and *Air* ($T(31) = -3.476, p = \mathbf{.002}$), but none between *DeskPlus* and *AirPlus* ($T(31) = -.711, p = 482$).

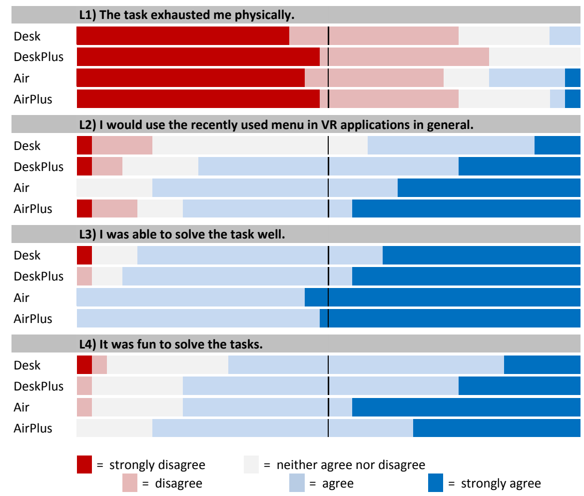

Figure 7: Listed are the results of all users that stated on four 5-point Likert scale items, regarding physical strain, general usability, confidence and fun, in addition to the SUS questionnaire after each condition. The black vertical bar depicts the median. Refer to Section 5.3 for the significance analyses.

5.3 Likert Scale Items

Subsequently to each SUS, participants answered four 5-point Likert scale items regarding the current menu configuration (see Figure 7). The scale reached from *strongly agree* (1) to *strongly disagree* (5). For the item *"The tasks exhausted me physically."* participants overall tended to answer that they do not feel exhausted. The analysis revealed a non-significant trend for haptic feedback having a main effect on the answer of this question ($F(1,32) = 3.710, p = .063$), though none effect of alignment ($F(1,32) = .678, p = .416$), and no interaction between the two factors ($F(1,32) < .001, p = 1.$). Furthermore, the participants on average agreed in *"I would use the recently used menu in VR applications in general."* and there was an interaction effect between haptics and alignment found ($F(1,32) = 5.029, p = \mathbf{.032}$). However, there was no main effect of haptics ($F(1,32) = 2.877, p = .1$), nor alignment ($F(1,32) = 11.148, p = .002$), as a paired-sample t-tests just revealed simple main effects between *Desk* and *DeskPlus* ($T(32) = -3.032, p = \mathbf{.005}$), as well as, *Desk* and *Air* ($T(32) = -4.662, p < \mathbf{.001}$). The participants also on average agreed on *"It was fun to solve the tasks"*, and there was a main effect of alignment found ($F(1,32) = 9.267, p = \mathbf{.005}$). Furthermore, there was no main effect for haptics ($F(1,32) = .204, p = .654$) and no interaction between the two factors ($F(1,32) = .377, p = .377$). Last, participants were asked to rate the statement *"I was able to solve the task well."*. The analysis again revealed a main effect

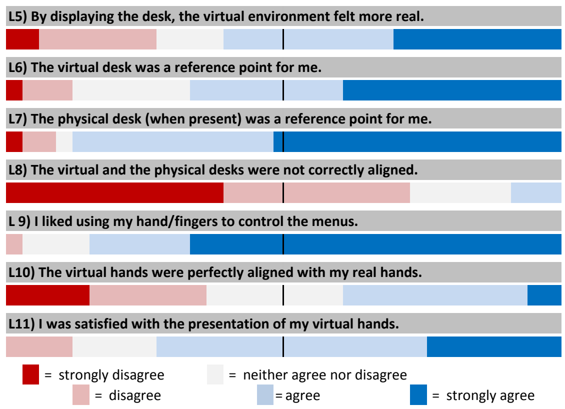

Figure 8: Listed are the answers of all participants to seven general 5-point Likert scale items, which were raised at the end of the study. The black vertical bar depicts the median.

of alignment ($F(1,32) = 7.973, p = \mathbf{.008}$), but no effect of haptics ($F(1,32) = .888, p = .352$) and no interaction between the two factors ($F(1,32) = 1.937, p = .174$). After the practical part of the study all participants were asked to state on some additional Likert scale items. The items and the answers are shown in Figure 8. For all items, but L10, a one-sample t-test ($p \in [.016,.001]$) revealed a significant weight to either agreement or disagreement.

5.4 Rankings

After the practical part of the experiment the participants were asked to rank the menu configurations regarding efficiency, induced physical strain, how well the menu configuration integrates into the setting, attractiveness and ease of use. The descriptives are summarized in Table 2. There was no statistically difference in the raking of the conditions regarding physical strain, $\chi^2(3) = 6.164, p = .104$. However, when grouped in passive haptic ($M = 2.74, SD = 1.10$, median 3, 2 to 4) and not passive haptic ($M = 2.24, SD = 1.10$, median 2, 1 to 3), with respect to H4, there was a difference in the raking of the menu configurations, $Z = -2.568, p = \mathbf{.010}$. Furthermore, there was a significant difference in the ranking regarding efficiency, $\chi^2(3) = 20.273, p < \mathbf{.001}$. The post hoc further revealed, that the *Desk* condition was lower ranked than all other conditions, *DeskPlus* ($Z = -2.454, p = \mathbf{.014}$), *Air* ($Z = -3.229, p = \mathbf{.001}$) and *AirPlus* ($Z = -3.568, p < \mathbf{.001}$). Then, *AirPlus* was ranked over *DeskPlus*, $Z = -2.001, p = \mathbf{.045}$. No significant difference was found between *Air* and *DeskPlus* ($Z = -1.432, p = .152$), as well as for *AirPlus* and *Air* ($Z = -.821, p = .412$). When asked to rank the conditions regarding their integration into the environment, the result differed significantly between the conditions, $\chi^2(3) = 9.262, p = \mathbf{.026}$. The pairwise analysis then showed that *Desk* was significantly lower ranked then *DeskPlus* ($Z = -2.558, p = \mathbf{.011}$) and *Air* ($Z = -2.689, p = \mathbf{.007}$). Additionally, there was a non-significant trend for *DeskPlus* to be ranked also lower than *AirPlus*, $Z = -1.910, p = .056$. There were no differences found for the other pairs of conditions. Next, there was a difference in the ranking of the menus regarding attractivenesses (look & feel), $\chi^2(3) = 18.709, p < \mathbf{.001}$. The participants again ranked *Desk* under all other conditions, namely *DeskPlus*($Z = -3.561, p < \mathbf{.001}$), *Air*($Z = -2.162, p = \mathbf{.031}$) and *AirPlus* ($Z = -3.441, p = \mathbf{.001}$). Additionally, *AirPlus* was ranked over *Air* ($Z = -2.301, p = \mathbf{.021}$), however *DeskPlus* was not ($Z = -1.408, p = .159$). Finally, there was no difference found between *DeskPlus* and *AirPlus* ($Z = -.0722, p = .470$). Asked for a ranking on the overall ease of use of the menu configuration, there was a significant difference between the conditions $\chi^2(3) = 20.818, p < \mathbf{.001}$ and *Desk* again was ranked worse than the other conditions, *DeskPlus* ($Z = -3.418, p < \mathbf{.001}$), *Air* ($Z = -3.281, p = \mathbf{.001}$) and *AirPlus* ($Z = -3.718, p < \mathbf{.001}$). There were no differences found for the other pairs of conditions.

6 Discussion

Starting with a reflection of the first hypothesis, we were not able to find a significant difference in the task completion times and thus cannot confirm **H1**, even though we were able to confirm **H1.1**, namely that participants looked around more in the desk-aligned conditions, and were faster interacting with the menu in the task-aligned conditions. However, the small difference vanishes in the overall task completion time, which might be also influenced by the fact that the menu had to be opened in the task-aligned conditions, as mentioned before. In consequence, we also have to reject **H2**, stating that *Desk* performs worst regarding the task completion time, even though it was the worst condition in nearly every other measure.

Also regarding the number of menu item selections and thus the miss-selections (false positives), we did not found any significant difference and therefore have to reject **H3**, which hypothesizes that the desk-aligned conditions generate more miss-selection due to the angle of the projection. Nevertheless, very surprisingly we found another type of error, namely the number of focus events per selection, which indicates i.a. false negative selections, to be significantly higher in the passive haptic conditions. Even though we expected an increased value here, w.r.t. **H3**, we instead expected it in the desk-aligned conditions to occur. The only plausible explanation we have for this are tracking inaccuracies, which also matches the observation we made through out the study. The conditions with passive haptic feedback much more rely on a precise tracking, as a selection has to be triggered exactly when the surface is touched. While it might be annoying when the selection occurs before reaching the surface, and this was possible to happen in all conditions, the situation is worse when a selection is not possible because the depth that is triggering the selection is not reachable. When the latter occurs and the selection is then successful on the second try, this is registered as one selection but two focus events. This happened rarely, as the overall usability and performance scores confirm, but still was observable. Additionally, the system never broke completely for a single user, which would indicate just bad calibration. Instead this occurs, as we investigated separately, when the users move their heads and so the position of the HMD-mounted Leap Motion controller. This alone should not influence the tracking negatively, but the controller gives just different *desk heights* for different position in its field of view and in the case of our perpendicular table the extreme points varied about $3.7cm$. The difference was much lower in the actual interaction space, but still head movements were able to change the tracking precision with respect to the actual table about a few millimeters.

Continuing with **H4**, we expected the conditions with passive haptic feedback to generate less physical strain than their counterparts. Regarding the pure ranking of the conditions (see Section 5.4), we can confirm this hypotheses. However, the effect size seems to be lower than expected and thus it is not showing in the objective data or L1 (see Figure 7). Additionally, there are no signs of fatigue visible with the course of any conditions (see Figure 6). The expose time to each condition was short (about 8 minutes), anyways our prior experiments and related work [3, 7, 21] suggested a stronger effect and we are not able to explain the differences.

Furthermore, **H5** expected the passive haptic menu conditions to feel more appealing, assuming a calibration that is precise enough, and the results and user feedback confirmed this. Finally, **H6** expected the passive haptic menus to generate a higher overall usability than the other menu conditions and we were not able to fully confirm this. First to say is that regarding their SUS scores (see Section 5.2) all menu configurations were rated at least *good* [1] and thus *usable* interfaces, while three even reached an *excellent* rating. In this overall good results, the *Desk* condition was the least usable, as expected. The other three performed comparable over all measures with different small advantages and disadvantages showing up. Therefore, our predicted overall menu ranking *AirPlus* > *DeskPlus* > *Air* > *Desk* revealed as being less strongly separated: *AirPlus* >= *DeskPlus* = *Air* > *Desk*.

	Physical Strain		Efficiency		Integration		Attractiveness		Ease of Use	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Desk	2.15	2	3.27	4	3.09	3	3.24	4	3.36	4
DeskPlus	2.88	**3**	2.61	3	2.22	**2**	2.18	**2**	2.24	**2**
Air	2.33	2	2.18	**2**	2.31	**2**	2.61	3	2.36	**2**
AirPlus	2.64	**3**	1.94	**2**	2.38	**2**	1.97	**2**	2.03	**2**

Table 2: After the practical part of the experiment, participants were asked to uniquely rank all menu configuration regarding the physical strain they induced, how efficient the task was solvable using them, how well the integration into the IVE was, how attractive (look & feel) they appeared and how their general ease of use was. The mean and median ranks are listed here. Highlighted are the winners w.r.t. to the median.

During the study we noticed that the individual preference of the menu configuration was very wide-spread. Even the least ranked *Desk* condition was arguably preferred by a few people. We expected the *AirPlus* condition being ranked most of the time over *Air*, but that was not the case and a few participants told us that they, on the one hand, expected and preferred the desk-aligned menus to be tangible as they were aligned with a solid desk, but on the other hand, that it felt weired to feel/touch a mid-air menu, which they expected to be *virtual* and thus not tangible. The results still make us confident that the advantages of passive haptic menus get stronger with more precise tracking. Interesting to note is that those menus are usable with this *simple* hardware setting. Nevertheless, both passive haptic menu configuration were tested under laboratory conditions and office desks are often not that clean or equipped with a wooden board. However, there are possible solutions for both, e.g., utilizing existing screens for the surface. Expected but still interesting was that, at least the *DeskPlus* condition, was able to keep up with the task-aligned conditions, even though it was not aligned with the task, as it could have a lot of advantages in different scenarios, one being always open and therefore contextually available at all times. However, the statistical analysis also revealed that the desk-aligned menus in general were stated to be less fun (L4) and participants felt less confident (L3) when using them.

7 Conclusion

In this work, we investigated the impact of passive haptic feedback and alignment (task-aligned vs. desk-aligned) of touch-based menus, given the constraints and possibilities of a seated, desk-based scenario. We found all menu configuration to be usable in general, but still found some evidence to prefer passive haptic feedback, as long as it is feasible to implement. Furthermore, we can advise to prefer passive haptic feedback, i.e., a physical desk substituted with a virtual one, when the menu is desk-aligned, even with simple finger/hand tracking. Finally, neither desk-aligned, nor task-aligned (mid-air) menus were in general able to perform superior to the other.

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