

# FeelVR: Haptic Exploration of Virtual Objects

Julian Kreimeier

Nuremberg Institute of Technology  
D-90489 Nürnberg, Germany  
julian.kreimeier@ohm-university.eu

Timo Götzelmann

Nuremberg Institute of Technology  
D-90489 Nürnberg, Germany  
timo.goetzelmann@ohm-university.eu

## ABSTRACT

The interest in virtual and augmented reality increased rapidly in the last years. Recently, haptic interaction and its applications get into focus. In this paper, we suggest the exploration of virtual objects using off-the-shelf VR game controllers. These are held like a pen with both hands and were used to palpate and identify the virtual object. Our study largely coincides with comparable previous work and shows that a ready-to-use VR system can be basically used for haptic exploration. The results indicate that virtual objects are more effectively recognized with closed eyes than with open eyes. In both cases, objects with a bigger morphological difference were identified the most frequently. The limitations due to quality and quantity of tactile feedback should be tackled in future studies that utilize currently developed wearable haptic devices and haptic rendering involving all fingers or even both hands. Thus, objects could be identifiable more intuitively and haptic feedback devices for interacting with virtual objects will be further disseminated.

## CCS CONCEPTS

• **Human-centered computing** → **Human-computer interaction (HCI)**; **User studies**; **Interaction paradigms**; **Virtual reality**; *Haptic devices*;

## KEYWORDS

Virtual Reality, haptic, exploration, user study

### ACM Reference Format:

Julian Kreimeier and Timo Götzelmann. 2018. FeelVR: Haptic Exploration of Virtual Objects. In *PETRA '18: The 11th Pervasive Technologies Related to Assistive Environments Conference, June 26–29, 2018, Corfu, Greece*. ACM, New York, NY, USA, Article X, 4 pages. <https://doi.org/10.1145/3197768.3201526>

## 1 INTRODUCTION

Virtual Reality (VR) fundamentally changed the way we interact with the computer. Instead of viewing digital content on a 2D display, one can intuitively see virtual objects and environments in 3D space. In addition, the immersion can be further enhanced by simulating haptic feedback. Thus, the user does not only see the object, but can also touch it. Hereby, one can benefit from haptic

devices, e.g., in medical applications like stroke recovery [17] or at one's workplace [4].

Due to their lack of vision, especially visually impaired people rely on haptic feedback. In general, the combination of VR and haptic feedback offers the possibility of exploring freely definable spatial information without the risk of colliding with a real object or having to be at the real location. Visually impaired people can use haptic feedback as substitution for visual information, for example, to explore 3D models of museum pieces [8], explore spatial information [13] or play games [18]. Due to the advantages in these exemplary scenarios, Virtual Reality is a promising technology to enable the visually impaired to participate in technological progress and to support them in their everyday life.

Physiologically, one must distinguish haptic from tactile feedback [6]. Haptic feedback (i.e., kinesthetic cues) utilizes the motion and positioning of hand and fingers in order to gain spatial information. Tactile feedback occurs when the human skin gets in contact with an object (i.e., cutaneous cues) and detects properties like temperature, mechanical pressure or vibration by specialized sensory receptors. Consequently, the properties of an object (like its size, shape, weight and texture) can be determined. Ideally, sighted people complementary combine this feedback with spatial vision in order to perceive objects in their environment. Unfortunately, blind people's spatial perception lacks stereoscopic vision and 3D information has to be perceived by tactile and haptic feedback. In everyday life, the human hand is a tailor-made system of many sensors and actuators for the visually impaired as well as for the sighted, which explores and identifies objects at an unsurpassed speed.

In virtual reality, however, there is no 'real' object with which the user can interact; on the contrary, the sensory information of the interaction with virtual objects must be made available to the user. There exists a multitude of approaches mimicking this interaction [1]. Current research results strived for low-cost wearable devices [5, 15] and optimized the process of rendering tactile information [16] to enable a more realistic interaction. The feeling of touching a (virtual) object can be also imitated by vibration, e.g., using a so-called vibrotactile glove [14]. Most consumer grade VR devices use vibrotactile feedback, e.g., the *HTC Vive* controllers. Since such devices are already widespread and supported by most software platforms, they represent an interesting option to make virtual objects palpable for many people.

Therefore, in this paper, we focus on how an off-the-shelf game controller performs at haptic exploration compared to previous research results. To achieve the best possible comparability, conditions similar to those of the previous studies were met. Similar to previous evaluations, we want to investigate, how quickly and correctly geometric objects can be identified. In addition, we want

---

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from [permissions@acm.org](mailto:permissions@acm.org).

*PETRA '18, June 26–29, 2018, Corfu, Greece*

© 2018 Association for Computing Machinery.

ACM ISBN 978-1-4503-6390-7/18/06...\$15.00

<https://doi.org/10.1145/3197768.3201526>

to investigate the influence of open or closed eyes on the identification time and rate, which has not yet been explicitly considered. In the following sections, we present related work on the haptic exploration of virtual objects, propose our approach based on off-the-shelf components and present our comprehensive study. Subsequently, the results are discussed in detail and main findings are presented. Finally, we propose several future developments.

## 2 RELATED WORK

The earliest results concerning haptic exploration of virtual objects were published by Colwell et al. in 1998 [2]. They conducted a study on perceiving the size of virtual objects that were basic geometric objects from 1.0-2.5 cm size. As haptic interface a 3 Degree of Freedom (DoF) Force Feedback device was used. One of their main findings was that users “...perceive the sizes of larger virtual objects more accurately than those of smaller virtual objects...” and “...may not understand complex objects from purely haptic information”. Two years later, Gunnar Jansson used simple geometric objects (virtual and real models), which subjects had to identify [7]. Thereby, the exploration of the virtual objects was performed using a 6 DoF *Phantom* haptic device, real objects were explored using one finger or the complete hand. Compared to natural interaction with the whole hand, the proportion of correct object identifications was worse with the *Phantom* device. Also, the exploration time with just one point of contact (i.e., real finger or haptic device) was distinctly higher. He also found out that larger objects (10-100 mm object size) are recognized faster and more reliably than smaller ones (5-9 mm). Though there is potential for improvement due to a learning effect, the limitation to one point of contact generally constricts the haptic perception dramatically. Kirkpatrick et al. [11] came to similar conclusions and also suggested more contact points to improve the haptic perception.

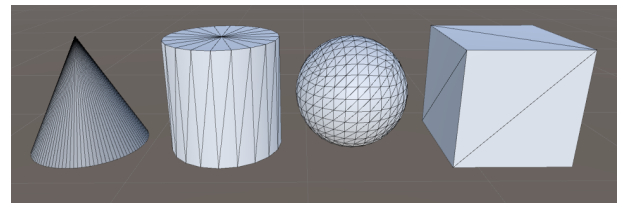
Stamm et al. [19] utilized a *Phantom* Device with more complex and randomly rotated objects in the size of 12x12x6 mm. The results mainly coincide with Jansson’s and Larsson’s experiments [9] and revealed simple, non-rotated geometric objects to be the easiest to recognize. Furthermore, Frizoli et al. [3] increased the number of contact points to three and evaluated a haptic interface that included thumb, index and middle finger, to identify basic shapes. Unfortunately, the advantage of three contact points could not be played out, the exploration times and proportion of correct answers did not improve as expected. The cause was seen in the absence of spatially distributed feedback on the fingertips, i.e., the local quality and not the sheer quantity of (tactile) feedback is crucial. Jansson and Monaci also concluded, that “...largest improvement can be expected if spatially distributed information is made available within each contact area. If that is made, an improvement of performance can be expected also with an increased number of contact areas. Increasing only the number of contact areas will not give the same result.” [10]. It has also been analyzed with real objects, that a “...loss of spatially distributed cutaneous inputs...” causes additional cognitive load and “...sequential point contact exploration imposes a heavy memory load on object processing” [12].

Lately, Jonatan Martínez Muñoz [14] proposed an optically tracked glove that holds several vibrotactile actuators and contact points.

With a sophisticated and spatially interpolated activation, users in their study identified basic geometries of 50, 100 and 250 mm size. The proportion of correct answers and exploration times was also compared to a distinctly more expensive exoskeleton (*Cyber-Grasp*) providing force feedback to each finger. Though the glove is remarkably less expensive, it performed remarkably well and brought another type of feedback to haptic exploration. However, when processing an object, vibrotactile feedback does not hinder the user from moving his hand through the virtual object, which costs additional cognitive load in contrast to force feedback.

## 3 EXPERIMENT

The main goal of our study was to evaluate the performance of an off-the-shelf VR system with regard to haptic exploration and to compare the results with similar previous studies. As in previous studies, we determined the identification time and recognition rate for each virtual object. The subjects had to identify four simple geometric objects (see Fig.1) with open and closed eyes. We suspect that objects can be recognized more quickly and reliably by the subjects with closed eyes since it is easier to concentrate on the haptic feedback with closed eyes. We also assume that objects with the greatest possible morphological difference are better distinguishable, in our study this would be the case with the cone and the cube. These are two of the four objects in our study, which are geometrically identical to the ones Jonatan Martínez Muñoz used [14]. The recognition of smaller objects was not practicable with the *HTC Vive* controllers. Our recognition rates and exploration times will presumably turn out to be somewhat worse, as the subjects in our study do not feel any spatially distributed feedback on their hands and can only use kinesthetic cues. The following sections describe the experimental environment in detail.



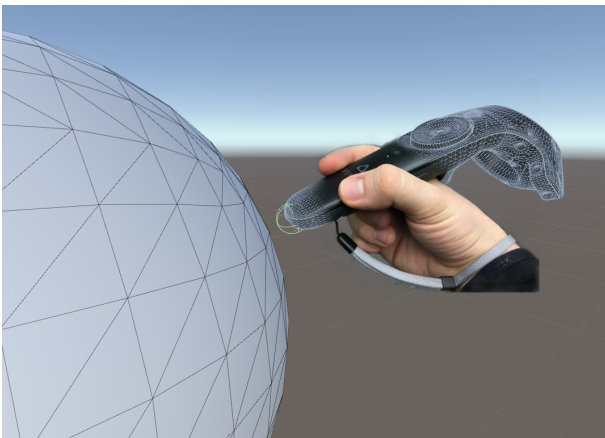
**Figure 1: The four virtual objects (cone, cylinder, sphere and cube) to be identified by the subjects.**

### 3.1 Method

The subjects had to identify a cone, a cylinder, a sphere and a cube, each with a maximum size of 25 cm. The objects were not rotated and positioned in 3D space as congruent as possible to ease the localization. 10 sighted subjects took part in our study, 8 of them were male and 2 female. The mean age was 28.8 years with a standard deviation of 5.21.

Each subject was initially introduced to the VR system and explained her or his task to identify virtual objects. Then, the four possible objects were presented on the computer screen and the investigator ensured that all objects were understood and correctly memorized. In the next step, the cube served as a test object to get to know using the controllers, and for orientation in space. After a

few minutes the user declared himself ready to start and the first randomly selected object (except for a cube) was displayed. The time measurement started at the first touch with the virtual object and ended with the statement of the subject. After notation of the subject's statement, exploration time and statement's correctness, the next (random selected) object was displayed. When the subjects explored the virtual objects, they could not see the computer screen at any time and had to rely entirely on the interaction using the controllers. Analogously, the remaining three objects were processed and the results briefly discussed. In the next run, the subjects should recognize the objects with their eyes closed, the procedure was analogous to the previous run. Finally, all results were discussed and the subject gave a concluding comment.



**Figure 2: Photomontage showing the handling of the controller in the real world combined with the representation in the virtual world.**

### 3.2 Software and Hardware

Basically, interaction with virtual objects is most intuitive when it feels like real. The human hand is unsurpassed because it combines sensory as well as actuator technology. This superb functionality can only be approximated by technical means (i.e., interacting with virtual objects). To carry out our study, we used two common *HTC Vive* controllers (see Fig.2), that were detected by the included *Lighthouse* tracking system. To process the controller's position in 3D space, the *Unity 5.4.2* platform and the *Steam VR* library were used. Also, haptic rendering and collision detection were implemented using *Unity's* off-the-shelf resources. On the tip of each controller, a collision sphere was located that triggers an event in case of colliding with the virtual object (see Fig.2). Whenever this event was detected, the vibration of the controller with maximum intensity was activated. Once the controller was detected outside the object, the vibration command was not further triggered and the vibration stopped immediately. This haptic rendering approach was developed in a preliminary study and ran without any noticeable delay.

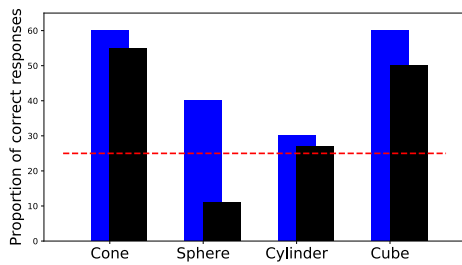
## 4 RESULTS AND DISCUSSION

As the main result of our study, Fig.3 presents the detection rate of all subjects with open and closed eyes. If all subjects had perfectly identified every object, all bars were at a level of 100%. If the subjects had randomly guessed to identify the object, all bars were homogeneous at the chance level of 25% (dashed red line). Since the latter is not the case, it can be assumed that the detection of virtual objects with the *HTC Vive* controllers has worked. With open eyes, cone and cube were identified most often correctly (55.5% and 50%, respectively). The sphere was considerably often mistaken for the cylinder. With closed eyes, cone and cube were also most frequently correctly identified (each 60%). This will presumably rely on the fact that cone and cube are the most different and can be distinguished best, because one object is pointed and round, the other flat and squared. With open eyes, the user cannot concentrate solely on haptic feedback and the similarly rounded sphere and cylinder objects could be no longer distinguished and were mixed.

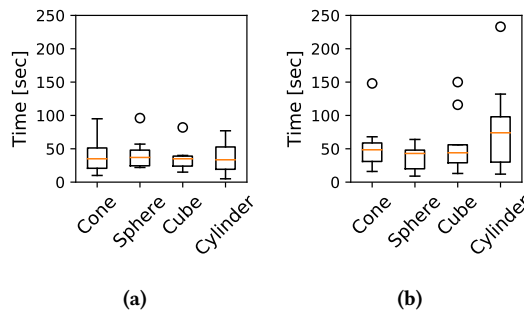
With closed eyes all objects are recognized more often, this is especially good to see the sphere, because here, the blue and black bar are clearly of different heights. In both cases, the proportion of correct cylinder identifications is slightly higher than the random level, and in sphere's case it falls even well below this level with open eyes. This low value results from the fact that the sphere was often mixed up with the cylinder. However, in both cases (i.e., open and closed eyes) cone and cube were obviously correctly identified the most frequently, as already mentioned above. Fig.4 shows box plots of exploration times for each object, with open eyes these times generally appear higher than with closed eyes. The quantity and position of outliers support this difference, too. If one looks at the exploration times of all subjects and objects and considers the variable eyes open or closed, a Wilcoxon signed-rank test with  $Z=-1.82$ ,  $p=0.034$  and an *effect size* of 0.49 confirms our initial hypothesis. These results are probably based on the fact that the subjects were able to focus better on the haptic interaction having their eyes closed, which resulted in lower exploration times.

Compared to the (blindfolded) identification performance of the same objects with a vibrotactile glove [14], our setup cannot match the objection recognition performance of the glove due to the limited quantity and quality of feedback. Especially the results of a (high end) force feedback exoskeleton cannot be reached due to the limitation of feedback in our study, which impedes the object identification. These differences are explainable due to the different systems used for haptic feedback, i.e., the *HTC Vive* controllers offered only two points of contact and had no spatial interpolated feedback across the human hand. Thus, it is more time consuming and arduous to integrate the shape of the virtual object mentally. Since some subjects reported brief dropouts during tracking or haptic feedback, this process was made even more difficult, resulting in longer exploration times and an inferior identification of the virtual object.

The percentage of correct identifications in our study is usually about 10-20% below those of the vibrotactile glove, only cone and cube were recognized with closed eyes just as well (about 60% answers were correct). In general, these two objects showed the best performance in our study and therefore came closest to their results. In their study, the recognition was optimal for the cone and the



**Figure 3: Detection rate per object with closed eyes (blue) and open eyes (black), the chance level is depicted as dashed red line.**



**Figure 4: Box plots of exploration times per object with closed (a) and open (b) eyes.**

cube and worst for the cylinder. The median values of the exploration times per object in our study are approx. 30-50 sec, which also corresponds to those of the vibrotactile glove [14]. Certainly, the statements of our study are not yet generally valid due to the small number of subjects and their individual mental processing of information, but they are largely consistent with previous studies, which makes our conclusions appear reasonable.

### 5 CONCLUSION AND FUTURE WORK

In this paper, we proposed to use an off-the-shelf VR System to provide vibrotactile feedback for the haptic exploration of virtual objects. In contrast to previous approaches, the user did not receive force or vibrotactile feedback using his hand, but vibrotactile feedback with two HTC Vive game controllers. Four basic geometric objects had to be identified by 10 subjects with open and closed eyes. The results reveal that essentially cube and cone were detected the fastest and most reliable, as they show the greatest morphological difference. The exploration times of all four objects were significantly lower, when the subjects closed their eyes, because they could thereby better concentrate on the haptic feedback. The remaining objects, i.e. the cylinder and the sphere, were less often recognized and often confused in the condition of non-closed eyes. The results largely coincide with comparable previous studies and show that a ready-to-use VR system can be used for haptic exploration. The limitations of fast and correct identification of virtual objects are most probably due to the number of contact points, local distribution and type of tactile feedback.

Future studies with more participants and objects should evaluate haptic exploration using current wearable devices and rendering while involving all fingers and both hands. Especially for visually impaired people, this technology is an exciting possibility to convey spatial information.

### REFERENCES

- [1] Carlos Bermejo and Pan Hui. 2017. A survey on haptic technologies for mobile augmented reality. *arXiv:1709.00698 [cs]* (Sept. 2017). <http://arxiv.org/abs/1709.00698> arXiv: 1709.00698.
- [2] Chetz Colwell, Helen Petrie, Diana Kornbrot, Andrew Hardwick, and Stephen Furner. 1998. Haptic Virtual Reality for Blind Computer Users. In *Proceedings of the Third International ACM Conference on Assistive Technologies (Assets '98)*. ACM, New York, NY, USA, 92–99. <https://doi.org/10.1145/274497.274515>
- [3] A. Frizoli, R. Barbagli, S.L. Wu, E. Ruffaldi, M. Bergamasco, and K. Salisbury. 2004. Evaluation of multipoint contact interfaces in haptic perception of shapes, Symposium of multipoint interaction. *IEEE ICRA 2004, proc* (2004), 177–188.
- [4] Markus Funk, Juana Heusler, Elif Akcay, Klaus Weiland, and Albrecht Schmidt. 2016. Haptic, Auditory, or Visual?: Towards Optimal Error Feedback at Manual Assembly Workplaces. In *Proceedings of the 9th ACM International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '16)*. ACM, New York, NY, USA, 43:1–43:6. <https://doi.org/10.1145/2910674.2910683>
- [5] Timo Götzelmann. 2017. A 3D Printable Hand Exoskeleton for the Haptic Exploration of Virtual 3D Scenes. In *Proceedings of the 10th International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '17)*. ACM, New York, NY, USA, 63–66. <https://doi.org/10.1145/3056540.3064950>
- [6] Christian Hatzfeld and Thorsten A. Kern. 2014. *Engineering Haptic Devices: A Beginner's Guide* (2nd ed.). Springer Publishing Company, Incorporated.
- [7] Gunnar Jansson. 2000. Basic issues concerning visually impaired people's use of haptic displays. In *International Conference on Disabilities*.
- [8] Gunnar Jansson, Massimo Bergamasco, and Antonio Frisoli. 2003. A new option for the visually impaired to experience 3D art at museums: manual exploration of virtual copies. *Visual Impairment Research* 5, 1 (Jan. 2003), 1–12. <https://doi.org/10.1076/vimr.5.1.1.15973>
- [9] Gunnar Jansson and Karin Larsson. 2002. Identification of haptic virtual objects with different degrees of complexity. In *Proceedings of Eurohaptics 2002*. Citeseer, 57–60.
- [10] Gunnar Jansson and Linda Monaci. 2006. Identification of real objects under conditions similar to those in haptic displays: providing spatially distributed information at the contact areas is more important than increasing the number of areas. *Virtual Reality* 9, 4 (April 2006), 243–249. <https://doi.org/10.1007/s10055-006-0021-y>
- [11] Arthur E. Kirkpatrick and Sarah A. Douglas. 2001. A shape recognition benchmark for evaluating usability of a haptic environment. In *Haptic Human-Computer Interaction*. Springer, Berlin, Heidelberg, 151–156. [https://link.springer.com/chapter/10.1007/3-540-44589-7\\_16](https://link.springer.com/chapter/10.1007/3-540-44589-7_16) DOI: 10.1007/3-540-44589-7\_16.
- [12] Susan J. Lederman and Roberta L. Klatzky. 2004. Haptic identification of common objects: Effects of constraining the manual exploration process. *Perception & Psychophysics* 66, 4 (May 2004), 618–628. <https://doi.org/10.3758/BF03194906>
- [13] K. Moustakas, G. Nikolakis, K. Kostopoulos, D. Tzovaras, and M. G. Strintzis. 2007. Haptic Rendering of Visual Data for the Visually Impaired. *IEEE MultiMedia* 14, 1 (Jan. 2007), 62–72. <https://doi.org/10.1109/MMUL.2007.10>
- [14] Jonatan Martínez Muñoz. 2014. *A Vibrotactile prototyping toolkit for virtual reality and videogames*. Ph.D. Dissertation. Universidad de Castilla-La Mancha.
- [15] C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, and D. Prattichizzo. 2017. Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives. *IEEE Transactions on Haptics* PP, 99 (2017), 1–1. <https://doi.org/10.1109/TOH.2017.2689006>
- [16] A. G. Perez, D. Lobo, F. Chinello, G. Cirio, M. Malvezzi, J. S. Martin, D. Prattichizzo, and M. A. Otaduy. 2017. Optimization-Based Wearable Tactile Rendering. *IEEE Transactions on Haptics* 10, 2 (April 2017), 254–264. <https://doi.org/10.1109/TOH.2016.2619708>
- [17] Norali Pernalet, Amar Raheja, and Alex Knaack. 2015. Eye-hand Coordination Assessment Method Using a Haptic Virtual Environment with a Complex Valued Neural Networks Training Algorithm. In *Proceedings of the 8th ACM International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '15)*. ACM, New York, NY, USA, 53:1–53:4. <https://doi.org/10.1145/2769493.2769591>
- [18] M. Petridou, P. Blanchfield, R. Alabadi, and T. Brailsford. 2011. User centred design and development of an educational force-feedback haptic game for blind students. In *Proceedings of the 7th European Conference on Management Leadership and Governance: ECGBL 2011*. Academic Conferences Limited, 465.
- [19] Maik Stamm, M Ercan Altinsoy, and Sebastian Merchel. 2010. Identification accuracy and efficiency of haptic virtual objects using force-feedback. In *3rd International Workshop on Perceptual Quality of Systems*. Bautzen, Germany.