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Virtual Kayaking: A study on the effect of low-cost passive haptics on the user experience while exercising

Angelos Barmpoutis[1], Randi Faris[1], Samantha Garcia[2], Jingyao Li[1], Joshua Philoctete[1], Jason Puthusseril[2], Liam Wood[2], Menghan Zhang[1]

[1] University of Florida, Digital Worlds Institute, Gainesville, Florida 32611, United States of America
[2] University of Florida, Computer and Information Science and Engineering, Gainesville, Florida 32611, United States of America
angelos@digitalworlds.ufl.edu, {randi.faris, sgarcia22, jingyaoli, josh2497, jasonputhusseril, liamwood, zhangmenghan}@ufl.edu

Abstract. This paper presents the results of a pilot study that assesses the effect of passive haptics on the user experience in virtual reality simulations of recreation and sports activities. A virtual reality kayaking environment with realistic physics simulation and water rendering was developed that allowed users to steer the kayak using natural motions. Within this environment the users experienced two different ways of paddling using: a) a pair of typical virtual reality controllers, and b) one custom-made "smart paddle" that provided the passive haptic feedback of a real paddle. The results of this pilot study indicate that the users learned faster how to steer the kayak using the paddle, which they found to be more intuitive to use and more appropriate for this application. The results also demonstrated an increase in the perceived level of enjoyment and realism of the virtual experience.

Keywords. Virtual Reality, Passive Haptics, Physical Education, Kayaking

1 Introduction

Kayaking is an outdoor activity that can be enjoyed with easy motions and with minimal skill, and can be performed on equal terms by both people who are physically able and those with disabilities [1]. For this reason, it is an ideal exercise for physical therapy and its efficacy as a rehabilitation tool has been demonstrated in several studies [1-6]. Kayaking simulations offer a minimal-risk environment, which, in addition to rehabilitation, can be used in training and recreational applications [5]. The mechanics of boat simulation in general have been well-studied and led to the design of high-fidelity simulation systems in the past decades [3,7]. These simulators immerse the users by rendering a virtual environment on a projector [1,4,6] or a computer screen that is mounted on the simulator system [2,8]. Furthermore, the users can control the simulation by imitating kayaking motions using remote controls equipped with accelerometers (such as

Wii controllers) [5] or by performing the same motions in front of a kinesthetic sensor (such as Kinect sensors) [4,6].

The recent advances in virtual reality technologies and in particular the availability of head mounted displays as self-contained low-cost consumer devices led to the development of highly immersive virtual experiences compared to the conventional virtual reality experiences with wall projectors and computer displays. Kayaking simulations have been published as commercial game titles in these virtual reality platforms [13]. However, the use of head mounted displays in intensive physical therapy exercises bears the risk of serious injuries due to the lack of user contact with the real environment. These risks could potentially be reduced if the users maintained continuous contact with the surrounding objects such as the simulator hardware, the paddle(s), and the floor of the room, with the use of passive haptics. Additionally, the overall user experience can be improved through sensory-rich interaction with the key components of the simulated environment.

This paper assesses the role of passive haptics in virtual kayaking applications. Passive haptics can be implemented in virtual reality systems by tracking objects of interest in real-time and aligning them with identically shaped virtual objects, which results in a sensory-rich experience [9,10]. This alignment between real and virtual objects allows users to hold and feel the main objects of interaction including hand-held objects, tables, walls, and various tools [11,12].

In this paper we present a novel virtual reality kayaking application with passive haptic feedback on the key objects of interaction, namely the paddle and the kayak seat. These objects are being tracked in real-time with commercially available tracking sensors that are firmly attached to them. Although the users' real-world view is occluded by the head-mounted display, the users can see the virtual representation of these objects and naturally feel, hold, and interact with them. Subsequently, the users can perform natural maneuvers during the virtual kayaking experience by interacting with our "smart" paddle using the same range of motions as in real kayaking.

The proposed system was assessed with a pilot user study (n=10) that tested the following hypotheses: a) The use of passive haptics helps users learn kayaking faster and operate the simulation better compared to the conventional controller-based interaction. b) The use of passive haptics improves the level of immersion while kayaking in virtual reality.

The study was undertaken at the Reality Lab of the Digital Worlds Institute at the University of Florida. The volunteers who participated in this experiment were randomly assigned to the study and control group and experienced the proposed virtual kayaking system with and without the use of passive haptics respectively. The data collection was performed with pre- and post-test surveys. In addition, the progress of each individual user during kayaking was recorded and the collected timestamps were analyzed.

The results from this study are presented in detail and indicate that the use of passive haptics in this application has a statistically significant impact on the user experience and affects their enjoyment, learning progress, as well as the perceived level of realism of the virtual reality simulation.

Fig. 1. The proposed "smart" paddle with the two VR controllers rigidly affixed to the two blades for 6-DOF tracking and vibration feedback when submerged in the virtual water.

Fig. 2. The experimental setup in the Reality Lab of the Digital Worlds Institute. The virtual model of the kayak is superimposed to show the alignment between the real and virtual spaces.

2 Methods

A virtual reality kayaking simulation was developed by imitating state-of-the-art kayaking simulations that are currently available in commercial virtual reality platforms [13]. The developed virtual environment featured realistic physics simulation and photorealistic water rendering with reflection, refraction, distortion and Fresnel effect. The user could steer the kayak by naturally moving a pair of typical virtual reality controllers that were visualized as two short paddles in the virtual environment (Fig. 3 top). This type of interaction was considered the baseline in our study as it represents the common way of interaction in modern virtual reality systems.

Additionally, our virtual kayaking simulation provided an alternative mode of interaction using a custom-made paddle controller. More specifically, two hand-held controllers (Oculus Rift) were rigidly attached to the blades of a real paddle as shown in Fig. 1. The placement of the controllers with the rings of LED markers around the paddle allowed continuous unobstructed 6 degree of freedom tracking. The physical paddle was aligned with a 3D model of a paddle in the virtual space (Fig. 3 bottom), so that the users could naturally hold and feel the paddle while being in the virtual environment. In both types of interaction, the controllers provided vibration cues when the corresponding virtual paddles were submerged in the virtual water.

Furthermore, in our experimental setup the chair that was used during our study sessions was aligned to the 3D model of the kayak as shown in Fig. 2. More specifically, the flat arms of the armchair were aligned to the flat sides of the 3D model of the kayak so that the users could feel the size of the virtual kayak. This way the users could intuitively control the range of their motions while paddling in virtual reality and thus avoid hitting the armchair with the physical paddle. The position and orientation of the chair was tracked in the 3D space with respect to the virtual reality headset without requiring the attachment of any additional markers to the chair because its position was fixed within the real physical space.

A virtual environment with a river was designed and made long enough to allow 8-10min of kayaking. The river was divided into 5 segments with checkpoints that were distributed along the river and served as progress indicators. Finally, the virtual environment included several other decorative as well as collectible objects that motivated the users to steer the kayak towards them in order to collect points (see Fig. 3 top). A virtual screen in the kayak displayed the time, progress/checkpoints, and score in the game as shown in Fig. 3.

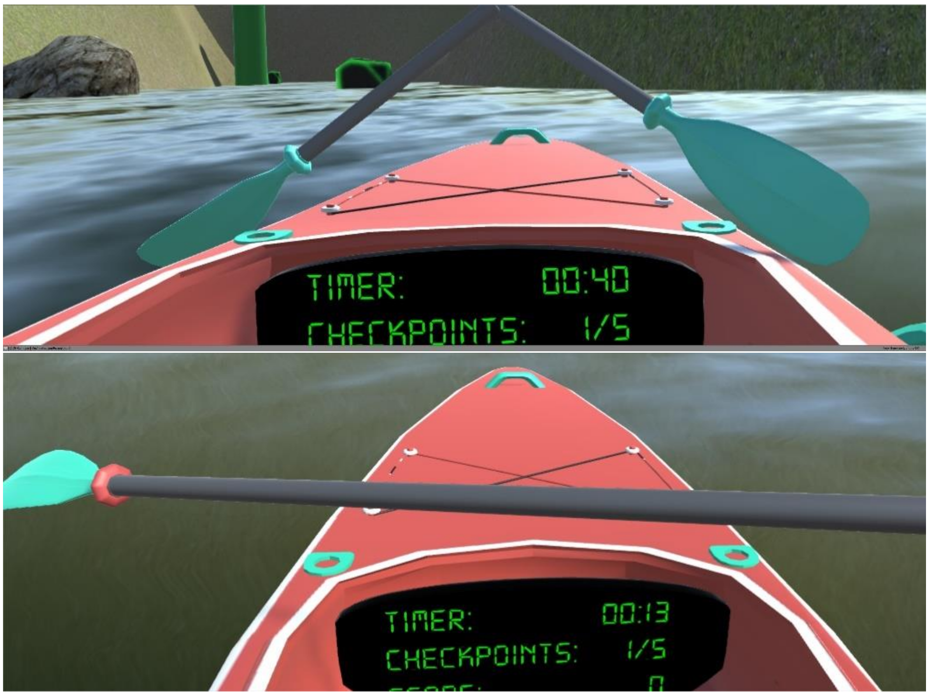

Fig. 3. Screenshots from the virtual kayaking environment that demonstrate the two cases in our A/B tests: top) two short paddles controlled with the typical VR controllers, bottom) one long paddle controlled with the paddle of Fig. 1.

3 User Study

A small-scale pilot study (n=10) was conducted at the Reality Lab of the Digital Worlds Institute in order to test the two hypotheses stated in Sec. 1 (IRB 201902921). The study was structured as a randomly ordered A/B test. The data were collected through pre- and post-test questionnaires as well as through automatically recorded time-stamps during the kayaking simulation.

The variable in the A/B test was the mode of interaction, i.e. paddling using a pair of typical virtual reality controllers versus the proposed "smart" paddle. The order was randomly assigned to the subjects in order to minimize bias. At the end of the study the users responded to questions such as "Did you find the A or the B experience more enjoyable?" by selecting one of the 5 following responses: 1) clearly A, 2) slightly A, 3) about the same, 4) slightly B, 5) clearly B. Because of the randomization of the order of the A/B tests, after the end of the study the responses were transcribed so that they all have the same A/B reference. Table 1 presents the detailed list of metrics used in the survey.

Additional demographic, kayaking-specific, and open-ended feedback questions were included in the pre- and post- test questionnaires. It is worth mentioning that 60% of the participants had real kayaking experience at least once before this study and 30% of the participants stated that they used VR often.

Metrics	Paddle %	χ^2	p
It was more appropriate for this application.	100%	20	p<.001
It was clearer on how to operate	95%	16.2	p<.001
My virtual experience felt more real	95%	16.2	p<.001
My virtual experience was more enjoyable	90%	12.8	p<.001
I learned faster how to steer the kayak	90%	12.8	p<.001
It could help me improve my skills in kayaking	75%	5	p<.05
It could help me improve my fitness	75%	5	p<.05
It was more intense experience	70%	3.2	p<.1
I felt less dizzy	70%	3.2	p<.1
It was overall easier to kayak	60%	0.8	N/S
It was more comfortable to use	55%	0.2	N/S

Table 1. The list of metrics used in our A/B test.

4 Results

Table 1 lists the percentage of responses that favored the proposed "smart" paddle interaction for each metric/question in our survey. A chi-square test of independence was performed to examine the relation between each metric in this table and the type of interaction (virtual reality controllers vs. smart paddle). The probability of each test and the corresponding χ^2 values are shown in the last two columns of Table 1.

According to the results the users found that the proposed smart paddle was more appropriate for this application (χ^2=20, p<.001), it was clearer on how to operate

(χ^2=16.2, p<.001), felt more real (χ^2=16.2, p<.001), and kayaking was more enjoyable (χ^2=12.8, p<.001) compared to the same experience with traditional VR controllers. These findings support our hypothesis that the use of passive haptics improves the level of immersion while kayaking in virtual reality.

Additionally, the results indicate that the users felt that they learned faster how to steer the kayak using the proposed paddle (χ^2=12.8, p<.001), which is in agreement with the timestamps collected during their virtual kayaking experiences. More specifically, the plot in Fig. 4 shows the progress of the subjects during their experience "A". The subjects who used the proposed paddle in their first experience finished the level in 20% less time (585 sec. vs. 760 sec.), which corresponds to an overall 30% increase in their speed compared to those who used the typical VR controllers.

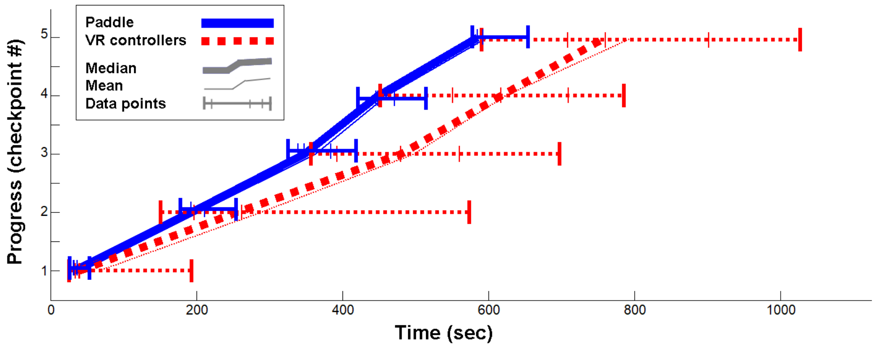

Fig. 4. The progress of the subjects in our kayaking simulation during case A of our A/B tests. The plot compares the subjects who used our paddle (solid blue line) with those who used two typical VR controllers (dashed red line).

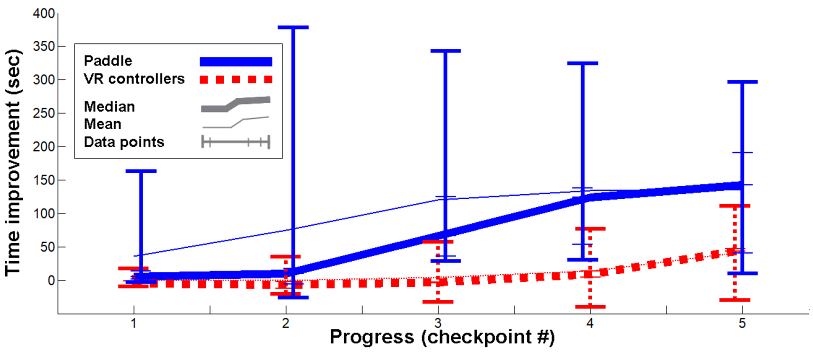

Fig. 5. The time improvement of the subjects during case B of our A/B tests with respect to their performance in A. The plot compares the subject based on the controller used in test B.

Similar observations can be made for experience "B". As expected, all users improved their performance during their second experience, which indicates that the skills acquired in our simulation are transferable between the two modes of interaction. The plot in Fig. 5 shows the time improvement from “A” to “B”. The subjects who used our proposed paddle in their second experience improved their previous performance 3 times more (315%) compared to those who used the typical VR controllers (142sec. vs. 45 sec improvement). These findings support our hypothesis that passive haptics help users learn kayaking faster and operate the simulation better compared to the conventional controller-based interaction.

There was no significant association found between the order of the experiences in the A/B tests and the responses. However there was a small inclination towards “intensity” (the first experience felt more intense, χ^2=1.90) and “dizziness” (the users felt more dizzy in the second experience, χ^2=1.90). Although these findings are not statistically significant, they may indicate that: a) the longer the users experience kayaking in VR the more probable it is to feel dizzy, and b) the user’s knowledge from the first experience influences their perception of the second experience as “less intense”.

Furthermore, as part of our pre-test questionnaire we asked the users how to paddle in order to turn the kayak to the right and we provided them with 3 possible responses: a) paddle to the left, b) paddle to the right, c) I do not know. Half of the participants did not answer correctly this question in the pre-test questionnaire. However, all of them corrected their response in the post-test survey. This indicates that our kayaking simulation teaches proper manuvering techniques through a risk-free experiential learning environment.

Finally, the users who provided feedback by responding to our open-ended question at the end of the study mentioned that the proposed paddle made the kayaking simulation “surprizingly more real than expected”, and that the use of the paddle in combination with the vibration cues created the impression of “water resistance”. One of the points of criticism was about the lack of hand tracking, which could improve the interaction with the paddle even more, according to the users.

5 Conclusions

This paper demonstrated that the use of passive haptics in virtual reality has significant effect on the user experience. A small-scale study was conducted to assess a virtual kayaking simulation with custom-made low-cost passive haptics. The results indicate that the use of passive haptics improves the level of immersion while kayaking in virtual reality and helps users learn kayaking faster and operate the simulation better compared to the conventional controller-based interaction. The results also demonstrate that the skills acquired in our kayaking simulation are transferable between the two modes of interaction and that our virtual environment teaches proper manuvering techniques through experiential learning.

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