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Floor-based Audio-Haptic Virtual Collision Responses

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Abstract

Virtual collisions are considered an important aspect of creating effective travel interactions for virtual environments; yet, they are not yet well understood. We introduce a new floor based audio-haptic interface for providing virtual collision feedback, the soundfloor. With this device, haptic feedback can be provided through the floor of a projection VR system, without disturbing the visual presentation on the same floor. As the impact of feedback is not yet known for virtual travel, we also present a series of experiments that compare different feedback methods coupled with classic collision handling methods. The results of the experiments show only limited benefits of collision handling and of additional feedback for performance. However, user preference of context appropriate feedback is evident, as well as a preference for the floor based haptic feedback. The experiments provide evidence of best practices for handling virtual travel collisions, namely that context appropriate feedback should be preferred and that quality sounds are sufficient when haptics cannot be provided.

Categories and Subject Descriptors (according to ACM CCS): COMPUTER GRAPHICS [I.3.6]: Methodology and Techniques—Interaction techniques COMPUTER GRAPHICS [I.3.7]: Three-Dimensional Graphics and Realism—Virtual reality INFORMATION INTERFACES AND PRESENTATION [H.5.2]: User Interfaces—Haptic I/O

1. Introduction

Virtual environments (VEs) are both limited by and benefit from the fact that they are not physical. While they typically represent a world that should more or less correspond to our physical world, the user's experience of them is limited to the physicality of the display technology used, often just visual. One of the classic issues of VEs is the non-physicality of the environment, in particular that objects can move through each other. In travel interactions, this means one can move through obstacles that would be impassible in the physical world. While this may occasionally be desirable, such interactions are removed from the experience of the real world.

In order to make virtual environments more tangible, we created a floor based haptic feedback device, the "soundfloor." It provides limited haptic feedback to the user through the flooring of our immersive VR installation. The haptics are driven by low frequency sounds over a series of audio-tactile transducers mounted to the underside of the floor. The soundfloor is capable of generating pulsed, vibration and impulse effects to the entire projected floor surface. In this paper, we introduce the soundfloor, which has been used in other manners [HB12], and investigate its impact on virtual collision interactions.

Although the feeling that virtual collisions for travel are needed for virtual environments to seem real is widespread among VR researchers, little has been reported on the topic. We, therefore, also address the questions of whether collision responses during virtual travel improve the interaction in immersive environments and whether, by adding collision notifications, the interaction can be further improved. In [BB10] we reported on initial findings of an experiment that explored a spectrum of feedback methods. Here, we present an analysis of that experiment and report on two new experiments that deepen the understanding of the collision feedback for travel. The second experiment focuses on the effect of feedback modality. The third experiment compares a set of feedback methods coupled with a "slide" response method, popular in games.

We introduce the soundfloor interface in the next section. We then present the design of the interaction experiments in Section 3. The results of each of the three experiments follow in Section 4. Finally we discuss the implications of the experiments before concluding the article.

2. Soundfloor

The floor of our interaction space is a specially prepared device we refer to as the "soundfloor." It is unique in several aspects of its design. The soundfloor is integrated into the the projected floor surface of an "L" shaped display. Existing haptic flooring surfaces have been tile based and not integrated into the visual portion of the VR system [TT98, VCG*08, VLI*10]. The tiles of those systems would create visual artifacts, if projected on. Our display does not cause visual artifacts, as the floor is a single contiguous material.

The soundfloor is created by attaching a number of audio-tactile transducers with good low-frequency response to the under side of the floor of our L-shape. Similar transducers were used in the tiled system of Visell et al. [VCG*08] Audio-tactile transducers generate vibrations, which they pass on to the materials with which they are firmly coupled. They are similar to speakers but the voice coil is connected to a small weight. When the voice coil is moved through audio signals, counteracting forces affect connected materials. The material's properties determine the extent of the effect and whether the vibration is audible.

The floor of the L-shape sits upon a wooden riser construction, approximately 15cm high. The projection surface is a thin acrylic surface placed on the riser. The transducers are attached directly to the flooring, which is a good resonator. Further, the transducers are positioned across the floorspace, such that users always feel the output regardless of position on the floor. In this way, all positions on the floor can be haptically driven and also spatially controlled as they can be separately addressed.

A diagram of the layout of the transducers in our setup is shown in Figure 1. The construction required extra support running though the middle, which also stops the resonance. Two transducers are needed for homogeneous perception in the central area. As a side effect we are able to mostly isolate the haptics for left and right feet, when the user is centered in the display and, therefore, straddling the support. The left and right feet could then be addressed individually if required. However, in the work presented, all transducers were driven at the same time.

In the setup used in this study, the transducers are driven as five separate channels by a spatial audio system which allows spatial panning between the transducers. The transducers of the double middle column are tided together, forming three haptic units. This means that any sound sample can be played through the floor, giving unique effects. When the transducers are driven by a single impulse bass sound, a haptic impulse is felt through the flooring by the user standing in the display. Likewise vibrating sounds led to vibrations of the floor surface in the same frequency. This simple method allows us to easily experiment with different haptic responses. However, it must be noted that although small compared to the vibrations felt, the driving sound is audible. The audio-tactile transducers in our installation had a frequency range of 20 to 80 Hertz. In the experiment, frequencies between 28Hz and and 60Hz were reproduced.

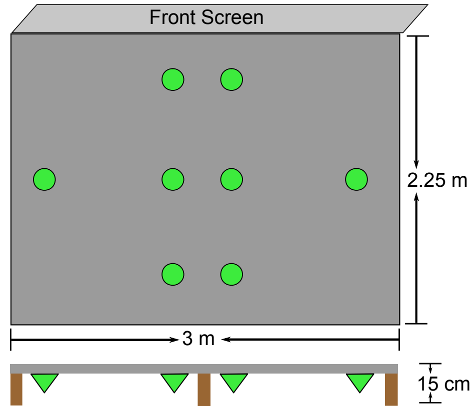

Figure 1: soundfloor installation: The layout of actuators in our "L-shape" immersive VR system.

3. Experimental Design

Our initial intention was to evaluate the utility of the soundfloor for virtual collision feedback. However, there is currently little known about the effectiveness of collision responses in general. To address this, three related experiments were performed, in which our floor based methods are compared with other forms of feedback. The experiments are designed to look at the impact of collision response method, feedback method, and modality of that feedback on interaction quality.

The first experiment broadly investigated a spectrum of possible notification methods. Early results of that initial experiment were introduced in [BB10]. A more detailed statistical analysis is provided here. The second experiment looks more closely at the impact of modality. The third experiment explores notification in the context of a "slide" method. The experiments sought to test the following hypotheses:

H 1 The addition of collision notification feedback will raise the user's awareness of collisions.

H 2 With improved feedback the user will be perform travel tasks more efficiently.

H 3 With improved feedback the user will collide less frequently in terms of: a) virtual travel collisions with the wall b) physically moving their heads through the wall.

H 4 Improved feedback can be achieved through multi-modal (auditory and/or haptic) feedback,
(*i*) where haptic+auditory > haptic > auditory > no feedback
(*ii*) and will additionally be moderated by how fitting the feedback is to the collisions.

H 5 Haptic feedback provided by the "soundfloor" will provide the best results and be preferred by the users.

Improved performance in H2, both fewer collisions and faster times, was expected based on the idea that they would collide less given feedback and is supported by prior results [JL97]. In particular, with the *stop* method all movement is arrested slowing the user. The highly related H3 is posited, because we would expect the realism of the environment to be improved though the feedback. In the ordering of feedback modalities, expected edge of haptics above audio is due to the interaction being tested, collision, which is highly associated with haptics.

The three experiments shared the same single factor, repeated measures design. The independent variable of manipulation was the collision response. Each experiment used different sets of methods and the number of methods changed per experiment (n=9, n=4, and n=6). The order in which the participants experienced the methods was counterbalanced through randomization and balanced for the initial method experienced to permit additional between subjects analysis. The same protocol was followed for each experiment. Excepting the addition of two additional demographic questions, all measures remained the same across the experiments. As the design was kept identical, direct comparison between the experiments is possible.

3.1. Collision Response & Notification

We used three basic collision handling responses, *no collision*, *stop*, and *slide* methods. In the stop response, movement is halted immediately and completely on collision. The slide response allows movement along a surface after collision, halting only the penetrating motion.

There are a potentially infinite number of possible collision notifications. Based on literature review, experimentation, and early pre-tests, we chose to test the following feedback methods with a stop response:

visual The collided object was modulated with a red color.

buzz A 1.9 second long buzzer sound was played.

thump A thump sound was played; the .3 second long sound approximated running into the wall.

rumble A rumble sound was played; the .7 second long sound approximated the vibrating of something running across the wall.

bass thump The same thump sound was played with extra low frequency support through a subwoofer; the sound level was similar to the floor thump.

floor thump A thump of the floor was performed on all transducers (same sound as thump sound).

floor rumble A rumble of the floor was performed on all transducers (same sound as rumble sound).

wand rumble The wand device rumblepack was activated for the length of colliding movement plus 0.1 second.

The *visual* and *buzz* methods are alert style messages; they were chosen to be similar to those reported in existing works [BB07, SBH07, WLIB05]. The last three methods are haptic/tactile methods. Devices with rumble packs have been used by various groups already - for example [WLIB05]. However, no one has yet reported on the effectiveness of these devices. The *floor thump* method can be imagined as the feeling that someone is hitting a wooden floor with a hammer from the other side. The *floor rumble* is similar, but with a vibrating movement. It is analog to the *wand rumble*. The audio methods, *thump* and *rumble*, were analogs of the *floor thump* and *floor rumble*. They used the exact same sounds that drove the floor and enable a controlled comparison of the haptic and audio modalities. Similarly the *bass thump* uses a deep bass sound through a subwoofer that matches the tone of the *floor thump* more closely than the *thump* sound just over the speakers.

The slide response includes multiple phases, potentially requiring new solutions. The two phases are: the moment of initial impact and when "sliding" along the contact surface with some velocity. For the impact, the thump methods from the stop response can be employed. For the sliding portion of the response, the rumble method above was used during the duration of the collision handling response. The following *slide response* feedback methods were used:

rumble A rumbling sound was played continuously during sliding contact. This sound was the same as the *rumble* feedback above.

floor rumble The rumble sound continuously drove the soundfloor during sliding contact.

floor thump A thump of the floor was performed at the first moment of impact. This sound was the same as the *floor thump* feedback above.

thump/ rumble The impact sound and rumble sounds were combined.

floor thump/ rumble The impact and rumble sounds drove the soundfloor.

3.2. Virtual Environments

The experimental scenario was in a maze setting. Nine unicursal mazes (single path, no forks) based on 6x6 cell grids were used. The traveled length of each maze was approximately 53m. The hallways were 1.5m wide. The hallways were textured as red brick walls and with a tiled floor. The walls, floor, and ceiling were all rendered using a parallax normal mapping shader. Five waypoints were added to the each maze, to increase the probability of collisions. At the end of the maze was a "portal," which transported the participant to the next maze, when collided with by physical movement. A more in depth description of the environment can be found in [BB10].

To help neutralize learning effects, an environment was introduced that allowed the user to become comfortable with the chosen travel method. A planar world was used to keep the participants naive of the collision response. The plane was covered with an animated grass and a road made of worn yellow bricks. The participants were tasked with following the "yellow brick road," providing a similar task to our experimental scenario.

3.3. Equipment & Software

The experiments were performed in our "L-shape" immersive projective display system. This was a projected display system with two co-joined surfaces (floor and a single wall) that form an 'L'. The floor projection is 3m x 2.25m, and the wall projection is 3m x 2m. The projectors are driven at a resolution of 1400x1050 in an active stereo setup. The user was tracked using a ARTrack2 optical tracking system with eight cameras from A.R.T.(http://www.ar-tracking.de/). The L-shape had a multi channel sound system for spatial sound with speakers at the four corners of the display approximately at ear height and a subwoofer. Interaction was performed with a wand, created by equipping a Wii remote with a tracking target for the ARTrack.

The virtual environments were developed using the VR Juggler libraries with OpenSceneGraph(OSG) for rendering. The interaction code was written using the ACTIF framework [HWA*08]. The maze scenery described below was generated from files generated by the Daedalus maze software (http://www.astrolog.org/labyrnth/daedalus.htm). The file format was lightly extended for our purposes. The geometry of the mazes was generated at run-time by a custom C++ loader. Several shaders written in GLSL were used.

The virtual travel method selected was a standard velocity based movement controlled by a wand. This method lends itself to the ray intersection method, as a ray can be generated based on the user's position and travel velocity. A collection of intersection rays proportional to the velocity were used to predict the collision. The rays were in the direction of travel (.66*velocity) and 45^o to either side (.5*velocity). An offset of .3m for the body was added to each ray.

3.4. Measures

The following performance measures were recorded: the completion time for reaching the end of the maze, each collision caused by the virtual travel method (*mover collision*), each time the user's head went through a wall (*head collision*), and the time of each waypoint sensor activation. A single mover collision was defined as any time the user collided with the wall until at least one frame occurred where the user was not in collision with the wall.

After each condition the participants answered a short series of questions about their experience. They were asked to rate how quickly they performed the task on a 5 point Likert scale. They were also asked how many times they collided while completing the task.

A summary questionnaire was used to ascertain user preference. The questionnaire explained that they had experienced *X* different collision methods (9, 4, and 6 respectively), which were listed by names similar to those used here. They were asked, "With which method did you come through the maze quickest?" Additionally, the participants were asked to order the methods from the one they least preferred to the one they most preferred.

Standard demographic information was collected from all participants. In the first experiment, a standard question as to the level of gaming experience, based on hours per week playing, was asked. This question elicited confusion in many participants, as they reported informally that the answer depended on when. In most cases they reported currently playing less than previously. In response, we introduced two additional questions in the following experiments. We asked the same question as above, but for "currently" and "previously" time frames. We also developed a new measure, based on the gamer types that have been developed by the International Game Developers Association SIG on casual gaming [IGD06]. They identify four gamer types: hard core, core, casual, and non gamers.

3.5. Analysis

The data analysis was performed using PASW Statistics 18. All analyses were performed at the .05 level. The performance data was analyzed using repeated measures ANOVAs. Non-parametric data, e.g. Likert scale responses, was analyzed using appropriate methods, Kruskal-Wallis for analysis of variance and Fisher Exact Text (FET) for test of fit. The FET test was used in place of χ-square, since not all cells had observations. Kendall's coefficient of concordance was used for interrater agreement of ranking data. The FET and Kendall's concordance were performed in R.

3.6. Procedure

Participants were welcomed and briefly told that they would be taking part in a Virtual Reality study using the L-shape display that was in the room. They were instructed that they could end their participation at any time without any repercussions. The were asked first to fill out the pre-questionnaires. At this point the display was started in the warm-up environment. The participants were invited into the display system and briefed on how the interaction worked. They were tasked with becoming comfortable with the virtual travel method and left to explore the grass world for as long as they liked, typically between two and five minutes.

When the participants indicated they felt comfortable with the travel method, the task was explained. This was done in the physical space of the L-shape, using printed pictures of the maze environment to explain the waypoint sensors and the end point. They were instructed to complete the maze as quickly as possible, while still triggering the waypoints. Timing was mentioned. The virtual environment was then changed to the test environment with the first test method in use. After successfully completing the maze, they filled out questionnaires in written form.

The participants were informed that a number of runs through mazes would be performed, and the use of the portal was explained. When they were prepared, they moved through the portal. The timing was started immediately. After each run, questions were aurally administered. The participant did not leave the display system.

After completion of all tests, the summary questionnaire was given. In the cases, where the participants had not experienced all methods, i.e. by not colliding with the walls, they experienced the others in a post session. If the participants expressed confusion on which methods were which, they were allowed to reenter the environment to experience the methods. The methods were activated one after another and they collided with some wall.

4. Experimental Results

4.1. Experiment I

Nine response methods were tested in this experiment. Two basic response methods without feedback were used, *no collision* and *stop* responses. Seven notification methods were coupled with the stop response. These were: *buzz, visual, thump, rumble, floor thump, floor rumble, wand rumble*. The order of treatment was randomized.

Fifteen participants, 11 male, were recruited from campus and were naive to the purpose of the experiment before participating. The mean age was 26.5 (SD 3.2). Except for one participant, all reported normal or corrected to normal vision, color vision, and stereo vision. One participant reported not having stereo vision. 60% (nine participants) reported having no experience with Virtual Environments. In equal thirds (five each), the participants reported their time spent gaming as “none,” “up to 3 hours per week,” and “3 to 14 hours per week.”

Analyses of variance showed no significant effects by response method for any measure. An analysis of the demographic data revealed no significant effects. The post experiment ratings of the fastest method, seen in Figure 2, did not

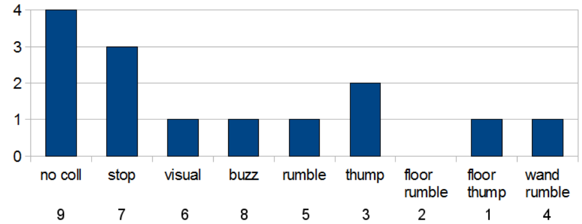

Figure 2: Experiment I: # of responses per method to: “With which method were you the fastest?” Below each method the modal rank of the post session rankings is listed.

differ significantly from a random distribution (Fisher Exact Test). However, a slight preference for the methods without feedback, *no coll* and *stop*, existed. The method selected by the participant as the one with which they were fastest coincided with the actual fastest method only twice (*thump* and *floor thump* in maze 8 & 9 respectively).

The rankings of the methods showed a clear ordering *floor thump* $>$ *floor rumble* $>$ *thump* $>$ *wand rumble* $>$ *rumble* $>$ *visual* $>$ *stop* $>$ *buzz* $>$ *no collision*. The modal rank is listed in Figure 2. Kendall’s concordance showed a medium interrater agreement on the rankings of the methods [W=.59, $p(\chi^2[8]) < .0001$].

4.2. Experiment II

The second experiment investigated the effect of the different modalities more closely, using a selection of the feedback methods, in order to see if an effect of modality did exist. Three conditions from the previous experiment were used: *stop*, *thump*, *floor thump*. Since the soundfloor based *thump sound* differed not only in terms of the haptic component, but also tonally, we added the *bass thump* condition. With this experiment we also introduced the new gaming measures; otherwise the experimental design remained the same.

Sixteen people, 4 females, participated in this experiment. They were recruited on campus and were naive to the purpose of the experiment. The mean age was 28.8 (SD 9.2). All participants reported normal or corrected to normal vision, color vision, and stereo vision. 56.25% reported currently not playing games, 12.50% less than 3 hours/week, and 31.25% played 3-14 hours per week. 12.5% reported previously playing 14+ hours/week, 37.5% played 3-14 hours per week previously and 50% reported not playing previously. The gaming self identification resulted in: 43.75% non-players, 18.75% casual, 12.50% core, and 12.50% hardcore players. 63.5% reported having VE experience.

A significant effect by method was found with an ANOVA for the “difference between number of perceived and actual mover collisions” [F(3,60)=3.50, p=.021]. Post Hoc Tukey HSD indicated that the *stop* (without feedback) method had significantly larger difference (less perceived than actual collisions) from the *bass thump* and *floor thump* methods, at the .038 and .032 levels respectively. A trend was also identified in the number of virtual collisions, but failed to reach significance [F(3,60)=2.30, p=.087]. No other effects by method were found.

Both the number of mover collisions [F(3,12)=4.69, p=.022] and head collisions [F(3,12)=5.04, p=.017] showed a significant effect by GamerType in repeated measures analyses of variance. Inspection showed that one of the two "hard-core gamers" collided very frequently. When removed as an outlier (Z=3.33 and 3.37 respectively), no significant effect by GamerType existed. No further significant effects were found and no significant effects were found by the amount of time spent gaming. An effect by VE experience on average completion time was found [F(1, 14)=6.83, p=.02]. Those with VE experience completed the mazes quicker.

The perception of which method was the fastest was not significantly different from random [P=.5932, FET]. The participants ranked the methods by preference as: *floor thump* > *bass thump* > *thump* > *stop*. Kendall's concordance showed strong inter-rater agreement on the rankings of the methods [W=063, p(χ^2[3])<.01].

4.3. Experiment III

The first two experiments were based on the *stop* response; Another basic response method can be implemented, the *slide* response. Although the method is very popular in computer games, we are aware of a single study that has looked at it and only in a desktop setting without feedback [JL97]. This experiment investigated feedback responses in relationship to the slide method.

The slide method has two components to it, the impact and sliding phases. We test a number of feedback methods, based on those previously developed. We used combinations of the thump impact and a rumble sliding effect. The methods tested are: *slide* (without additional feedback), *rumble*, *floor thump*, *floor rumble*, *floor thump/rumble*, *rumble/thump*. All sounds were played with the additional bass component. The order of treatment was randomized.

Sixteen users, 11 male, took part in this experiment. All but two were naive to the purpose of the experiment. Those two took part in Experiment II. The mean age was 27.9 (SD 4.5). All participants reported normal or corrected to normal vision, color vision, and stereo vision. 25% reported currently not playing games, 50% as <3 hours/week, 18.75% as 3-14 hour/week, and 6.25% as 14+ hour/week players. 31.25% reported playing no games previously, 12.5% as <3 hours/week, 43.75% as 3-14 hour/week, and 12.5% as 14+ hour/week. 43.75% responded differently for early verses current play time, generally playing less "currently." 25% self identified as non-gamers, 37.50% as casual, 6.25% as core, and 31.25% as hard-core games.

	Modal Rank	Mean	Std Dev
floor thump/ rumble	1	1.88	1.09
thump/rumble	1	2.94	1.73
floor rumble	3	3.38	0.89
rumble	5	3.56	1.63
floor thump	5	3.63	1.5
slide	6	5.63	0.89

Table 1: Experiment III: Statistics on the rankings given to the methods, 1 best to 6 worst.

Analyses of variance by method found no significant effects on any of the dependent variables. The number of perceived collisions was short of achieving significance [F(5,87)=2.19, p=.062]. Manual inspection showed that the *slide* (no feedback) condition had less perceived collisions than the other feedback methods. the *slide* response vs. the all feedback methods was significantly different (t-test) for the number of perceived collisions [t(91)=2.751, p=.007].

The completion time strongly correlated with both the number of head collisions and the number of waypoints triggered, [r(18)=.835, p<.001] and [r(18)=.646, p=.004] respectively. Perceived *quickness* (5 pt Likert question) correlated negatively with number of perceived *collisions* [r(93)=−.476, p<.001] and the real number of mover collisions [r(93)=−.2534, p=.017].

A significant effect by Gamer Type was found for the total number of mover collisions [F(3,10)=4.06, p=.04]. No post hoc analysis was possible, as only a single hardcore gamer was present in the data. That player also a very high number of collisions; at 136 it was the highest number recorded (mean 30, SD 40).

The selection of the fastest method did not differ from random [P=.15, FET]. However, this may be due to the small sample size, as manual inspect showed that the *slide* method was perceived as being fastest eight times. The results of the rankings of the different methods is shown in Table 1. The inter-rater agreement of rankings of the methods was only moderate [W=.43, p(χ^2[5])<0.01].

5. Discussion

H1 posited that adding collision notifications/feedback would raise the user's awareness of collisions. The results of Experiments II and III supported this hypothesis. In the *stop* condition of Experiment II, users perceived fewer collisions than in the best methods, *bass thump* and *floor thump*. In Experiment III, a t-test of no-feedback vs feedback showed significant differences, though the global ANOVA did not reach significance. It seems to follow that those methods that most closely approximate the collision do affect collision awareness. An analysis of the *stop* and *no collision* methods in Experiment I found a significant difference on t-tests for the number of head collisions [t(28)=−2.6, p=.015], where head collisions occurred less often in the *stop* condition. This is important as it shows that adding collision handling does reduce the number of times the user goes through virtual walls.

H2 hypothesized that given improved feedback users would perform the travel task more efficiently. Particularly in the stop handling based methods of Experiments I and II, where collisions slowed the participant down, we had expected better collision awareness to improve performance. This hypothesis was rejected in all three experiments. This result was surprising, as previous research in with interactions has indicated that added feedback improved performance [BPG*06, HS05, LMB*02, RCI*06].

H3 predicted that users would collide less with improved feedback. This hypothesis can also be rejected as none of the experiments showed significant differences. Even an extra analysis of global no-feedback vs feedback conditions did not expose any significant differences for number of collisions. Rejection of this hypothesis is interesting, as the prevailing belief in the community is that adding (multi-modal) feedback improves such performance factors. Also, given the strong reactions of participants to the floor based methods, we had expected them to collide much less. Some participants even avoided collisions in subsequent trials after the floor based methods. However, it seems the relative non-physicality of the feedback was not sufficient to dissuade participants from colliding, during a time based task.

H4 speculated that feedback would be improved by adding multi-modal (auditory and/or haptic) feedback. H4*i* posited an expected ordering, where haptic+auditory > haptic > auditory > no feedback. The results of our study can only partially support this. While there is no improvement to the performance based data, user preference data supports this very well. This can be seen in all three experiments. H4*ii* proposed that preference would additionally be moderated by how fitting the feedback is to the collisions. The results of experiment I indicate that this is true. Notification style feedback was, at best, rated the same as no feedback methods and the rumble methods (with stop response) were rated lower than the more appropriate thump methods. The relative rankings of experiments II and III further support this. Based on those preferences, we would suggest the use of rich audio cues that are context appropriate, when haptics are not an option.

The final hypothesis H5 was that our new haptic feedback provided by the soundfloor will provide the best results and be preferred by the users. This hypothesis is only partially supported. Only in very narrow cases, namely collision awareness, did this method give better results. Even then, the bass version of the same sound, without haptics, performed similarly. However, preference for this method was nearly universal. The users who did not place the floor based methods in the first places usually commented that it was too intense. Several users made comments like "ouch" or "I wanted to check my head to see if I had a bump." We feel the soundfloor based methods were effective and were well received by the users. However, in cases where such a floor can not be built, good sound feedback with significant bass components seems to be a viable alternative with no performance disadvantages.

We identified only a single study that looked at collision response methods for virtual travel [JL97]. Jacobson and Lewis researched the effect of *no collision, stop, and slide* response methods without any additional feedback. As their work was performed only in a desktop setting using a cursor position base movement method, it is worth comparing our results with theirs. They found significant difference in task times on an ANOVA. They did not report any post-hoc analysis. A comparison of the results of Experiments II and III were performed. No significant effects by experiment were found on any performance measures. This may be due to a number of factors. It may simply be a difference of immersive VR methods against desktop methods, or it may be due to having included a training period, which they do not mention having. It could also just be an artifact of the particular travel method we selected. This difference would be interesting to look at in more depth.

In experiments II and III we introduced two different metrics used for gaming experience. Time gaming currently and previously were highly correlated [$r(31)=.82$, $p<.001$]. The gaming type also correlated with both time gaming questions at the same level [$r(31)=.70$, $p<.001$]. Manual inspection shows high agreement at both extremes.

Using the data combined from those experiments we investigated any differences in these measures ability to detect differences. The traditional "how much time do you spend gaming" questions did not reveal any significant performance differences. However, GamerType showed effects for number of mover collisions [$F(3,26)=10.08$, $p<.001$], number of head collisions [$F(3,26)=8.24$, .001], and average completion time [$F(3,15)=4.83$, $p=.015$]. The average completion time for Experiment III was calculated for only the first four mazes to make it comparable to Experiment II. Post hoc Tukey HSD tests revealed that the Hard Core gamers had more collisions than Non Gamers, and were significantly faster than the Non Gamers. We interpret this as the effect of competitiveness differences between the groups, as the Hard Core gamers reported trying to get the "fastest" time through maze as their primary goal in questioning. The current time gaming had no significant effect on any of the measurements tested. We believe that this self report Gamer Type measure has a high potential for exposing gaming experience differences and should be further investigated.

6. Conclusion

In this paper we have introduced a new floor based interaction device, the soundfloor, and have reported on a series of experiments that investigated the effectiveness of collision response methods for virtual travel in an immersive setting. Our soundfloor audio driven haptic display is an integrated portion of our VR system. It is embedded into the floor, which is part of the visual display. It permits the addition of spatial haptics of both vibrational and impulse qualities. The haptics of the soundfloor are driven by audio-tactile transducers mounted in the floor of the system. It is a simple and cost effective addition to newly built projective VR displays which use a riser for the floor of the display. This paper presents one of various applications for the soundfloor, providing virtual collision feedback.

The study presented, composed of three experiments, focused primarily on feedback methods and their effects on participant performance and preference. Contrary to expectations and prevailing perceptions, the impact of having a collision response and extra collision notification on performance was very limited. Inclusion of a collision response only decreased the number of times the user's head penetrated walls. Adding additional notification improved participant awareness of the collisions, but had no significant effect on other performance measures.

User preference for feedback methods was generally universal. Context appropriate collision feedback, such our thump sound, was preferred over alert type notifications and non context appropriate feedback, such as typical "alert" sounds. The soundfloor delivered dull thumps and rumbles to the feet of participants in methods that were the preferred feedback methods.

Further research should be performed in a number of directions. The effectiveness of the popular slide response was called into question by this study and should be further investigated. The Gamer Type demographic metric introduced in this paper seems promising for gaining new insights into the effect of gaming on user experience and we believe it should be pursued in more depth. Various haptic mechanisms that can cover larger portions of the body have been developed in recent years, including vests with air pockets and vibrators placed over larger portions of the body. It would be interesting to see the effect of localized collision feedback on effectiveness of collision responses.

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