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Investigating the Role of Auditory Feedback in a Multimodal Biking Experience

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Abstract. In this paper, we investigate the role of auditory feedback in affecting perception of effort while biking in a virtual environment. Subjects were biking on a stationary chair bike, while exposed to 3D renditions of a recumbent bike inside a virtual environment (VE). The VE simulated a park and was created in the Unity5 engine. While biking, subjects were exposed to 9 kinds of auditory feedback (3 amplitude levels with three different filters) which were continuously triggered corresponding to pedal speed, representing the sound of the wheels and bike/chain mechanics. Subjects were asked to rate the perception of exertion using the Borg RPE scale. Results of the experiment showed that most subjects perceived a difference in mechanical resistance from the bike between conditions, but did not consciously notice the variations of the auditory feedback, although these were significantly varied. This points towards interesting perspectives for subliminal perception potential for auditory feedback for VR exercise purposes.

Keywords: auditory feedback, proprioceptive feedback, training, healthcare, virtual environment, virtual reality

1 Introduction

Auditory feedback is known to affect the perception of a multimodal experience. A classic example is the parchment skin illusion, where the interactive variation of auditory feedback affects subjects' perception of hand dryness when performing the action of rubbing hands in front of a microphone [7].

Previous research has also shown how sound, specifically music, can affect the perception of effort during exercise. In [8], using the Borg scale of perceived exertion, [2], it was shown how music versus non music affects perception of effort in aerobic training. Most of the studies present in the literature consider auditory feedback in the form of music. In this paper we are interested to investigate whether auditory feedback in the form of everyday sound effects affects perception of effort. In previous research, we showed that altering the frequency and amplitude of the friction sound produced by a pulley machine affects perception of effort [1]. The experiment was conducted placing a microphone attached to the string connected to the pulley machine, and manipulating in realtime the pulling sound while playing it back to the subjects through headphones.

In this paper we want to investigate whether perception of effort is affected by auditory feedback. Specifically, we used a virtual reality (VR) biking experience originally developed for elderly users, to motivate regular exercise [3]. Many elderly users who have very little strength, have experiencd increased motivation to keep going, or to push harder, if their exercise environment affords the motivation increase [?]. Specific for these type VR bike rides were their foundation on nature experiences, which showed to redirect attention from pain and boredom, onto experiencing something beautiful in VR instead [?]. This paper wants to keep investigating methods to further manipulate the user perception of exercise; this time how auditory feedback augmentation can possibly affect the perception of exertion.

2 Design

The system used to display the VR exercise setup had three main components; a visual display (custom-made park VE), bike interface (a consumer product chair bike and a wireless gyroscope-based microcontroller for the pedal arm), and two auditory displays (soundscape and auditory feedback from biking).

2.1 Visual display

Visuals of the park VE was a created using the Unity 5 engine. Fig. 1 shows an overview screenshot of the park VE.

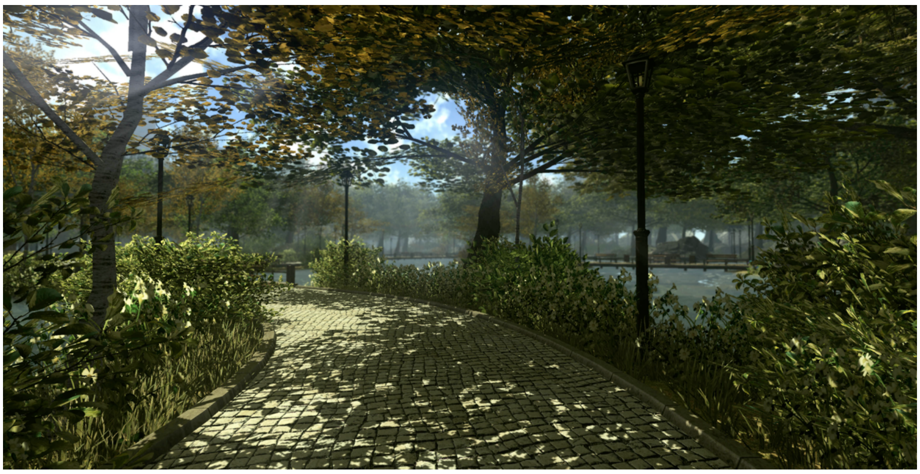

Fig. 1. The Park Virtual Environment

During active usage (biking), the user drives along a brick path, at a fixed route, through the park. No steering was needed for this experiment, as the VR camera was set to simply follow the path, using a pathfinding algorithm. The visual artistic direction of the park VE is directed toward a lush nature representation, targeting a 'restorative' experience of this type milieu [4].

Throughout any part of the VE, the path is surrounded by various types of flora (flowers, trees, rocks, a lake, waterfalls, plants), fauna (birds) and human construction (benches, small bridges, lamp posts, small fences).

To support the auditory display of biking, we wanted a visually explicit existence of a bike-type object in the VE. One concern, however, was issues developing kinematics and embodiment aspects related to the mapping the users' real world movements onto the biking and avatar behaviour in VR. Another concern was the chair bike used for the experiment; chosen for being a dominant bike-type for elderly rehabilitation, but with a specific biking-position (posture and seating position, seating height, etc.) to mimic in VR. The solution was to introduce a cabin-based recumbent bike to the VE (as seen in Fig. 2, left). A 3D model was created for Unity5, and attached to the VE camera in the park VE (as seen in Fig. 2, right). While driving the path, users would be able to see the

Fig. 2. Left: A cabin-based recumbent bike. Right: A 3D model of the bike in Unity5.

front of the cabin of the recumbent bike, as seen in Fig. 3. The visualization of the cabin would follow the path while the user would pedal, simulating recumbent bike actively steering itself along the trail.

The speed of the forward going motion for the visual display was controlled by the users' pedal action. Faster pedaling resulted in higher biking speed. The pedal speed was translated to Unity through a set of UDP and acceleration oriented scripts, controlling the VE camera forward.

Fig. 3. Left: A cabin-based recumbent bike. Right: A 3D model of the bike in Unity5.

2.2 Bike interface

The bike interface part of the setup consisted of a normal chair, a DeskCycle (a commercial chair bike), and a wireless microcontroller attached to the pedal arm of the DeskCycle. The DeskCyce features a knob on front of the pedals, which can regulate pedaling resistance (see Fig. 4).

Fig. 4. The mini stationary exercise bike used in the experiment.

Attached to one pedal is a small and compact wireless device built by our group which has been deployed successfully also in previous studies, see: [6]. The device contains an Adafruit Feather HUZZAH microcontroller board equipped with the ESP8266 WiFi chip, an ITG-3200 high precision gyroscope, and a

3.7V 1200mAh lithium polymer battery. The pedaling movement is sampled and transmitted at 20 Hertz resolution rate, which is enough to let the study participants perceive a consistent real-time synchronization between their pedaling gesture and the advancement of the VE visualization. The rotational speed of the bike pedal (radians-per-second) is sent via a WiFi UDP stream (UDP protocol is used - instead of TCP/IP - to achieve lower latency) to Unity5 and to MaxMSP, respectively for the control of visuals and sound.

2.3 Auditory feedback

The auditory feedback consisted of two different parts: the soundscape of the VE, and the the auditory feedback of the VR recumbent bike. The VE soundscape was handled by Unity5, and comprised of natural soundscape elements such as the sounds of wind, birds, waterfall, etc. and delivered through a frontal stereo loudspeaker setup (Logitech 2.1 Z623). The design of the soundscape followed the design direction found in [5].

The second audio element; the auditory feedback of the recumbent bike, was synthesized in MaxMSP according to the measured pedaling speed rate and delivered through one single Dynaudio BM5 MKIII studio monitor. Three elements took part in creating the recumbent bike sound:

- a "chassis sound": a white noise signal passed through three resonant band-pass filters (at frequencies: 220, 500 and 730 Hz, Q = 10, Gain = 1)
- a "chain sound": short bursts of white noise whose interval time and amplitude envelope was related to the pedaling speed
- one 60Hz humming sound which becomes more audible at high speed (simulating the typical bicycle hub noise) At different pedaling speed these elements are crossfaded to hear a natural transition from a predominant chassis sound at lower speeds to a predominant combination of chain and hub sound at higher speeds

3 Method

The test setup combined two computers (Dell PC and a 13" Macbook Pro), the two sound systems, the DeskCycle chair bike, the microcontroller interface and wireless router, and a Philips 55 inch LED TV. The desktop PC was running the Unity5 build, and connected to the 55" LED TV to display the Park VE. It was also connected to the Logitech 2.1 system for the Park VE soundscape. The Macbook Pro running MaxMSP was connected to the Dynaudio speaker through RCA, and to the microcontroller through the wireless router.

The experiment was performed in an office space, in a specific office with sound-isolation treatment, able to block sounds from surrounding spaces. The soundscape and the bike-specific sound outputs were fitted in the room to blend seamlessly into each other. This was done primarily through volume settings, and acoustics, according to the listener position. Speaker placement proved important for a convincing blend of the bike-specific and soundscape sound output. Ultimately, the Logitech speakers were placed next to the LED TV pointing towards the user. The Dynaudio monitor was placed on top of a cardboard box on the floor, underneath a desk, with the speaker baffle/woofers pointing upwards. The listener position was placed against the wall opposing the LED TV. The subwoofer was placed behind the furniture holding the LED TV, playing into the back of the office room.

With the chair properly placed, the sound from the Dynaudio monitor bounced off office surfaces and the back wall, to make the sound appear as if it was surrounding a seated user. This emulated very well the sensation of being very close to a sound emitting recumbent bike cabin. The final setup (here, with participant 21) can be seen in Fig. 5.

Fig. 5. Esperiment setup.

The 3 amplitude levels and 3 filters gave 9 conditions, which was repeated twice for each participant, in a randomized order. During the experiment, the Macbook Pro was used as the test conductor's user interface, to select the appropriate condition.

3.1 Participants

21 participants performed the experiment (10 female). The average age was 32 (stdev 10.3). No participants had impaired hearing. 16 had performed exercise regularly within the past 2 months, where 7 of exercise routines included biking. Other frequent routines included running (6), and fitness (6).

3.2 Procedure

The experiment procedure had participants enter the office room, and sit on the specifically placed chair. From there, they were introduced to the test procedure; how they would experience a display of a virtual environment park, and drive through it using a virtual cabin-based recumbent bike (participants were shown an image of one). Hereafter, participants were then introduced to the Deskcycle, and its resistance wheel. They were informed how they would need to perform 18 quick trials of 5 pedal pushes (2.5 rounds). After each trial, participants should stop pedaling immediately and rate their perceived exertion, using the Borg scale. All participants were presented with a printout of the Borg scale (Fig. 6) which they were always free to turn at any time during the experiment. Lastly, they were informed how the resistance wheel of the DeskCycle would be turned between each trial, and that they would not be allowed to look at- or know the resistance position. While logging demographics (gender, age, occupation), participants were also asked to report if they had performed regular exercise during the past two months, as well as which exercise type they had most often performed in their overall lifetime. After each concluded trial, the experimenter would note the participant's Borg RPE rating on a piece of paper, set the next condition using MaxMSP, and lean forward to turn the resistance wheel on the DeskCycle. The wheel would always end in the same position, but the wheel-turning was consciously exaggerated in terms of back and forth turning, so that participants would not be able to hear where it ended. During trials, volunteer responses from participants were noted by the experimenter, for instance if they stated that they believed the mechanical resistance had changed, or if they indicated notice to the auditory feedback changing. Comments or statements about the experience post-trial were also noted to the extent possible.

Borg	Rating Perceived Exertion Scale
0	Nothing at all
0.5	Very, very weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	-
7	Very Strong
8	-
9	-
10	Maximal

Fig. 6. The Borg scale print-out given to participants during the experiment

4 Results

When analyzed the reported Borg scale, no significant difference could be measured among the conditions. Figure 7 shows the mean (circle) and standard deviation for all participants for the different conditions. As can be seen in Figure 7, the differences among conditions are minimal, and the standard deviation is consistent. Between participants, the Borg scale was used quite differently, despite the chair bike resistance being equal in every session. Perceptions of how exerted they were, were quite different, with some participants stating that there was almost no resistance, and others perceiving the resistance to be heavy.

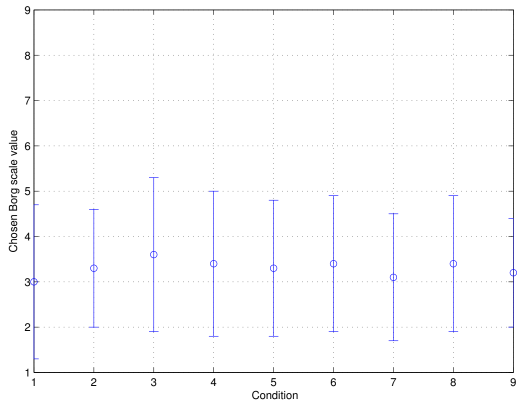

Fig. 7. Results from the experiment: the horizontal axes represent the condition, while vertical axes the value chosen in the Borg scale.

The qualitative responses gave interesting insights to participants rating tendencies. Qualitative responses from participants, both during and after the experiment were voluntary. But anything stated was noted by the experimenter, both during and after the participant session.

Using basic coding, responses were categorized related to participants statements on the audio feedback, perceived exertion change, whether they believed it to be resistance changing, or whether they perceived a big exertion change. 15 participants hinted to a belief in mechanical change on the bike, during the experiment. Of these, 7 suggested small changes, 6 suggested medium changes, and 2 felt a large variation. Participant statements also suggested that at least 14 participants did not notice sound changes at all, where 3 participants reported to have indeed noticed changes in audio. The last 4 participants remained unclear in this regard. Meanwhile none of the participants linked the audio to the sensations of exertion change during the experiment.

The most frequently mentioned aspects to the experiment from participants were a) how the differences were too small for ratings to differ more than one or two steps on the scale *"Hard to tell the difference, but the last ones were clearly geared higher than the previous"*; b) how 5 pedal pushes (2.5 full pedal rounds) were too short a while to manage to get a sense of the resistance properly (more time pedaling would produce more accurate results, according to these participants); and c) how some participants afterwards reported that they simply chose their ratings in small increments up or down, more so than really looking at their Borg RPE scale printout for the rating most representative of their perceived exertion: *"Hard to feel. I was measuring the resistance based on the previously given rating, perhaps more than the scale. The differences always came in small increments, up and down. Never in 'jumps"*.

Also interesting were the participants who found the resistance to have changed noticeably, based on their perceived exertion during trials; *"Felt like it went down hill sometimes. Sometimes visually too. Made pedaling easier."*, indicating how they sometimes felt that the perceived exertion change transposed itself onto the perception of other aspects of the biking experience, despite the participant well knowing that e.g. the visual change did not in fact happen. A follow-up question from the experimenter confirmed that participant did not notice the change in auditory feedback. One participant noticed that the sound changed, but had the experience that the sound feedback was faulty, as (paraphrasing) *"the audio did not at all correspond to the changes in resistance from the pedals"*. This indicates that while this specific participant noticed the auditory feedback, consciously interpreted it, and still thought a mechanical resistance was in fact changing.

After the experiment was completed, out of curiosity from the experimenter, the three subjects who noticed sound change were asked to listen to it again while bikiing, and give their interpretation of the audio effect, in relation to the perception of exertion. One participant commented that the high pass sound felt 'rusty' and made the bike feel as if resistance was higher. The low-passed condition was considered 'smooth', and thus signaling less resistance. Another participant highlighed how low pass filtering indicated low speed, whereas the amplitude represented friction.

5 Discussion

Results of the experiment showed that most subjects perceived a difference in mechanical resistance from the bike between conditions, but did not notice the variations of the auditory feedback, although these were significantly varied. And that most of those who noticed the variance, did not manage to understand its purpose in the experiment design.

This might be due to several factors. First of all the experience of the visual feedback might have been dominant, preventing subjects to focus on the auditory feedback. Moreover the variations in auditory feedback might have been too subtle in order to be perceived as significant. Looking a bit into the details; seeing as only a few participants noticed sounds to change, but must have noticed the biking sounds due to their sheer volume from the setup, the audio must have been perceived as simply a natural part of the biking experience/display. This credits the sound design of the bike feedback.

However, it does pose questions about a) the dampened role and perception of audio under heavy visual circumstances, or b) how sound experiments should be designed to both disguise its purpose, but still be sufficiently obvious to make a measurable difference. Investigations into prior work on these questions could direct the coming experiments. There is no doubt that seeing a participant majority rate their perception of exertion to change is interesting - but also useless unless we become more informed on the rationale behind it.

Parts of the experiment design that could have hindered the consistency of the results are the soundscape from the VE, the inconsistency in the route through the park between participants, the fake position change of the resistance wheel on the DeskCycle between trials, the free interpretation of the Borg scale between participants, the relative strength difference between participants (which there inevitably was), and the length of each trial with only 5 pedaling pushes for each trial.

The VE soundscape had its specific traits depending on where in the VE a user ventures. Some spots include lots of sounds from various birds, and a few spots include waterfalls. There is a risk that certain participants' perception of the biking sounds, could be cluttered from certain types of noises throughout the VE. For future studies, a more consistent soundscape should be prioritized.

A different VE design should also be considered for a future experiment. The park VE contains some sharp corners. The visual speed is very different in sharp corners, compared to going straight ahead. This is because the forward speed inside the VE is lowered in sharp corners, to ensure smooth turns and pleasant direction transitions. If the participant is placed next to a corner before commencing a given trial, and has 5 pedal pushes to get around the corner, the turn itself is the only motion gained, which becomes too different from a straight ahead experience to be categorized as mutually consistant. Therefore, a VE with consistant speeds in which ever position should be a priority.

Another potentially most influential factors in the experiment could be the turning of the resistance wheel. During the experiment, it acted both as a rhythm breaker between trials, but also as a 'suggestive black box', which constantly reminded participants of the possibility of resistance changing.

Participants' autonomous interpretation of exertion should also be controlled (or guided) more, given a follow-up study. Participants' interpretation of the scale varied a lot. Examples of how well-known physical activities would reflect a given rating could make the scale less abstract.

The strength between individual participants could have made a difference. Meanwhile, it is not obvious to these authors how to overcome that type of unknown variable.

The pedaling length of each trial could be extremely interesting to change for a future experiment. Many participants mentioned the 5 pedal pushes as a problem with the current method. The rationale from the experiment design was to avoid giving them too long to adjust to the resistance, between trials. Meanwhile, this rather poorly reflects an exercise run, so extending the trials could be both interesting and more validating of the concept, should it keep providing perceived differences with participants.

6 Conclusion

In this paper we presented an experiment whose goal is to investigate the role of interactive auditory feedback in affecting perception of effort during a biking experience in VR. Subjects were asked to bike in a simulated park, while exposed to varying auditory feedback where the frequency content and amplitude was varied. Quantitative results measure using the Borg scale showed that the perception of effort did not significantly increase when varying the auditory feedback. However, subjects reported a perceived change in mechanical resistance from the bike. These results provided some insights into the potential of interactive auditory feedback in exercise. Further investigations are needed in order to better understand if sound can significantly affect perception of effort.

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