Evaluating Auditory and Tactile Cues for Eyes-Free Exercise

ABSTRACT

Exergames have become pervasive thanks to enabling technologies such as the Microsoft Kinect and the Nintendo Wii. Similarly, exergaming is a popular topic in HCI research. Many primary cues, or cues necessary to play exergames, are visual. This may cause several issues such as degradation of experience and inaccessibility. This problem has led to eyes-free exergame development and the study of alternative modalities of cues, including audio and tactile. While there are examples of eyes-free output in exergames, there is no formal evaluation comparing different types of cues. In this paper, we describe an experiment where 16 participants completed jumping jacks and bicep curls with 1lb weights given four types of cues: counting *Voice*, notes increasing in *Pitch*, notes increasing in *Volume*, and vibrating *Tactile*. We found participants ranked *Voice* as highest for both exercises because it had the highest information entropy. Participants felt that *Tactile* was useful during bicep curls because it targeted the exercised muscles.

Author Keywords

Video games; exergames; eyes-free; audio cues; tactile cues; exercise.

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces.

INTRODUCTION

Exergames, or exercise games, have become pervasive with enabling technologies such as the Microsoft Kinect, Nintendo Wii, and games that have gained a large following like Dance Dance Revolution and Wii Fit. While exergames employ visual, audio, and tactile cues, many of the cues necessary to play a game, such as aligning one's body to an on-screen figure, are visual [6]. This can be an issue with current exergames, as visual cues can decrease the quality of an exercise [1], be inaccessible to the visually impaired [6], and not be useful when doing exercises that require facing away from the screen.

To address this issue, researchers have developed exergames with eyes-free cues or explored novel audio or tactile modalities. For instance, several exergames have been developed with eyes-free feedback for people who are blind or low-vision using Nintendo's Wii (e.g. [6]) or the Microsoft Kinect [8]. In addition, haptic cues have been explored in exergames as a means of leveling players of different abilities [10] and to help coach in snowboarding [9] or hand rehabilitation [7]. These solutions improved reaction time to feedback and gameplay experience.

While we see examples of eyes-free cues in exergames, there has not yet been a formal evaluation comparing different types of cues. However, different modalities of cues and feedback have been explored in CHI and UIST. For example, Hoggan et al. explored when audio and tactile feedback would be best suited for mobile devices [4], while Wall et al. explored the use of both modalities in the navigation of audio graphs [11]. Additionally, a comparison of visual and auditory feedback was explored in the domain of water conservation at the sink [1]. We present an experiment investigating the use of cues in eyes-free exercise to see how well users pace themselves during jumping jacks and bicep curls with 1lb weights given four types of cues: counting *Voice*, notes increasing in *Pitch*, notes increasing in *Volume*, and vibrating *Tactile*. We chose two familiar exercises to ensure that the type of cue was what influenced each person's pace and not their abilities. Each participant's pace and qualitative cues was recorded to help determine tradeoffs between the four techniques.

EXPERIMENT

The experiment was designed to determine how well participants paced themselves in jumping jacks (1 per second) and bicep curls with 1 lb weights (1 per 2 seconds) given audio and tactile cues. We chose these exercises because they were familiar, and they explored different types of exercise: aerobic and strength. In a user study, we obtained the pace in which participants completed 10 jumping jacks and 10 bicep curls with 1lb weights under four conditions: counting *Voice*, notes increasing in *Pitch*, notes increasing in *Volume*, and vibrating *Tactile* using an arm band.

Apparatus

Participants completed the exercises in front of a Microsoft Kinect. The program, implemented in C#, played each cue and recorded the highest and lowest point of their wrists while completing each jumping jack and bicep curl to the hundredth of a second.

Participants

We recruited 16 participants who completed lab study. There were 7 females and 9 males. Their average age was 25.5 with a range of 22-32 years (median = 28). All but 1 participant had current exercise experience including strength and flexibility exercises (13), aerobics (13), and team sports (4). The majority of participants (11) had experience playing exergames including sport games (9), dance games (7), and adventure games (2). Five participants had no experience because they did not like video games (2), were too busy, would rather be active outside, or no reason.

Jumping Jacks

Cues were given once per second with the intention to pace the exercise at one jumping jack per second[1].

1. *Voice* – Participants heard "start", followed by "one" through "ten".
2. *Pitch* – Participants heard piano notes in sequence: A, B, middle C, D, E, F, G, A, B, high C. Pitch A cued the participants to begin.
3. *Volume* – Participants heard middle C played progressively louder in volume. The first note cued the participant to begin.
4. *Tactile* – Participants wore an armband with a Samsung Galaxy S4. The phone would vibrate 500ms on, 500ms off eleven times. The first vibration cued the participant to begin.

Bicep Curls

Cues were given once per second, to cue the raising and lowering of the arms. The goal was to complete one full bicep curl every 2 seconds.

1. *Voice* – Participants heard "up" … "one" … "up" … "two", through "up" … "ten".
2. *Pitch* – Participants heard piano notes in sequence: E, F, G, A, B, low C, D, E, F, G, A, B, middle C, D, E, F, G, A, B, high C.
3. *Volume* – Participants heard middle C played progressively louder in volume. The note repeated 20 times. The first note cued the participant to begin.
4. *Tactile* – Participants wore an armband with a Samsung Galaxy S4, and felt vibrations 1 second on to cue raising the arms, followed by 1 second off to cue lowering the arms. This repeated 10 times.

[1] This is considered a brisk pace in: http://www.livestrong.com/article/433330-how-many-jumping-jacks-do-you-have-to-do-daily-to-lose-weight/

Procedure

We asked participants interview questions about their background with exercise and exergames. Participants completed 4x10 jumping jacks and 4x10 bicep curls with 1lb weights. After each exercise, participants ranked the cues and explained their rationale. The session lasted 1 hour, and they were compensated with a $10 Amazon gift card. We randomized the order of cues for each participant using a 4x4 Latin Square. For each participant, the order of cues given for jumping jacks and bicep curls was consistent.

Results

Below we present the results for participants' ability to pace themselves and their rank of the four cues for jumping jacks and bicep curls.

Jumping Jacks – Pacing at 1 per second

All 16 participants were able to pace themselves while completing jumping jacks during the *Voice*, *Pitch*, and *Volume* conditions. When taking an average of the median jumping jack interval time for each participant, the times were reported as .953 seconds, .967 seconds, and .964 seconds respectively. Because the median interval times were within .05 seconds of the goal pace, these three techniques were effective at pacing the participants. Pairwise comparison using the Wilcoxon Rank Sum report differences that are not statistically significant (see Table 3). In addition, both the median and Inter Quartile Range (IQR) of all four methods had differences that were not statistically significant using the Friedman Rank Sum test (median: χ^2 = 4.1373, df = 3, p = 0.25; IQR: χ^2 = 1.5478, df = 3, p = 0.67). This means that participants were consistent with their jumping jack pace regardless of cues.

The least effective cue was *Tactile*, with 3 of 16 participants only completing 6 jumping jacks in the 10-second timeframe. These participants were unable to feel the vibrations while moving: *I couldn't really feel this, and it might be because I was moving* (p11), and: *The vibration was kind of hard to feel. I thought I only felt 6.* (p16). These participants would therefore wait between jumping jacks to feel a vibration before continuing to the next one. The average of median times for each participant was 1.17 seconds, and there was a difference between *Voice* that was statistically significant (see Table 1). The average median time for participants able to feel the vibrations was 0.98 seconds, while three participants had an average median of 2.00 seconds.

Jumping Jacks – Preferred Cues

Participants had varied sentiments toward each cue, but there was a clear rank: 1st – *Voice*, 2nd – *Pitch*, 3rd – *Volume*, and 4th – *Tactile* (see Figure 1). To avoid biasing a participant's ranking, the researcher explained the four types of cues in the same order in which the participant experienced them. The pairwise differences in rank using Wilcoxon Rank Sum are in Table 1, where the difference in ranking between *Voice* and the other three types of cues was statistically significant.

Comparison	Median Time		Ranking	
	W	p	W	p
Voice vs. *Pitch*	104	0.38	**78.5**	**0.05**
Voice vs. *Volume*	102	0.33	**68.5**	**0.02**
Voice vs. *Tactile*	**72.5**	**0.04**	**50.5**	**<0.01**
Pitch vs. *Volume*	125.5	0.94	115	0.62
Pitch vs. *Tactile*	86	0.12	**74.5**	**0.04**
Volume vs. *Tactile*	85.5	0.11	93.5	0.18

Table 1. Pairwise comparisons of median jumping jack revolution time and ranking using Wilcoxon Rank Sum.

Voice ranked the highest among participants (see Figure 1) because it felt natural: *I am used to that. It is how I would normally do it, and so I kind of expected - I know how long it would be between them* (p2), and: *It automatically tracks that [counting] for you and reminds me of when I was doing martial arts so it has that element* (p3). In addition, *Voice* provided an extra piece of information the others could not provide – counting: *It was easy. It counts and you can just follow along without any problems* (p13), and: *It just made me feel easier to keep track of* (p15).

Pitch had mixed results. They were musical, but not as informative as *Voice*. Participants favored *Pitch* because it pertained to music: *I'm a musician; it's meaningful* (p1), and: *I like the idea of communicating in pitch* (p6). *Pitch* was able to convey progress: *They changed the note it was higher so I know it was going to the end* (p13). On the other hand, participants were not always keen on notes increasing in pitch: *The notes were super annoying because it's getting higher and higher and higher* (p12). In addition, *Pitch* sometimes did not communicate enough information: *I didn't have a sense of how far along I was at each point in time* (p3), or it communicated extraneous information: *When they [notes] went up I don't know why I guess maybe are you supposed to be increasing intensity?* (p9).

Volume also had a mix of positive and negative sentiment. Participants favored this technique due to its consistency: *I think what worked best was increasing in volume note because it was very regular* (p7), and: *I felt like it was more of a constant beat* (p10). However, *Volume* was not always viewed as useful: *It doesn't sound like a useful thing, it's the same note over and ove*r (p6), possibly because it doesn't convey a sense or progress: *I would hear a note and I wouldn't be counting in my head already* (p16). The change in *Volume* was not immediately perceivable by participants: *I couldn't tell the difference in volume for the first several* (p4), so this may have affected their sentiment.

Finally, *Tactile* was ranked last, because participants had a difficult time feeling the vibrations when their arms were moving quickly: *I liked the vibration the least because it was actually pretty hard to detect when I was moving* (p2), and: *I don't think it was a strong enough feeling so for that reason I didn't like it too much* (p3). Interestingly enough, three participants ranked *Tactile* as their first choice, notably because they felt it was tied to their body: *It was tied to my body, I could feel it* (p5), and: *Tactile feedback was directly tied to the activity I was doing, so as I was moving my arm I could feel the vibration so I knew whether I was on track* (p14). Finally, p4 liked the fact that *Tactile* was more discrete: *It was the least distracting*.

Comparison	Median Time		Ranking	
	W	p	W	p
Voice vs. *Pitch*	154	0.34	**31**	**<0.001**
Voice vs. *Volume*	107.5	0.45	**23**	**<0.001**
Voice vs. *Tactile*	129.5	0.97	**65**	**<0.01**
Pitch* vs. *Volume	**75**	**0.05**	95	0.20
Pitch vs. *Tactile*	111	0.53	166	0.14
Volume vs. *Tactile*	144.5	0.55	**189**	**0.02**

Table 2. Pairwise comparisons of median bicep curl revolution time and ranking using Wilcoxon Rank Sum.

Bicep Curls – Pacing at 1 per 2 seconds

All 16 participants were able to pace themselves while completing jumping jacks during the four conditions: *Voice*, *Pitch*, *Volume*, and *Tactile* conditions. When taking an average of the median bicep curl interval time for each participant, the times were reported as 1.990 seconds, 1.969 seconds, 1.999 seconds, and 1.981 seconds respectively. The Friedman Rank Sum Test reported that the difference in median and IQR were not statistically significant between the methods (median: $\chi^2 = 3.5419$, df = 3, p = 0.32; IQR: $\chi^2 = 0.9114$, df = 3, p = 0.82). Only one pairwise comparison using the Wilcoxon Rank Sum test between *Volume* (slowest) and *Pitch* (quickest) reported a difference in median pace that was statistically significant (W = 75, p = 0.05) (see Table 2). Otherwise, participants were successful at holding the desired pace of one bicep curl every 2 seconds.

Bicep Curls – Preferred Cues

Overall, participants gave similar rankings to jumping jacks with one notable exception: *Tactile* was rated much higher: 1st – *Voice*, 2nd – *Tactile*, 3rd – *Pitch*, and 4th – *Volume* (see Figure 1). The pairwise differences in rank using Wilcoxon Rank Sum are in Table 2, where the difference in ranking between *Voice* and the other three types of cues was statistically significant.

Voice was ranked first for similar reasons to jumping jacks above: hearing the progress or count: *I like having the extra information with the numbers* (p2) and: *I imagine when I'm*

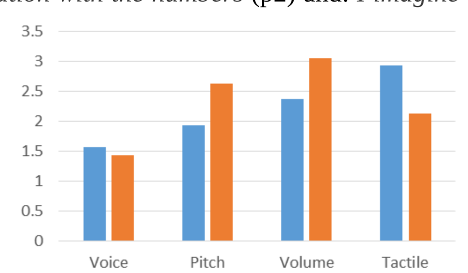

Figure 1. Average ranking for jumping jacks (left) and bicep curls (right) for each type of cue. Participants could call ties.

doing bicep curls, I will be counting through the numbers (p15). Participants liked *Voice* for new reasons, such as being an encouraging personal trainer: *I liked the voice best because it was encouraging* (p9), and: *I kind of like hearing a human voice it's like having a personal trainer* (p10).

Participants ranked *Tactile* higher than in jumping jacks because it was easier to feel the vibrations and it felt tied to their exercise. For example, participants felt it was attached to their body in an intuitive manner: *It was attached to the part of the body I was working out* (p1), and: *It was tied to my hand, I was exercising my hand* (p5). However, *Tactile* still had mixed reviews, because: *the vibration was really slight* (p9), and: *I felt like I needed to focus a lot on the vibration* (p10). While a slight vibration may be less obvious, it can also be a positive factor: *If you are listening to music you can still use that tactile cue* (p15).

Overall, participants ranked *Pitch* lower than in jumping jacks. Unlike before, the first note played was at a lower frequency, which was not preferred: *the lower notes are going to sound longer and it makes it hard to pick out the rhythm* (p7). It also may be difficult to maintain their progress: *I didn't know where that was ending* (p11) and: *I couldn't tell where I was* (p4). Finally, hearing several notes in a row may not be as pleasant: *It's going to get annoying because it goes up and up* (p3).

Like *Pitch*, participants ranked *Volume* lower than in jumping jacks. Twice as many notes were played, which made the sound less enjoyable: *It was monotonous* (p9), and: *It was a little bit annoying because it was monotonous* (p4). It also felt difficult to follow: *I had to be concentrating on the sound* (p5). This impacted P13's ability to pace: *At points I just kind of froze… 'Oh wait I gotta keep going'*.

DISCUSSION & CONCLUSION

While a majority of participants were able to follow the *Tactile* cues while performing jumping jacks, three experienced difficulty and only completed 6 of the 10 in the same time. In addition, two of the participants mentioned mechanisms that enabled them to pace differently than intended: *I didn't feel anything afterwards so I was doing random things at whatever pace* (p10), and: *The vibration I could barely feel. I initially felt it because I was standing still. I couldn't feel it, but I could hear it. Hearing it was confirmation that I was feeling it* (p9). This suggests that *Tactile* cues should be used with caution while completing faster paced physical activity. With a slower paced activity, such as bicep curls, there is potential: *Tactile could be good for exercises where you are holding something stationary* (p6).

It was also better to include more relevant information encoded in the cues. Overall, *Voice* was ranked first due to the extra information it provided with the count. Regardless of the cues presented for exercises with pace, providing progress will improve the experience. *Tactile* cues were ranked higher in bicep curls than in jumping jacks because it was tied to the part of the body in which they were exercising. Designers may be able to utilize musical cues by providing the finish tone initially or providing chords. Tactile cues could change in intensity or rhythm to convey progress. In addition, conveying multiple types of cues simultaneously is beneficial, to encode more information.

While we made informed decisions in our study design, there were limitations to our study. Initially, we had included a task where people received feedback to correct a yoga exercise. They heard *Voice* commands, followed by notes changing in *Pitch*, *Volume*, frequency, and vibrating *Tactile*. After a few participants, we realized that the corrections were not well-suited to be combined with other modalities, so we dropped it from the study. Future work would include investigating other types of feedback beyond pacing such as correctness or game status including score and rank in multiplayer games. Another interesting area to explore may involve combining modalities.

REFERENCES

1. Arroyo, E., Bonanni, L., Selker, T. Waterbot: exploring feedback and persuasive techniques at the sink. *CHI 2005*, ACM Press (2005), 631-639.
2. Doyle, J., Kelly, D., and Caulfield, B. Design considerations in therapeutic exergaming. *Pervasive Health 2011*, IEEE (2011), 389-393.
3. de Oliveira, R., and Nuria, O. TripleBeat: enhancing exercise performance with persuasion. *MobileHCI 2008*, ACM Press (2008), 255-264.
4. Hoggan, E., Crossan, A., Brewster, S.A., and Kaaresoja, T. Audio or tactile feedback: which modality when? *CHI 2009*, ACM Press (2008), 2253-2256.
5. Lanningham-Foster, L., et al. Energy Expenditure of Sedentary Screen Time Compared With Active Screen Time for Children. *Pediatrics 118*, 6 (2006), 1831-1835.
6. Morelli, T., Foley, J., Columna, L., Lieberman, L., Folmer, E. VI-Tennis: a Vibrotactile/Audio Exergame for Players who are Visually Impaired. *FDG 2010*, ACM Press (2010), 147-154.
7. Popescu, V.G., et al. A virtual-reality-based telerehabilitation system with force feedback. *IEEE Transactions on Biomedicine 4*, 1 (2000), 45-41.
8. Rector, K., Bennett, C.L., and Kientz, J.A. Eyes-Free Yoga: An Exergame Using Depth Cameras for Blind & Low Vision Exercise. In *Proc. ASSETS 2013*, ACM Press (2013), 12:1-12:8.
9. Spelmezan, D., Jacobs, M., Hilgers, A., and Borchers, J. Tactile motion instructions for physical activities. *CHI 2009*, ACM Press (2009), 2243-2252.
10. Stach, T., Graham, T.C.N. Exploring haptic feedback in exergames. *INTERACT 2011*, Sprinter (2011), 18-35.
11. Wall, S., and Brewster, S. Feeling what you hear: tactile feedback for navigation of audio graphs. *CHI 2006*, ACM Press (2006), 1123-1132.