Evaluating Auditory and Tactile Cues for Eyes-Free Exercise

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ABSTRACT
Exergames have become pervasive thanks to enabling technologies such as the Microsoft Kinect and 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 spawned 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. We present 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 that 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 Dance Dance Revolution. 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 [5]. 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 [5], and not be useful when facing away from the screen.

To address this issue, researchers have developed exergames with eyes-free cues, or by exploring 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. [5]), or the Microsoft Kinect [7]. In addition, haptic cues has been explored in exergames as a means of leveling players of different abilities [9], and to help coach in snowboarding [8] or hand rehabilitation [6]. TripleBeat created a virtual competition amongst runners, where the winner is determined by how well each runner achieved their goal [2], thus creating an even competition. These solutions improved reaction time to feedback and gameplay experience.

While we see examples of eyes-free cues in exergames, there is no formal evaluation comparing different types of cues. 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 1 lb 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 a person's pace was most likely influenced by the type of cues, 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. In a user study, we obtained the pace in which participants completed 10 jumping jacks, and 10 bicep curls with 1 lb 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.

p1 p5 p9 p13	*Voice*	*Pitch*	*Volume*	*Tactile*
p2 p6 p10 p14	*Pitch*	*Volume*	*Tactile*	*Voice*
p3 p7 p11 p15	*Volume*	*Tactile*	*Voice*	*Pitch*
p4 p8 p12 p16	*Tactile*	*Voice*	*Pitch*	*Volume*

Table 1. Order of cues presented for jumping jacks and bicep curls.

Participants

We recruited 16 participants who were able to complete the lab study. There were 7 females and 9 males. Their average age was 25.5 with a range between 22 and 32 years (median = 28). All but one of the participants had current exercise experience including weight lifting at the gym (8), biking (6), running (6), swimming (3), rock climbing (3), kayaking (2), squash, yoga, ultimate frisbee, soccer, treadmill, elliptical, boarding, spinning, TRX training, and roller derby. The majority of participants (11) had experience playing exergames including Wii Sports (6), Kinect dancing games (3), Dance Dance Revolution (3), Kinect Adventures! (3), Kinect yoga game, Wii volleyball game, and Wii zumba game. 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 are 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 are 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.

Procedure

Participants were asked interview questions about their background with exercise and exergames. Participants completed 4 x 10 jumping jacks and 4 x 10 bicep curls with 1lb weights. After each exercise, participants ranked the four cues and explained their rationale. The session lasted one hour in total, and they were compensated with a $10 Amazon gift card.

The order of cues was randomized for each participant using a 4x4 Latin Square. For each participant, the order of cues given for jumping jacks and bicep curls was consistent. See Table 1 for the order of cues given.

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, the 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: $\chi^2 = 4.1373$, df = 3, p = 0.25; IQR: $\chi^2 = 1.5478$, df = 3, p = 0.67). This means that participants were consistent with their jumping jack pace regardless of cues.

The cue that was least effective was *Tactile*, with 3 of the 16 participants only completing 6 of the 10 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 2). The average median time for participants able to feel the vibrations was

[1] This is considered a brisk pace in [3].

Comparison	W	p
Voice vs. *Pitch*	104	0.38
Voice vs. *Volume*	102	0.33
Voice* vs. *Tactile	**72.5**	**0.04**
Pitch vs. *Volume*	125.5	0.94
Pitch vs. *Tactile*	86	0.12
Volume vs. *Tactile*	85.5	0.11

Table 2. Pairwise comparisons of median jumping jack revolution time using Wilcoxon Rank Sum.

0.98 seconds, while the three participants had an average median of 2.00 seconds.

Jumping Jacks – Preferred Cues

Participants sentiments toward each type of cue had variety, 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 3, where the difference in ranking between *Voice* and the other three types of cues was statistically significant.

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; the notes were a double-edged sword. 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: *In general I like the idea of communicating in pitch* (p6). *Pitch* was able to convey a sense or 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 the notes increasing in pitch: T*he 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.

Comparison	W	p
Voice* vs. *Pitch	**78.5**	**0.05**
Voice* vs. *Volume	**68.5**	**0.02**
Voice* vs. *Tactile	**50.5**	**< 0.01**
Pitch vs. *Volume*	115	0.62
Pitch* vs. *Tactile	**74.5**	**0.04**
Volume vs. *Tactile*	93.5	0.18

Table 3. Pairwise comparisons of jumping jack ranking using Wilcoxon Rank Sum.

Finally, *Tactile* was ranked in 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*.

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 4). 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 5, where the difference in ranking between *Voice* and the other three types of cues was statistically significant.

Voice was ranked the highest for similar reasons to jumping backs above: hearing the progress or count: *I like having the*

Comparison	W	p
Voice vs. *Pitch*	154	0.34
Voice vs. *Volume*	107.5	0.45
Voice vs. *Tactile*	129.5	0.97
Pitch* vs. *Volume	**75**	**0.05**
Pitch vs. *Tactile*	111	0.53
Volume vs. *Tactile*	144.5	0.55

Table 4. Pairwise comparisons of median bicep curl revolution time using Wilcoxon Rank Sum.

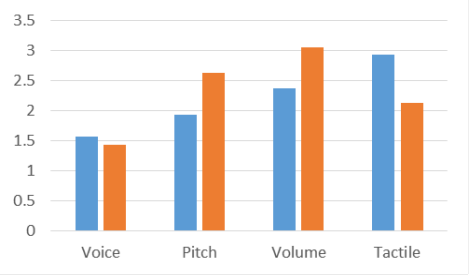

Figure 1. Average ranking for jumping jacks (left) and bicep curls (right) for each type of cue.

extra information with the numbers (p2), and: *I imagine when I'm doing bicep curls, I will be counting through the numbers* (p15). Interestingly, participants liked the 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). In addition, it may be hard 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 it was boring* (p9), and: *It was a little bit annoying because it was monotonous* (p4). *Volume* was also felt more difficult to follow: *I had to be concentrating on the sound* (p5). This impacted

Comparison	W	p
Voice* vs. *Pitch	**31**	**<0.001**
Voice* vs. *Volume	**23**	**<0.001**
Voice* vs. *Tactile	**65**	**< 0.01**
Pitch vs. *Volume*	95	0.20
Pitch vs. *Tactile*	166	0.14
Volume* vs. *Tactile	**189**	**0.02**

Table 5. Pairwise comparisons of bicep curls ranking using Wilcoxon Rank Sum.

P13's ability to pace: *At points I just kind of froze… 'Oh wait I gotta keep going'*.

DISCUSSION

While a majority of participants were able to follow the *Tactile* cues while performing jumping jacks, three experienced difficulty, only completing 6 or 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).

The more relevant information encoded in the cues type, the better. 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 was 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.

CONCLUSION

To be filled in by 9/19 at the latest

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