TimeFit: Designing a Temporal Guide for Resistance Exercise

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Abstract
Time under tension is an important factor of resistance exercise. However, it is difficult to keep track of each time interval in every phase of resistance training. To discover solutions to this problem, we designed TimeFit, a wearable device application that provides the exerciser with either auditory or haptic cues. To investigate the feasibility of TimeFit, we conducted an experiment with 17 participants and and follow-up interviews with them to gain insights for design guidelines. Participants who performed the exercise with auditory cues were the most accurate in terms of timing. Some participants reported that they could maintain good form and focus more on their muscles as TimeFit counts the time of each phase for them. We suggest a guidance system for resistance exercise drawn from quantitative and qualitative findings on sensory modality and cognitive load.

Author Keywords
resistance training; time under tension; phase-specific duration.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction

Resistance exercise is essential in a balanced exercise program because it provides various health benefits [3]. It is important to follow the prescribed routine rigorously as it helps to improve muscular strength, endurance, and balance [9]. To carry out resistance training exactly, three factors are considered: exact posture, an appropriate number of repetitions, and time under tension (TUT) [12]. While previous studies on supporting resistance training with various methods such as visual cue [2], Microsoft's Kinect [11], and wearable device using accelerometers [7, 8] have been carried out, only a few studies on the TUT have been conducted.

TUT is defined as the total time for which the muscles apply force to the implement [4]. Therefore, strength training should be performed based on micro timescales for effectiveness. People who do not adhere to the prescribed TUT experience much less stimulating exercise. Rathleff et al. [10] proposed the add on system to elastic band using a stretch sensor. Their experiment showed that the system could quantify TUT of shoulder-abduction strength training for accurately identifying training adherence and quality of shoulder-abduction strength training. This solution, however, only tracks TUT and does not give cues for performing resistance training properly. In this study, we provide users with a cue to help them to keep track of the time in each phase

We designed TimeFit, a wearable device application that provides either auditory or haptic guidance to make the user to perform resistance exercises on time for each phase of movement.

We conducted an experiment to measure the accuracy of time. To investigate the degree of the cognitive overload and for how long does it affect the error of duration in each phase of exercise, NASA-TLX [5] survey followed the experiments

User study results that prove TimeFit helps in mitigating the error in time and cognitive load of the user. Participants reported that they could maintain exact form and focus more on their muscles as TimeFit counts the time of each phase for them.

The contributions of this paper are as follows. First, TimeFit provides phase-specific cues that could aids users to train their muscles in correct durations. Second, we examined the impact of the cues on both cognitive burden and the accuracy of movement. Last, the results provide useful insights on the design of the guidance for resistance training in terms of sensory modality and cognitive load.

System design: TimeFit

TimeFit aims to offer a guide for the punctual duration of phases with a wearable device. Inspired by American College of Sports Medicine resistance training guidelines [1], we designed the TimeFit to provide either an auditory or haptic cue for each phase of movement. Visual cues have been excluded in this research because they are secondary to auditory and haptic feedback in a workout setting. For example, it would be unnatural for an exerciser to work out while looking at the display of a wearable device. Furthermore, watching visual cues would hinder exercisers from maintaining good form while training.

Figure 1 shows that how TimeFit works for the exerciser. An auditory cue plays a piano "Doh"(C4) key for three seconds in the lifting phase, two seconds in the holding phase, and three seconds in the the lowering phase, and there is no auditory cue for two seconds in the rest position. In order to differentiate the holding cue from the moving phase (lifting, lowering), a series of three staccato (shortened duration)

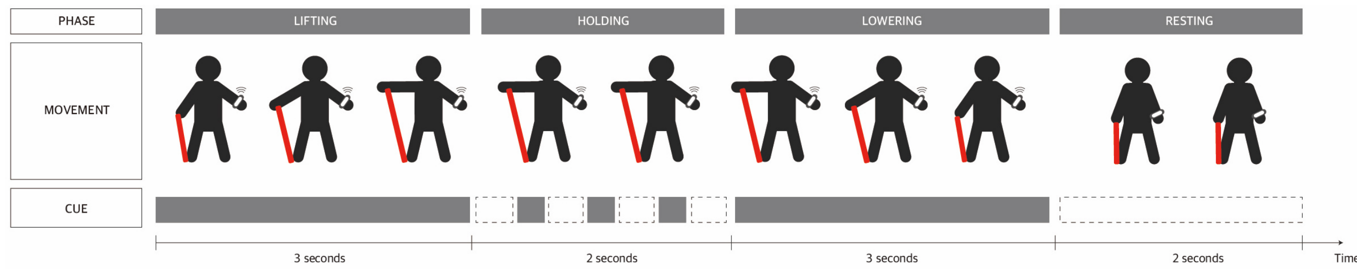


Figure 1: TimeFit is designed to help exercisers to perform resistance exercise effectively by working out on time in each phase. Most of resistance training consists of the four phases of movement such as lifting, holding, lowering, and resting. For each phase, a wearable device provides either an auditory or haptic cue to let the person know when to lift, hold, and lower the elastic band.

cues are played. We developed an Android Wear application using an ASUS ZenWatch 2 [1] which has an internal speaker.

Experiment Design

This study investigates three research questions: 1) Does a cue help the user to keep track of the time in each phase? 2) Which sensory modality is helpful for reducing the cognitive load? 3) Additionally, which sensory modality of cue is suitable for resistance exercise? To address these research questions, we conducted an experiment to measure the time accuracy. We also carried out NASA-TLX survey to investigate cognitive load. we interviewed the participants about their preference of sensory modality and the reason of cognitive load on training. Behavior experiment was designed as within-subject to verify the feasibility of TimeFit. Participants were asked to complete NASA-TLX survey to measure the cognitive load during workout. After the session, we interviewed the participants about their opinion on sensory modality and the reason of cognitive load on training.

Recruitment

We recruited 17 participants (M:9, F:8) who do not suffer from extreme physical or medical symptoms of the upper body. The average age of participants was 27.9 years old (SD=3.6). For minimizing personal characteristics, the participants of this study were screened with under the two criteria mentioned below. First, we limited the participants' experience in a fitness center to one year. Second, the strength of elastic bands, denoted by different colors, used by participants was determined by the participants' physical ability based on Borg category ratio 10 scale rating of perceived exertion [4].

Procedure

We asked the participants to use an elastic band fit per their physical ability when exercising with 1) auditory cues, 2) haptic cues, and 3) no cues. Because this experiment was conducted by within groups, we tried to minimize the learning effect by conducting the experiment every other day.

[1] https://www.asus.com/ZenWatch/ASUS_ZenWatch_2_WI501Q/

Additionally, the order of the cue types was randomized.

The participants performed shoulder abduction exercises with the prescribed elastic bands. They were asked to exercise for three sets of 15 repetitions. The rest time between each set was limited to three minutes [1]. They were also requested to perform the exercise over the duration of each phase: three seconds for lifting, two seconds for holding, three seconds for lowering, and two seconds for resting. As a tutorial, the participants repeated the shoulder abduction exercise three times following the Thera-Band manual [2] Every participant wore the TimeFit on their left arm and performed the exercise with their right arm. The movement and behavior of the participant was recorded on video without the presence of researchers to reduce the Hawthorne effect [6]. Participants were asked to wear earplugs before starting the experiment of haptic cues. We did not want participants to workout in response to the buzzing sound of haptic cue instead of vibration itself.

Survey & Interview

To investigate the degree of the cognitive overload and for how long does it affect the error of duration in each phase of exercise, NASA-TLX [5] followed the experiments. Semi-structured interviews were conducted to obtain insights into the implications of TimeFit. The participants commented on both the pros and cons of each cue type and the changes between sets.

Data Analysis

We analyzed the video recordings of each workout by the participants [3]. The examination was carried out through a frame-by-frame analysis of the video recordings [10]. The starting point (lifting and lowering) of the shoulder abduction movement was specified as the first frame when the hand started to pull the elastic exercise band. The end point of the moving phase was defined as the last frame when no movement was recorded. The starting point of the stopping phase (holding and resting) was the same as the end point of the moving phase, and vice versa. After finishing the video analysis, we conducted the statistical analysis with One-Way RM ANOVA on the time error. The purpose of the statistical analysis was to examine the sum of the absolute value of errors per the cue types. We used the absolute value of error to avoid the offset effect in-between the phases.

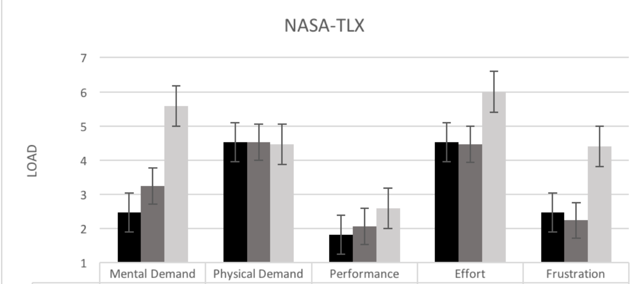
Cognitive load: NASA-TLX
The qualitative analysis aimed to verify the cognitive loads per the various guide types. The scores of cognitive load drawn from NASA-TLX were analyzed by One-Way RM ANOVA. NASA-TLX consists of seven questionnaires and is based on the seven-point Likert scale.

Quantitative Results

1. Time error
Across all guide types, the auditory guide had the lowest mean error. A repeated-measure (RM) one-way ANOVA revealed that there was a significant effect for mean error ($F2, 32 = 9.541$, $p < 0.001$). Bonferroni-corrected pairwise comparisons revealed that the mean error for no guidance was significantly higher than those for audio ($p < 0.001$) and haptic guidance ($p < 0.001$). Our results show that there was a 0.9-second difference per repetition, and total times of 13.5 seconds per set, and 40.5 seconds per day for the three sets.

[2] http://www.thera-band.com/userfiles/file/resistance_band-tubing_instruction_manual.pdf

[3] VLC media Player



	Mental Demand	Physical Demand	Performance	Effort	Frustration
Audio	2.47	4.53	1.82	4.53	2.47
Haptic	3.24	4.53	2.06	4.47	2.24
No guide	5.59	4.47	2.59	6.00	4.41

Figure 2: NASA-TLX results. Each error bar represents the standard error..

2. Cognitive load
Mental Demand
Audio guidance required the lowest mental demand. In contrast, no guidance required the highest mental demand. There was a significant difference in effect for mental demand (F2, 32 = 42.2, p < 0.001). Bonferroni-corrected pairwise comparisons revealed that the mental demand for no guidance was significantly higher than that for audio (p < 0.001) and haptic guidance (p < 0.001).

Performance
The performance was the most demanding when exercising without any guidance. The performance of the audio guide was less demanding than others (F2, 32 = 4.539, p = 0.0184).

Effort
The most effort required was with no guidance. In the the load of effort, the audio and haptic guides resulted in lower numbers than the no guidance (F2, 32 = 6.47, p < 0.01).

Frustration
The load of frustration shows that the haptic guide, audio guide, and no-guide were arranged from lowest to highest for load of frustration (F2, 32 = 9.223, p < 0.001).

Qualitative Results

The insights of participants were drawn from the in-depth interviews. We discovered three findings for each cue type.

The auditory cue is straightforward. So, the participants could concentrate on their exercise form.
P25 commented ”I did not have the burden of keeping track of the duration in every phase and even the number of repetitions, so I was able to concentrate on the form and this was very comfortable.”

The haptic cue is beneficial for providing a private guide.
P16 said “I think the benefit of the haptic cue is that it can give me a private and personal guide when I perform the exercises in a social context such as a gym. If I used an audio guide amongst many people, it would be very embarrassing.”

No cue leads to cognitive interruptions due to no existence of internal reference for time; it also reduces the motivation.
P14 said “When I did an exercise without any guide, it was cognitively demanding. When I counted the seconds to perform it accurately, I forgot the total number of repetitions. This got me thinking about my performance because I did not know whether I was doing well or not.” P14 commented “Because I did not receive any cue, I lost motivation and felt that the exercise was challenging compared with other cue types.”

Design Implications

Provide an adaptive cue to the movement of exercise.
In the lifting phase, ascending auditory cues or gradually increased haptic cues are good for informing the exerciser of the progression of movement.

Give cues even in the resting phase
P19 said, "Pulling is most demanding for getting the timing right. A preamble should be provided. It would be better to count the repetition in the resting." Giving a preamble cue in the resting phase to prevent the exerciser from abruptly beginning the lifting phase.

Discussion

The time error of all phases was significantly different between the result with auditory or haptic cue and without the cues. The difference of time was 0.9 seconds, which is relatively small. But we argue that this study has the potential when applied to high intensity exercise, rehabilitation and physiotherapy, in which the exercises has the long durations for motions. Then, the difference between with and without guides will be obvious.

For patients, TimeFit could enhance the adherence to the exercise program and improve the efficacy and safety of the exercises by ensuring they are performed accurately.

Future Work

There are still limitations to be considered in designing TimeFit. In this study, we tested weak baseline (no cues), which is easy to beat compared to auditory and haptic cues. Validity of TimeFit could be improved to set the baseline with metronome or periodic cue.

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