StrengthGaming: Enabling Dynamic Repetition Tempo in Strength Training-based Exergame Design

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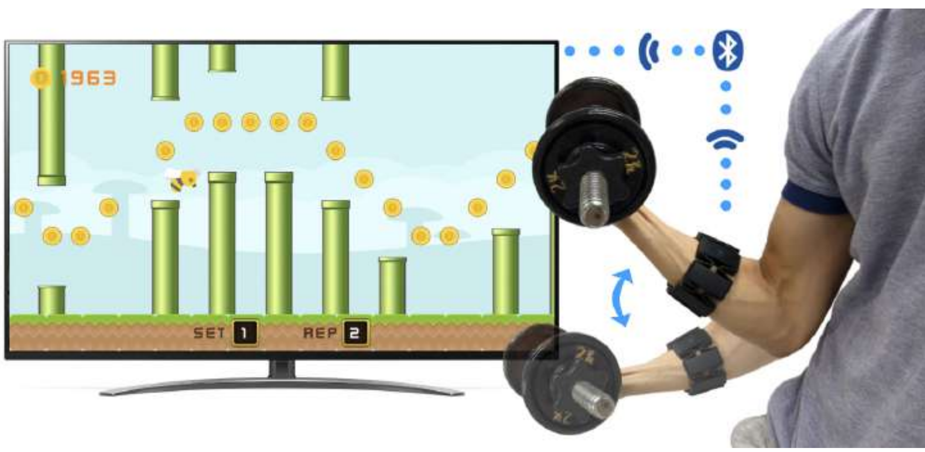

Fig. 1. StrengthGaming maps exercise motions to control FlappyBird [25] in real-time and uses dynamic tempo variation to improve game's entertainment level.

Strength training improves overall health, well-being, physical appearance, and sports performance, with training programs specifying variables such as sets, repetitions, rest time, weight, and tempo. The repetitive nature of strength training, typically performed at fixed tempo, has made it challenging to develop entertaining exergames for common strength training exercises. We present StrengthGaming, which uses scaling and shuffling technique to provide tempo variations to strength training while preserving the training volume and training goals. It affords game designers more flexibility in designing strength training-based exergames. We developed a prototype game, inspired by FlappyBird, that uses a wearable orientation sensor to track the repetition tempo to control a flying character, using both fixed tempo design and dynamic tempo design. Results from our 24-person user study showed that dynamic tempo was significantly more entertaining than fixed tempo ($p<0.01$), and was preferred by participants.

CCS Concepts: • **Human-centered computing** → *Field studies*; *Interaction design.*

Additional Key Words and Phrases: Wearable Computers, Games/Play, Sports/Exercise.

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1 INTRODUCTION

Strength training improves overall health, well-being, physical appearance, and sports performance. The World Health Organization (WHO) specifically recommends that *"muscle-strengthening activities should be done involving major muscle groups on 2 or more days a week"* with aerobic exercises in order to improve cardio-respiratory and muscular fitness, bone health, and to reduce the risk of depression and noncommunicable diseases (NCD), such as heart disease, stroke, cancer, chronic respiratory diseases and diabetes, which are the leading cause of mortality in the world [18].

There has been extensive research on improving training effectiveness for specific training goals such as hypertrophy (i.e. size of muscles), strength, endurance, and power, by designing training programs using variables that includes the number of *sets*, *repetitions*, *rest time*, *weight*, and *tempo* [1, 19]. As shown in Figure 2, *tempo* describes the timing ratio of the three distinct phases of an exercise repetition according to muscle activities: 1) *concentric*: muscle shortening, 2) *isometric*: maintaining the same muscle length, and 3) *eccentric*: muscle lengthening. In this particular example, the ratio is 1:1:1.

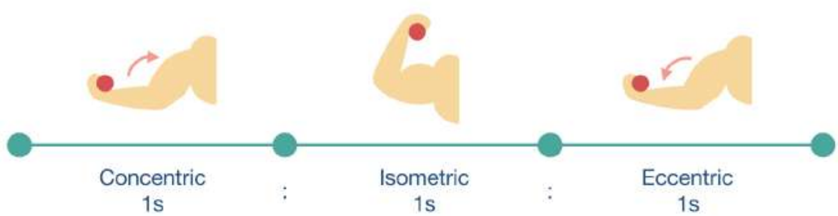

Fig. 2. Tempo is the time ratio for the three phases of a repetition: 1) concentric: muscle shortening, 2) isometric: maintaining the same muscle length, and 3) eccentric: muscle lengthening.

The 4 training goals have specific training variables, as recommended by the American College of Sports Medicine (ACSM) [1, 19], shown in Table 1. Specifically, it shows the optimal training tempo ratios for each training goal. For example, the optimal tempo ratio is 2:1:4 for maximizing muscle size and 1:1:1 for maximizing strength. Currently, the repetitions are performed with fixed

Goal	# of Sets	# of Reps per Set	Tempo	Rest between Sets
Hypertrophy	1-3	8-12	2:1:4	1-2min
Strength	1-3	8-12	1:1:1	1-3min
Endurance	1-3	10-15	1:-:1	<1min
Power	1-3	3-6	-	1-3min

Table 1. Summary of the training guidelines for different training goals for novice by the American College of Sports Medicine (ACSM) [1, 19].

repetition tempo throughout the entire training session. The repetitive motion and monotonous tempo make it challenging to create entertaining exergames based on strength training.

We present StrengthGaming, which uses a dynamic tempo variation technique, scaling+shuffling, to enable tempo variation in strength training, while preserving the training volume and training goals. By enabling tempo variation, it enables game designers to design more entertaining exergames based on strength training's repetitive motion, while maintaining compliance with training guidelines.

To demonstrate and evaluate its effectiveness, we designed a game inspired by FlappyBird. Users control the game by performing strength training exercises using a wearable sensor, as shown in Figure 1. Instead of tapping on screen to fly the bird up, we designed the gameplay to have the position of the bird continuously reflect the progress throughout a repetition (i.e. the maximum and minimum muscle contractions are mapped to the highest and lowest positions of bird, respectively).

Our dynamic tempo variation technique, scaling+shuffling, preserves strength training program's specification of repetitions and time under tension, which is described as training volume [28]. Instead of being constrained by the monotonous motions and fixed tempo of strength training repetitions, StrengthGaming allow exergame designer to have the flexibility of dynamic, varying tempo to design more entertaining games while maintaining compliance with training guidelines.

To evaluate the user experience, we conducted a 24-person study to compare 4 conditions: game with dynamic tempo, game with fixed tempo, with only visual guidance, and with no guidance. Results showed that all visual and game conditions significantly improving the tempo accuracy ($p<0.01$). In terms of entertainment level, dynamic tempo was rated significantly higher than all other conditions ($p<0.01$), and was most preferred by participants.

Since strength training is inherently mobile given its flexibility to be conducted in variety of locations, including gyms, fitness centers, hotels, and home, we thus utilize the wearable and mobile technology to achieve our tempo variation design, which helps game designers to create more entertaining exergames. Our contribution is a novel approach to provide tempo variation to strength training while preserving training volume and training goals, to enable the design of significantly more entertaining strength-training exergames.

2 RELATED WORK

Modern sedentary life whose influence on human health has recently stimulated the growing use of gamification [4] in order to motivate people to engage in physical activity. We reviewed the related work combining exercises and games and separated the work into three main categories: exercise and then play, exercise and play at the same time, and strength training and play at the same time.

2.1 Exercise then Play

Ubifit [3] is a system that uses on-body sensing, machine learning and personal mobile displays to encourage physical activity. *H-Run* [10] uses the player's body composition data to generate a virtual character that can move in the game environment. *Exermon* [27] is an exergame that cares for a monster through performing strength training, and lets players use growing monsters to compete in first-person boxing game. *Walkr Fitness Space Adventure* [8] is a commercial mobile game that uses walking to earn energy that can be used to explore the virtual galaxy. These use exercises asynchronously from the gameplay, and provide such a motivation for players to keep exercising. These works utilize social network built upon the physical display to motivate users to keep exercise, and then use the data collected during activities to provide feedback after exercising. Our work focuses on enabling designers to design synchronous, exercise motion-controlled gameplay that is more entertaining.

2.2 Exercise and Play

Exercising games, or exergames, are designed according to exercise motions. FF Mueller et al. [15] proposed a framework for designing exergames, and described a variety including table tennis, jogging and hanging off the bar. *JumpGym* [17] is a multiplayer exergame that aims to engage people in physical activity in public places where they have to wait. Chatta et al. [2] explored a generalizable approach to transfer existing commercial games into exergames. Many commercial games and products have been proposed to provide more entertaining exercise experiences. Nintendo's Wii Fit games [16] and Microsoft's kinect-based games for Xbox [14] allow people to do exercises at home in a fun way. Reax Lights [20] is a wireless LED system which reminds user where to go or what to do during training through projection light. PRAMA [7] is a gym space that consists of interactive equipment similar with the Reax Lights to enable users to do a variety of training.

2.3 Strength Training and Play

We are not the first work to incorporate gamification with strength training. Richards et al. [21–23] proposed three game design methods to overcome the problem of lacking agency in repetitive-motion exergames. Agency refers to the *"ability to act within an environment"* [21], and the more agency a game achieves, the better the experience. The work also developed Brain & Brown, a strategy card game for strength training. The main goal of the game is to defeat the opponent using cards with specific exercise motion whose power is decided by how well the motion is performed. This game gives feedback after players finish the motion, where we want to give feedback when performing exercise motions and improve entertainment level by varying training tempo.

In addition, there are some existing commercial products combing strength training and games. *eGym* [6] are commercial exercise machines with gamification elements to reward users for having the correct repetition tempo. The interface uses points moving on a curve as visual guidance. *SymGym* [26] combines video game controller with resistance training machines to move the characters by varying the intensity of the exercise, and supports classic games, such as Pac-Man or Asteroids. *eGym* adds tempo as part of gameplay, and *SymGym* provides a way of use the intensity of strength training with video games to make training more entertaining. Our work combines the advantages of both to provide improved tempo with more entertaining experience using strength training exercises.

3 PROTOTYPE DESIGN

Strength training exercises is well-defined in kinesiology [9], including trained muscles, action guide, and direction of force. Among all 111 exercise motions described by Strength Training Anatomy [9], we chose a common motion, *bicep curl*, to be the exercise of our prototype. Users hold weights in the hands with palm facing upward to lift the dumbbells up and to lower them. The vertical movement of the weights is similar to the character in the class game, FlappyBird [25]. In the original gameplay, players tap or click to flap the wings and fly up to avoid collision with obstacles. We designed our game based on its visual as it is instantly familiar to most people, and modified the gameplay for strength training.

3.1 Modifications of FlappyBird Gameplay

Strength training guidelines [1] show that different training goals have different optimal tempo for the three distinct phases of exercise repetition: concentric, isometric, and eccentric. For muscle hypertrophy, the optimal tempo is 2s:1s:4s, while 1s:1s:1s is for maximal strength.

To guide users to perform each phase of the repetition at the optimal tempo, the first modification is changing FlappyBird gravity system to real-time reflection of the progress of the repetition, i.e.

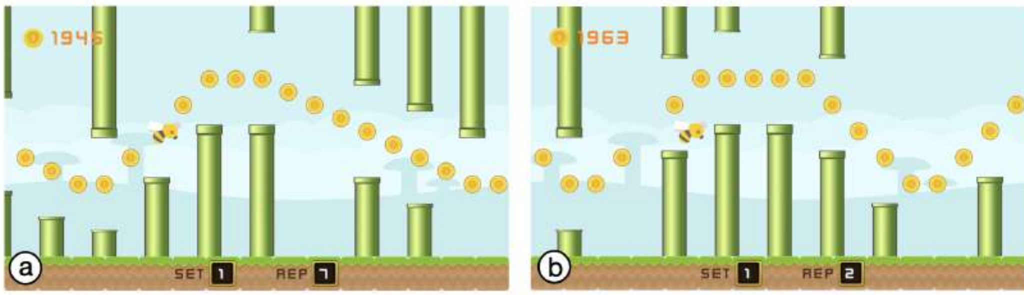

Fig. 3. The arrangements of pipes and coins to encourage users to achieve the optimal tempo, showing optimal tempo for: (a) hypertrophy @ 2s:1s:4s (b) maximal strength @ 1s:1s:1s.

the height of the dumbbell in the case of bicep curl. The second modification is not ending the game when the bird collides with a pipe, but rather use a point system where a coin adds points and pipes deducts points. The allows the entire training sets to be completed and training goals to be maintained. The position of pipes and coins are generated according to the optimal tempo, as shown in Figure 3, which creates a path that encourages users to achieve the optimal tempo while playing the game.

3.2 Tempo Variation

Training guidelines use workload and training volume, which is the total number of performed repetitions and time under tension [28], to quantify training. Our goal is to maintain training volume and training goals by keeping optimal ratio in training tempo while enabling designers to have tempo variation within a training session, to reduce repetitiveness and predictability in their game design. The technique we propose is described below, and shown in Figure 4 a):

- **Scaling:** changes the duration of the three phases of an exercise repetition equally, while maintaining the target tempo ratio within a single repetition. For example, a repetition 2s:1s:4s scaled 50% becomes 1s:0.5s:2s. The total duration of a set can be maintained by scaling up and down different reps, for example, a set [2s:1s:4s, 2s:1s:4s] becomes [1s:0.5s:2s, 3s:1s.5:6s].

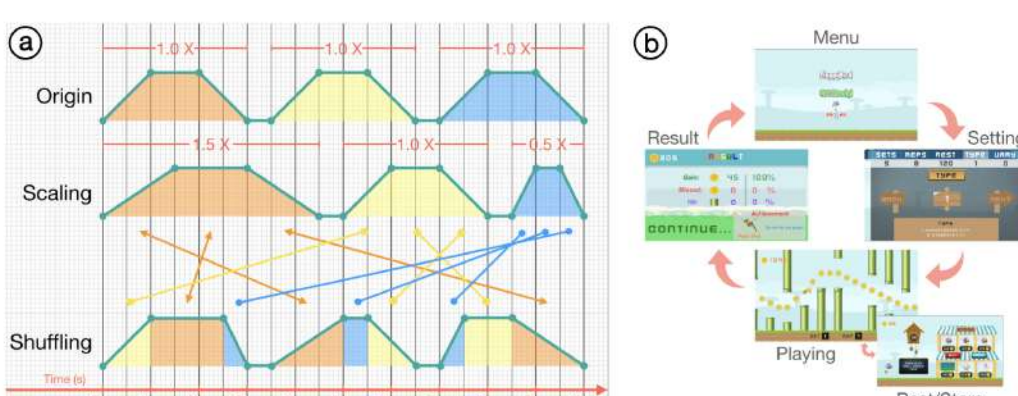

Fig. 4. (a) The tempo variation technique, scaling and shuffling, shown using tempo 1s:1s:1s as an example. (b) Game flowchart of our StrengthGaming prototype modified based on FlappyBird.

- **Shuffling:** swaps the durations of the same phase across two or more (scaled) repetitions. For example, a set [2s:1s:4s, 1s:0.5s:2s, 3s:1s.5:6s] can be shuffled to [1s:1.5s:4s, 3s:1s:2s, 2s:0.5s:6s].

3.3 Implementation

Wearable inertial measurement unit (IMU) sensors support mobility and can track strength training exercises. We used the MYO's [12] IMU due to its integrated Bluetooth and our prior successful experience using its real-time API. We computed the orientation of the MYO device based on the accelerometer and gyroscope data in quaternion provided by MYO's Unity SDK [13]. The sensor readings are used to sense players' progression throughout the bicep curl and are used to control the height of the bird in the game. As shown in Figure 1, our system gets sensor data, pitch angle of the MYO, over Bluetooth, and our game was developed using Unity 3D to support multiple platforms, including Android, iOS, MacOS, and Windows.

3.4 Gameplay

Players go through the cycle of the game as shown in Figure 4 b). The first scene players will see is the menu page, which leads to the the setting page where players input their desired number of strength training parameters, including sets, repetitions, rest time between sets, training tempo, and game variance. As the game starts, players aim to collect the coins and avoid hitting the pipes. With the current state of training information displayed below, they can keep track of how many sets and repetitions they have done. During the rest time between sets, players are led to the store page, where they can purchase and equip game items using the coins they earned, providing players with a sense of agency. A countdown timer is presented on the store page to remind players about the remaining rest time. After finishing all the sets, the result page shows up and displays four main things for players to evaluate their game performance: the number of coins collected, coins lost, pipes hit, and achievements.

4 EVALUATION

We designed and conducted an user study to evaluate the tempo accuracy and entertainment level of our proposed approach.

4.1 Experimental Design

4.1.1 Setup. The study was conducted in a fitness room at a local university to reflect the environment of typical strength training sessions. Participants were asked to wear a MYO sensor armband [12] on their forearm of the habitual hand, sitting with the same weight being held in the other hand to prevent injury. The screen was placed at the same height as their line of sight.

4.1.2 Conditions. To evaluate the effects of visual feedback on exercise, we applied similar methodology proposed by Doyle et al. [5] which they designed their study with three conditions having different levels of feedback, including *Control* (no feedback), *Video* (limited feedback shown prior to study), and *Exergame* (real time visual feedback). A key limitation of their study was that it did not evaluate a live visual feedback condition as a baseline, so that the game condition would confound two factors: 1) live visual feedback and 2) game interface. In our study design, we specifically controlled it through separating them into *Visual Guidance* and *Game - Fixed Tempo*" conditions, which showed the same fixed training tempo. Finally, we conducted the experiment under four conditions:

- **None:** Participants kept the tempo without any assistance.
- **Visual Guidance:** A moving object was used as a metronome, and simulated specific and fixed training tempo.

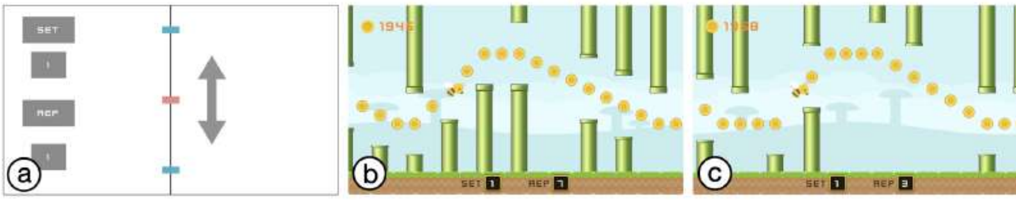

Fig. 5. Screenshots of conditions, using tempo 2s:1s:4s as example. (a) Visual Guidance (b) Game - Fixed Tempo (c) Game - Dynamic Tempo

- **Game - Fixed Tempo:** Participants followed the game path with fixed tempo.
- **Game - Dynamic Tempo:** Participants followed the game path with dynamic tempo using scaling and shuffling variation technique.

4.1.3 Tempo. We summarized the training guideline [1, 19] in Table 1, and used tempo 2s:1s:4s, which is for the purpose of muscle hypertrophy, and tempo 1s:1s:1s, which is for the purpose of maximizing muscle strength.

4.1.4 Procedure. One-repetition maximum (1RM), is the maximum amount of weight that one can achieve in one repetition. Before the study, a preliminary test was performed to measure participants' 1RM, and the appropriate weight was calculated by an online RM calculator.

Participants were then asked to execute bicep curl on their habitual hand with the loading of 50% of 1RM, to balance among effort, fatigue, and safety. For each condition, participants would perform bicep curl for 8 repetitions in 1 set, and there was a two-minute rest between each set.

Participants were asked to complete 1 set for one of the two tempos and rate the entertainment level for each of the 4 conditions on a 7-point Likert scale and report their preferences. Next, they repeated the tasks for the other tempo. Finally, participants provided feedback about the experience.

To avoid the interference of fatigue and becoming more skilled over time, the order of the 4 conditions and the 2 tempos was counterbalanced. The whole study took about one hour, including exercise time, rest time and interview time.

4.1.5 Participants. We recruited 24 participants (age 18-24, Mean= 22.3, SD=1.3, 12 females) from a local university. While 21% of participants did not have exercise habits, the rest exercised at least once a week, including aerobic exercise, swimming, playing volleyball, basketball, table tennis and badminton. 54% of participants had experiences in strength training.

4.2 Tempo Accuracy

The training guidelines of American College of Sports Medicine (ACSM) cites several studies that showed tempo being an important factor for training effectiveness. With all else being equal, improving tempo accuracy would improve effectiveness.

Tempo accuracy was calculated using the difference between the actual time performed by participants and the target time described by training guidelines. First we splitted each phases according to the sampled data from MYO to get the actual time of each phase by participant, denoted by t_{user}. Phase error was calculated by eq. 1, where $t_{standard}$ was the suggested time provided by training guideline. We then used root-mean-square deviation (RMSD) formula in eq. 2 to measured accuracy, where E represented error in each one of three phases, denoted by e_i, with i=1~3 being concentric, isometric, and eccentric phases respectively.

$$PhaseError = \frac{|t_{user} - t_{standard}|}{t_{standard}} \quad (1)$$

$$Accuracy = 1 - RMSD(E) = 1 - \sqrt{\frac{\sum_{i=1}^{3} e_i^2}{3}} \quad (2)$$

We ran ANOVA test on the accuracy for integration of the two tempo and pair-wise comparison of each conditions. As shown in Figure 6, there was significant differences between all 3 conditions with visual guidance vs. the condition without any assistance (p < .01), improving accuracy from 64% to 71-74%. However, there was no statistical difference between the 3 conditions with visual guidance. Despite adding gamification and adapting dynamic tempo in our prototype, players were able to achieve similar accuracy as the visual condition without any gameplay.

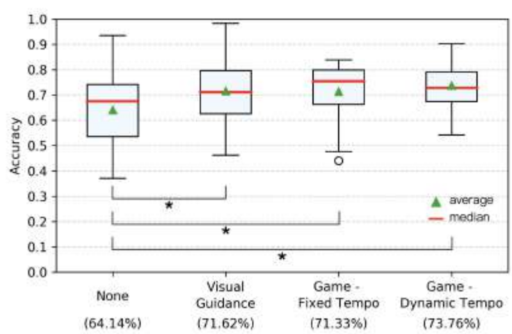

Fig. 6. Box plot of exercise tempo accuracy for four conditions.

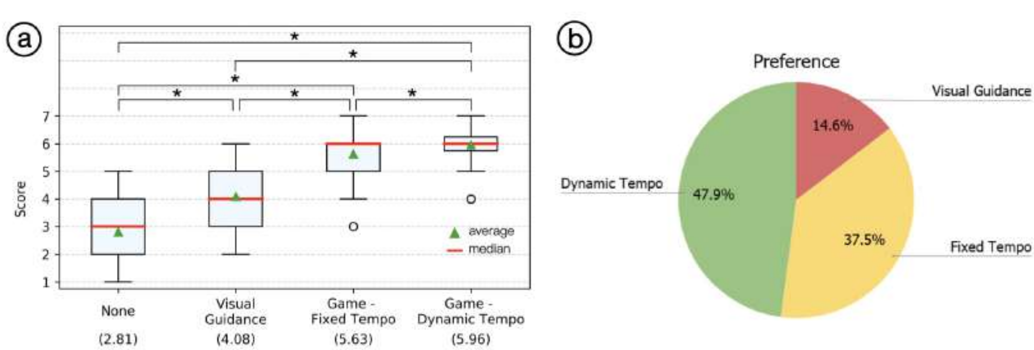

Fig. 7. (a) Box plot of entertainment rating on a 7-point scale for the four conditions. (b) Distribution of overall preference for the top ranked condition.

4.3 Entertainment Level

Participants' ratings for entertainment level is shown in Figure 7 a). The average scores were 2.81 for *None* condition, 4.08 for *Visual Guiance* condition, 5.63 for *Game - Fixed Tempo* condition, and 5.96 for *Game - Dynamic Tempo* condition. We ran the Friedman test and the Bonferroni post-hoc test for pair-wise comparison, which are the recommended statistical tests for Likert data. The result shows significant difference between all pairs ($p<.01$). Both gaming conditions were rated significantly more entertaining than the non-gaming conditions, and that dynamic tempo was significantly more entertaining than fixed tempo.

In terms of preference ranking, the distribution of the top ranked choice is shown in Figure 7 b). Dynamic tempo was most preferred by the most participants, with 47.9% vs. 37.5% for fixed tempo and 14.6% for visual guidance.

5 DISCUSSION AND LIMITATIONS

5.1 Fun vs. Effectiveness

Some participants commented that playing games for strength training is more suitable for beginners and for people who want and need more motivation for exercise. Professional trainers and athletes likely have higher motivation, and may benefit less from such exergames.

Some participants raised concerns about reduced training effectiveness when exercising while playing the game. For example, P7 mentioned *"The game is fun, but I am worried that it will reduce training effect."*

Our tempo variation is designed to preserve the training volume to ensure compliance with training guidelines. In addition, visual guidance significantly improves training tempo accuracy.

To get additional perspective on this issue, we interviewed 3 certified, professional trainers to get their feedback on tempo variation and training effectiveness (trainers T1, T2, and T3).

First, scaling technique is already used by T1, and all trainers expressed that scaling naturally occurs as users fatigue. Second, shuffling is not practical for person-to-person instructions. However, all three trainers agreed that the use of technology to provide live and accurate feedback makes it possible. Third, all three trainers said that our tempo variation design is novel, and meets their training guidelines of preserving the ratio of time-under-tension. Although they are not aware of scientific literature on the relationship between tempo variation and effectiveness (most likely because such fine-grained tempo variation was not possible before), T3 commented that such variation will likely improve training effectiveness similar to how cross training introduces variation to improve fitness. Despite potential effectiveness, T3 cautioned that game designers should should be aware that the maximum speed of a repetition may decrease as workloads approach users' maximum workload.

Furthermore, there is research on differences in training effect between internal focus and external focus, where internal focus meant *"focused on contracting the target muscle"* and external focus meant *"focused on the outcome of the lift"* during training. Schoenfeld et al. [24] conducted studies of 8 items as training effect, including muscle thickness, isometric muscle strength, body composition and anthropometry. The results showed that internal focus and external focus have higher effect in different items. For instance, internal focus has more changes in elbow flexor thickness and external focus has more changes in isometric knee extension.

5.2 Fun vs. Safety

"If I am too excited about the game, my posture may gradually become incorrect as the game progresses" (P10). Because users are focusing on the game, there is less attention paid to monitoring postures.

Our prototype currently only uses an single IMU to sense user's motions, and cannot reflect whether user performs the exercises correctly. One potential solution is to use more wearable sensors use computer vision techniques such as Kinect and GymCam [11] to monitor proper postures and provide feedback to users. Feedback can be integrated into the game, such as deducting coins when an incorrect posture has been detected.

5.3 Adaptations to Other Exercise Motions

We only present one application of game and exercise motion in this paper. However, we have received much feedback that expects more applications for different exercise motions. In order to adapt games to other exercise motions, we need to survey both in exercise motions and games respectively to pick up suitable material for strength training exergames. Then, finding out the common points between exercise motions and games is necessary for cascading them together. Take our prototype for example, both bicep curl and flappybird involve moving something up and down. The same consideration also can be adapted to other exercise motions. For instance, trunk rotation needs sitting people to rotate barbell putting on their back left and right, which is similar to driving a car in racing games.

5.4 Designing for Strength Training

Participants enjoyed the simple visual guidance design of the game and that *"using games to express exercise motion is easy to follow and especially suitable for beginner new to strength training."* (P8). *"Through the arrangement of upcoming coins, I know exactly how long I need to hold the dumbbell in isometric phases."* (P9).

Participants also there motivated by other game elements, including coins accumulation and store during rest time. *"I exercised hard to get coins because the coins motivate me."* (P4) and *"It's great that the game gives me incentives to exercise by allowing buying game items in store and achievements"* (P12). Some participants further expressed that they would like to see more games and more strength training exercises supported: *Having many different games to choose from will help me stay motivated."* (P7), *"I hope it supports more exercise motions and different types of games to play."* (P2). We are exploring how to map different exercise motions to popular games, so that the system can suggest different games to choose from for a particular exercise.

6 CONCLUSION

We present StrengthGaming, which introduces tempo variation to strength training's repetitive motions to allow designers to have more flexibility in creating more entertaining game designs. We developed a prototype game and implemented a scaling+shuffling dynamic tempo technique to add tempo variation. Results from our 24-person user study showed that StrengthGaming's dynamic tempo design significantly improved the entertainment level and is most preferred by participants compared to fixed tempo.

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