MuscleMemory: Identifying the Scope of Wearable Technology in High Intensity Exercise Communities

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***Abstract*—Group-based, high intensity exercise programs motivate athletes to participate in healthy lifestyle changes. Since classes are in a group setting, athletes may not receive the individual attention necessary to master correct form - an important factor to maximize exercise and avoid injury. In this paper, we investigate the potential of a wearable, ambient display technology, MuscleMemory, to help athletes maintain good form and improve communication in high intensity, group-based exercise communities. We explored the feasibility of MuscleMemory by contextually interviewing 14 high intensity exercise community members to understand when they need the most assistance and how communication between coaches and athletes can be improved. Participants thought MuscleMemory could be used to improve how coaches communicate with their athletes - especially to coordinate coaching between different coaches and provide objective feedback.**

I. Introduction

Group-based physical activities encourage retention in exercise programs, create camaraderie, and allow coaches to easily share information [1], [2]. Unfortunately, similar to education [3] or therapy sessions [4], participating in group-based exercise programs also means that individual athletes may not get as much feedback nor a consistent exercise experience between classes taught by different coaches. Athletes need feedback in situ to help them reach their goals and remain injury free - a major concern for these programs [5], [6].

Researchers in the CHI and TEI communities recently investigated wearable technologies for physical activities and rehabilitation [4], [7]–[9] that increase engagement and communication about exercise by publicly visualizing health data. Athletes with wearables better understand their own health data and are motivated to continue improving their performance. The information is visible, thus bystanders can view data and encourage the wearer. These projects that enhanced exercise experiences for cyclers [9], runners [7], [8], and people in rehabilitation settings [4] motivated us to investigate how an ambient, wearable display could be integrated into group-based, high intensity exercises programs to improve personalized feedback and athlete-coach communication.

Research in the area of high intensity, group-based classes indicates that anywhere from 19.4% [6] to 73.5% [5] of athletes sustain an injury during class training sessions - the most frequent injuries happen to major joints [6]. Athletes attempt to prevent injury and support joints with knee sleeves and performance tape [10], however these preventative items only support the athlete physiologically and psychologically, they do not help athletes maintain correct form which can also help reduce injury. In this paper, we explore how to provide feedback to athletes and coaches on an athlete's form contributing to wearable physical activity enhancing systems by introducing MuscleMemory, a wearable knee sleeve that detects and displays feedback when squats are correctly performed (performance is based on program guidelines [11]).

We investigated the feasibility and potential application of MuscleMemory by contextually interviewing 14 high intensity exercise community members - 8 athletes and 6 coaches. One researcher demonstrated the MuscleMemory prototype– a wearable Arduino-based system with a custom bend sensor that visually displays one's squat depth with a set of LEDs– as a discussion probe to provide participants with insights into the potential of ambient, wearable feedback. Coaches and athletes thought our prototype served four purposes - (1) a learning tool, (2) an extra set of eyes, (3) an objective feedback mechanism, and (4) a continuity of coaching device.

Our three main contributions are: a wearable technology prototype, MuscleMemory, for high intensity exercise communities; qualitative results identifying how athletes and coaches perceive communication and feedback in group-based exercise settings; and design suggestions for these communities.

II. Background

In this study, we focus on the use of technology in specific group-based, high intensity exercise programs. We refer to the *program* as the overall structure, class setup, training, competitions, and exercises that are approved by the overseeing administrative body. The program influenced the development of interconnected *communities* made up of coaches and athletes that foster an all-encompassing lifestyle that includes diet, exercise, work-out fashion, and lexicon. We use the term *athlete*, not in the traditional sense of someone playing a particular sport, but as someone in the community who usually frequents a particular class time.

One of the authors is an athlete in a community. Some research motivation and questions were a result of her own experiences within the program. All participants were recruited from external communities in which the author did not participate. The other authors are not associated with any group-based, high intensity exercise programs.

We limited our design space to focus on squats because (1) they are a significant part of the approved exercise by the high intensity, group-based programs - making up four of the nine primary movements [11] and (2) athletes in these communities often wear knee sleeves to support joints and avoid injury [10] - thus providing an ideal piece of athletic equipment to enhance with an ambient display and sensing technology. The program

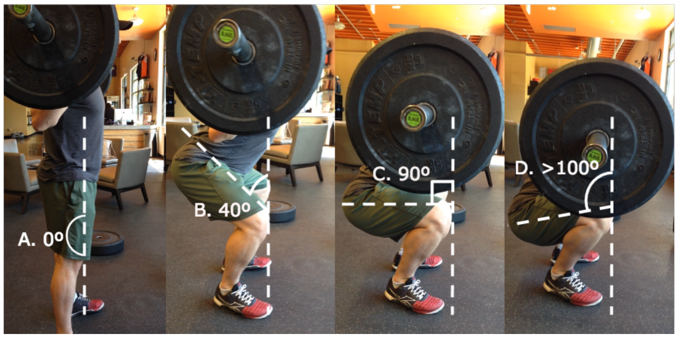


Fig. 1: Different angles of a person's squat depth.

trains members to squat (both body weight or with a barbell) below parallel because this form has been shown to increase gluteus maximus activation [12], maximize mechanical effort of knee extensors [13], and increase concentric work per repetition [14]. Though some researchers only investigated the benefits of above parallel versus parallel squats, lower squats reduced tension on the spine [15] and improve hip extension muscles [16]. Squat depths are typically measured in terms of flexion at the knee, with a fully extended leg having a flexion of 0° (Figure 1A). We define squats as above parallel if they are at or around 40° (Figure 1B); parallel if they are at or around 90° (Figure 1C); and below parallel if they are greater than 100° (Figure 1D) [17].

While exercises are completed individually, each class creates a team-like atmosphere. It is not uncommon to see athletes encouraging one another to complete a workout or pushing each other to squat with a heavier weight. Wearable technologies can help athletes see when someone needs further encouragement or assistance.

III. Related Work

We provide a broad overview of research and commercial systems that improve athletic performance through ambient or personalized feedback. We also briefly describe technologies that athletes in this community currently use to contrast how innovative MuscleMemory is in this community's context.

A. Improving Performance through Visual Data

Researchers employed ambient data displays to motivate triathlon athletes [7], runners [8], and cyclists [9] which thereby improved their performances. Walmink et. al. [9] developed a display for cyclers' helmets that displayed their current heart-rate. The visual heart rate data created a shared experience because cyclers relied on their partner to relay the information. Paired cyclers experienced similar levels of exertion and created a sense of social support and teambuilding.

Mauriello et. al. [8] created Social Fabric Fitness (SFF) for running groups. The group leader wore the SFF display on her back to share group pace, distance, and heart rate. They found that runners were not concerned about their biometric data, e.g., heart rate, being shared with fellow runners, and felt motivation from their displayed information. Curmi et. al. [7] developed HeartLink, a tool that shared triathlete and runner biometric data in real-time on a website that created a sense of togetherness among viewers. Viewers felt more connected with runners when they could see their heartrates. Athletes, who knew their data was being shared online, felt like people were around them and cheering when they were alone. MuscleMemory builds on this work by promoting camaraderie and increased communication through the visualization.

Doyle et. al. [18] designed an application for older adults that monitored and gave feedback on their detected mood, sleep, and social interaction. Participants noted that if they were already doing what the application advised, it "reinforced" their confidence. Similarly, we designed MuscleMemory based on what the athletes already know to do from their training sessions, thus we aimed to improve their confidence by providing feedback on actions that they knew they should be doing. Researchers also found that participates were more engaged with their physiological heart rate data if it was represented in a physical object [19]. Participants used 3D printers to print objects (e.g., a frog or cube) that changed in size based on their heart rate data. This finding informed the MuscleMemory design in that we enhanced a physical object, a knee sleeve, to represent physiological data, knee bend.

Mueller et. al. identified a framework for virtual reality exertion game (exergame) designs by evaluated three different exergames (Table tennis for three, Jogging over distance, and Remote Impact) through different body lenses [20]. They developed a framework of rules, play, and context. We used their framework when considering different situations athletes can face when squatting, specifically the *uncertainty* of squat depth and *understanding* through the kinesthetic awareness.

Pijnappel and Mueller also developed design considerations for interactive technologies for exertion activities [21]. They developed 9 prototypes for skateboarding that utilized real time feedback that is useful, encouraging, but not distracting to the user. Four important themes emerged: location of feedback in relation to the body, timing of feedback in relation to peaks in emotions after attempts, aspects of attempts emphasized by feedback, and aesthetic fittingness of feedback. Similar to skateboarders, athletes must focus and acknowledge risks when attempting heavy squats, thus designs should account for risk versus reward while not distracting athletes.

This research evolved from PTViz [4], a wearable knee brace for physical therapy patients performing at-home exercises. Their prototype was made up of a thigh enclosure, a calf enclosure, and a bend sensor. The thigh enclosure contained electroluminescent (EL) wires that created a visual representation of the angle detected from the bend sensor. The authors postulated that PTViz could improve patient-physical therapist concordance, although a longitudinal study was not reported. We expanded upon this study by creating a single wearable for visualizing knee bends that can be customized to an individual's range of motion.

We used a knee sleeve that athletes in these communities already use, possibly allowing seamless adoption of our prototype. Instead of focusing on patients in rehabilitation therapy, we designed our prototype for athletes performing squats in a gym setting with coaches and other athletes who can provide feedback based on the ambient display information. We investigated how a wearable display could benefit multiple people and not just the individual wearing the device.

B. Technologies in the High Intensity Exercise Communities

Wodify[1] is a website and mobile application used in gyms in the communities we studied. Coaches can manage memberships and log workouts, while athletes can enter personal records, track their overall performance, and compare their performance with others. All information is manually entered.

Coach's Eye[2] is a multi-platform application developed for recording, playing-back, and analyzing sport performance. Group-based, high intensity exercise programs frequently use Coach's Eye to monitor squat form. Coaches record an athlete performing a squat, playback the video, and determine if the athlete squatted to full-depth. While the app provides rich tools for playback, it does not give the athlete real-time feedback and is difficult to use in class settings where a coach must monitor multiple athletes.

The Fixometer[3] is a mobile application that provides real time feedback about a person's kettlebell swings, a common movement in high intensity exercise communities. An athlete swings a kettlebell over her head and shows control with arms locked out at the top. The developers used a NODE[4] attached to the kettlebell to detect the moment it is stable over someone's head. The application screen is red until the kettlebell is stable. Once the kettlebell is fixed, the screen flashes green and a repetition is incremented. The application also has the option to include a beep along with the green screen. This application is commonly used in kettlebell competitions where athlete's scores depends on how many times they can fix a kettlebell overhead. Our prototype is similar, displaying a green light once an athlete squats to their desired depth.

We developed MuscleMemory based on the current research in wearable, ambient displays for physical activity and applications available to the target community. Current technologies enhance experiences for people doing traditionally individual activities - running, cycling, and at home physical therapy - by providing real-time feedback and, in some cases, making the activities more communal. Our design goals were to provide athletes and coaches in group-based, high intensity exercise programs the ability to get real-time feedback on their squat form and engender more communication between community members to improve an athlete's performance.

IV. METHODS

We received institutional ethics board approval before recruiting participants. Eligible study participants were over 18 years of age and either a coach at a gym or someone who regularly performs squats during high intensity exercise. For simplicity, we refer to non-coaches as "athletes." We initially recruited participants as either an athlete or coach, however during interviews with the athletes, four mentioned coaching experience. For these athletes, we subsequently created a third participant category, athlete/coach, for interviews with mixed viewpoints. We asked participants questions about their coaching or athletic background and experiences in the gym. Athletes were asked to perform a squat at a warm-up weight while thinking aloud. All participants were shown a demonstration of MuscleMemory and asked for feedback.

TABLE I: Participant Information

Type	ID	Gender	Age	Gym	Experience (In years)	Region
Athlete	A1	F	28	G3	>5	South West
	A2	M	28	G3	>5	South West
	A3	F	23	G5	<1	Central East
	A4	F	28	G6	1-3	South East
Athlete/ Coach	AC1	M	25	G3	3-5	South West
	AC2	M	37	G4	>5	South West
	AC3	M	26	G5	>5	Central East
	AC4	F	26	G6	3-5	South East
Coach	C1	M	24	G1	1-3	North Central
	C2	F	25	G2	<1	South West
	C3	M	56	G2	>5	South West
	C4	F	22	G1	<1	North Central
	C5	M	26	G2	>5	South West
	C6	F	39	G6	1-3	South East

A. Participants

We recruited 14 participants from 6 gyms in 4 different states. Participants were equally split by gender and ranged in age from 22-56 years old - more demographics are available in Table I. Athletes and athlete/coaches indicated that they, on average, performed squats alone twice a week and in a group four times a week.

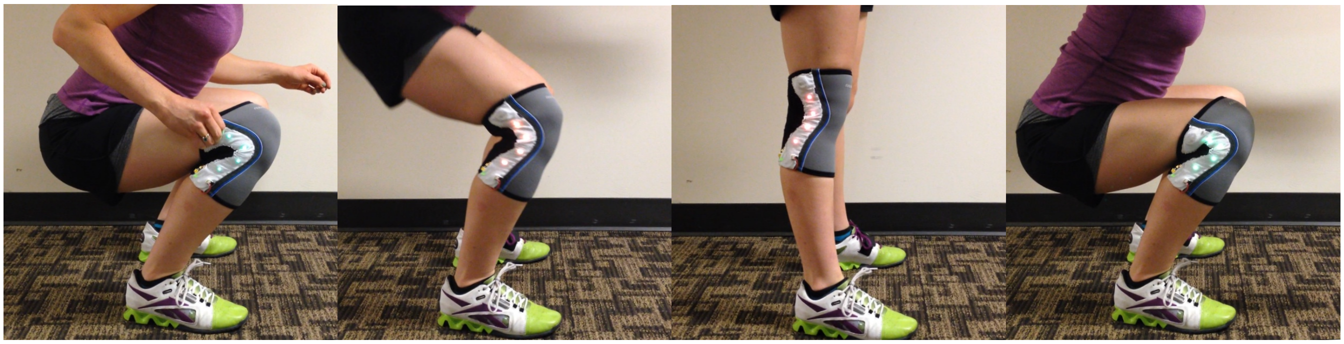
B. Interviews

We developed questions to understand current practices and experiences in exercise communities that squat below parallel. We were interested in how long people had coached or squatted, how current classes were conducted, what issues people may have with squats, and the feasibility of MuscleMemory in their exercise practices. We used a contextual inquiry approach [22] to explore these questions. All interviews were conducted in gyms where participants performed or coached squats. We asked coaches and athletes how they normally spent their time and attention to gain a deeper understanding of the typical class environment. Coaches were asked about their normal class sizes and how they managed time between athletes. We asked athletes how often they worked out in a group and how much feedback they received from their coaches. Athletes performed a squat at a warm-up weight to aid us in understanding any issues they had when performing squats. Athletes were asked to think-aloud, describing what they check for when squatting. We were mostly interested in (1) if athletes squatted below parallel; and (2) what body cues were important when performing a squat.

During the interviews, one researcher demonstrated how MuscleMemory worked (as shown in Figure 2). For interviews with athletes, we conducted the demo after they performed a squat, allowing them to reflect on their squats and think about how it could enhance or distract from their experiences in the gym. We wanted to know if coaches felt it could improve their teaching and if athletes wanted a visual representation of their squat performance.

Answers to interview questions were audio-recorded, which took on average 10 minutes. We video-recorded athletes while they performed squats. No participants were given incentives for the interviews.

[1] http://www.wodify.com/
[2] http://www.coachseye.com
[3] http://worldkettlebellclub.com/fixometer/
[4] http://www.vernier.com/products/sensors/wireless-sensors/node/



(a) Setting the value, green lights (b) Standing, yellow lights (c) Standing, red lights (d) Squatting to value, green lights

Fig. 2: MuscleMemory's visual representation of squat depth.

C. Analysis

Our data included interview audio recordings and video recordings of athletes performing squats. We transcribed and coded recordings and took screen shots of videos when participants reached the lowest point of their squat. We used an open coding method for the interview data [23]. Two researchers independently developed a set of codes, discussed discrepancies, and finalized a set of codes.

V. MuscleMemory

Our wearable interface is made up of a neoprene knee sleeve, a custom bend sensor, a custom push button, Adafruit Flora board, and four RGB Smart NeoPixels (see the Instructable for more details[5]). We acknowledge that squats are complex movements that require athletes to focus on many physical cues to execute them correctly, however we limited our design space to focus specifically on squat depth because it is the one cue that athletes cannot physically check without some external artifact - such as a mirror.

A. Visual feedback

We created a visual representation of a user's knee angle that corresponds to squat depth that immediately verifies when an athlete has squatted to the desired depth. To achieve this, we sewed four RGB NeoPixels vertically along the outer peripheral area of the knee sleeve to indicate an unstored knee angle, the current knee angle, and the target knee angle. When the board is powered, the RGBs blink red, indicating that the target squat-angle has not been set (Figure 2a). When the athlete reaches the desired target depth, she presses the push button. The RGBs flash green, indicating that the value has been set. As the athlete stands up, RGBs change from green to yellow to red (Figure 2b and Figure 2c, respectively). As the athlete squats back down, RGBs change back to green and blink once the target-depth is reached again (Figure 2d). We covered the RGBs with diaphanous fabric to diffuse the light.

Earlier in our design process, we considered other forms of squat depth feedback. A buzzer could be too noisy or distracting in a group setting. The buzzer would need to be loud enough that the wearer hears it over music played at a potentially high volume, while simultaneously quiet that other athletes are not distracted while performing squats nearby or listening for their own buzzer. We knew that researchers have found vibrotactile feedback effective for teaching someone to play the violin, they also mentioned feedback was ignored or undetected when a task was mentally taxing [24]. In addition to loud music, these gyms are also filled with sounds of barbells being dropped, often vibrating the entire gym. We also did not want to potentially distract athletes with sensations on their knee while concentrating on their form. Lastly, we did not want to design a technology that would take away from the role of a coach. By providing feedback exclusively for the athletes, a coach may remain unaware an athlete needs assistance.

B. Knee Angle Measurement and Storage

We designed a push button for the athlete to calibrate her own target squat angle since each individual has a unique squat depth and full range of motion (ROM). Knee angles are measured by resistance values from our bend sensor. We found that the bend sensor performs best when placed vertically on the posterior knee. The bend sensor and push button were made using tutorials found on Instructables [6,7]. While the board is on, the target angle is stored. When the board is turned off, the value is reset. Future designs will include multiple sensors for a more accurate detection of knee angles, permanent storage of an athlete's unique squat depth, and participants' suggestions which we present in our findings.

VI. Findings

Overall, participants gave encouraging feedback regarding the potential benefits of MuscleMemory. We found they were more concerned about overall squat form than squat depth alone. We also found that participants thought our prototype could help coaches improve their time management, communication with athletes, and continuity of coaching.

A. Current Scope of Technology

Participants gave mixed feedback on their current use of technology for monitoring their general health and progress

[5]www.instructables.com/id/squat-sense

[6]http://www.instructables.com/id/Neoprene-Bend-Sensor-IMPROVED/

[7]http://www.instructables.com/id/Sew-a-Soft-Circuit-Touch-Sensor/

in the gym. A2, AC3, and AC4 reported that they use either a physical notebook or an application for recording their workouts and repetitions. Six of the fourteen participants mentioned using Coach's Eye. Two coaches indicated that using Coach's Eye was beneficial for one-on-one interaction with athletes, but was too difficult to use during class time. C4 mentioned his use of Coach's Eye depended on the amount of people, "*...a little one-on-one session, just with friends, we would bring out Coach's Eye, something like that, but not in a group of 12.* A2 used Coach's Eye when there was no one in the gym to provide feedback about his squat performance. "*I have [Coach's Eye] that I'll use when I train alone. I video record my movement, and then in between lifts, I'll play it back in slow motion.*" Generally, video recording was only used when it became apparent that an individual needed specific attention determining what went wrong in a lift, hoping to identify errors after the fact.

After we demonstrated MuscleMemory, one coach discussed the increasing prevalence of technology in gyms. "*I mean, they've got a holder on their squat rack for the iPhone so that they can monitor their time or their reps. Everybody uses their mobile device now for everything, for fitness for [pause] so, if the app gave them a beep, and audible, or an audible signal, because they're, you know, looking ahead, it's in the squat rack, they hit depth, bingo.*" (C3) He was enthusiastic about combining MuscleMemory with a mobile application to determine when someone squatted below parallel.

B. Important Mechanics of Squats

We asked athletes and athlete/coaches to perform squats, thinking aloud as they did so, to address what part(s) of squat form they found important. We also asked coaches if some cues worked better than others, and most responded with examples of frequent cues they give their athletes.

1) Coaches Providing Feedback about Squats: Coaches discussed the learning process that went into providing useful feedback for each individual athlete. C5 told us he usually used a mixture of auditory and visual cues until he learned what worked best for an athlete. Another coach identified the complexity of the squat movement addressing all of the different cues that could be used to say the same thing.

"*If someone is struggling with getting that depth, some cues might not work as well for others. So just being able to use multiple cues, whether that be 'Chest up,' or 'Knees back,' or 'Weight back in your heels,' they all, they all kind of get at the same point, but just knowing how each athlete will take it. Or maybe it doesn't work for them, try a different way, kind of thing. So some people it's mobility issues, some people have never squatted to that depth before, also just being able to try different things with each athlete until you figure out what works for them.*" (C4)

C6 mentioned that she was least concerned with depth, and more interested in proper form overall. Due to the complex nature of the squat, she focused on other factors (knees out, chest up) before she addressed depth.

2) Athletes Performing Squats: All athletes and athlete/coaches listed a series of cues while they performed squats. The two biggest cues mentioned were "knees out" and "hips/butt back." We found that all athletes mentioned initiating the squat by bringing their hips or butt back, and all but one athlete mentioned making sure their knees were out during a squat. While five of the eight athletes mentioned their depth when performing squats, we were surprised this was not a bigger concern because they learned the importance of squats below parallel during introductory classes. Athletes focused on multiple body parts to stay in good form which resulted in the correct depth.

C. Coaching Time Management

Coaches generally spent the warm-up portion of class addressing individual athletes and spent the remainder of time observing the class as a whole. Coaches indicated a typical class contained 12 athletes of varying skill levels and speeds, causing them to spend the workout portion "gazing over" the class as a whole. One-on-one time in class settings were rare and usually only occurred with beginner athletes.

D. MuscleMemory Benefits

After one of the authors demonstrated our prototype, participants identified four major uses of MuscleMemory: (1) a learning tool, (2) an extra set of eyes, (3) an objective form of feedback, and (4) a continuity of coaching device.

1) Learning tool: We learned that when athletes had problems getting to full-depth, a coach placed a box or ball under the athlete as a point of reference. One coach indicated, once that object is taken away, the athlete has trouble reaching full-depth again. "*Coaches use a device like [a box] to get people thinking about sitting back onto something, um, but then when that object's not there they ... don't have the same mechanics so they don't have that same sense. But if people can learn to have the proper mechanics while still having some sort of measurable gauge in depth, um, I think that could be a useful tool.*" (AC2) They both mentioned placing objects under athletes as a way of teaching depth and viewed MuscleMemory as an alternate way for people to get comfortable in a squat.

2) Extra Set of Eyes: Participants imagined using MuscleMemory when it is hard to detect incorrect form. "*Coaches can more easily identify which people are having difficulty. ... If there were multiple people using this in a class and can identify which people are not getting below parallel and, you know, address those people specifically rather than having to go around and look at every single person.*" (AC2) AC1 described how it could be useful when squatting alone. "*More information available while training makes everyone better. That's when problems usually arise – when you're not getting feedback. So, you think you're doing things properly when in fact you may not be.*" Participants perceived visual feedback being most useful when performing squats with multiple people needing assistance or alone with no one providing cues.

3) Objective Feedback: Coaches explained the difficulty they faced when determining if an athlete squatted below parallel, while athletes talked about times when they were not sure if they squatted to full depth. They both agreed that our prototype could provide objective feedback about if and when someone reached full-depth in a squat.

Some people who lack the mobility or are overcoming an injury might not be able to perform a squat below parallel.

Coaches indicated MuscleMemory could still provide appropriate feedback. "*It's another way for the coach or clinician, whatever the case may be, to get an objective feedback. I mean ... we tend to have landmarks that we use: the hip crease, the top of the knee. But depending on the person and their physiology and their current level of mobility, parallel or below parallel might not be an appropriate depth for them to get to.*" (C3) Coaches thought MuscleMemory had the potential to ensure their athletes squats as low as they are physically capable. They could still use it to objectively determine if someone reached their target depth, with each depth relative to the person squatting.

4) Competition Setting: Within the program are several high-stakes competitions where athletes are judged on a variety of movements. Many participants mentioned these competitions after we demonstrated MuscleMemory. They noted the importance of athletes training properly for them. As mentioned by C1, "*With those competitive athletes, making sure they're hitting depth every time so when they're judged, they know what it feels like when they hit depth.*" They also discussed inconsistent judging. While judges usually score based on a certain standard, because each athlete gets their own judge, there can sometimes be differing opinions. Two participants talked of replacing judges altogether "*so there is no question... it's hard to tell a parallel air squat a lot of the time, so to be able to standardize that and quickly reference that every time an athlete goes down and hits that position would be huge for a competition setting, too.*" (C5)

5) Continuity of Coaching: While cues depended on the athlete, time spent with an athlete depended on the coach. We expected athletes' time and experience in the program to dictate how much feedback they received, but found "*some coaches are more, you know, they walk around and give everyone a lot [of feedback] and then some don't really.*" (A4) Most coaches discussed how their coaching styles depended on the athlete, and being able to know ahead of time who typically had problems with squats would be beneficial.

C5 presented us with a scenario of an athlete, *Bob Joe*, who always had problems with back squats, " *I'd know that I need to work with an athlete in some regards to their movement. Right? So if... I'm getting a notification out on their back squat, they never hit parallel, well, we have an issue there, right? So Bob Joe might need to work on his ankle flexibility so he can get below parallel, or whatever. You know, hey, his movements need to be fixed here and there. So it would be good to have, you know, a list of being like 'Here are our athletes that are having difficulty getting into a below parallel position.'*"

In addition to being able to personally assess Bob Joe's performance, he discussed ensuring other coaches know the difficulties Bob Joe faced in the gym. "*Let's say I'm not coaching a class, or have a new coach, or that athlete goes to a different class then the one I typically coach, and is working with a coach he's never worked with before, now if they have that information, they're like, 'Hey, Bob Joe has a really hard time getting below parallel.' Um, even though they've never worked with him before, they know that issue exists. That would be really beneficial.*" Coaches tailor their coaching styles depending on the athlete, so substitute coaches could know what techniques work for each athlete - in a sense providing a continuity of coaching.

E. MuscleMemory Drawbacks

We also identified three major limitations of our prototype: (1) general issues with knee sleeves, (2) limited method of feedback, (3) potential dangers of interaction.

1) Knee Sleeves: Some participants had qualms with constantly wearing knee sleeves. Though some mentioned the unobtrusiveness, one athlete and two athlete/coaches indicated that our prototype could get in the way and be too bulky. Two coaches stated they did not like relying on knee sleeves to assist squats, and they should only be worn when attempting a max-weight. "*...If we always wear a knee sleeve, we may rely on it. So when we're doing yard work or working around in the house, we don't have a knee sleeve on.*(C1) Thus, athletes who do not regularly wear knee sleeves may be reluctant to use MuscleMemory.

2) Feedback: Half of the participants (three athletes, two athlete/coaches, and three coaches) were concerned with the visual representation of squat depth because they did not want athletes to look down when they should be looking straight ahead. AC3 pointed out, "*...it's hard to see the light flashing green on the side...I think it would be kind of difficult to be in that squat position, and then, like, making sure to look down, 'cause then you'd kind of move in a weird way, I guess.*" As another participant mentioned, for particularly fast movements, a light may blink too quickly for someone verifying depth. A beep would be an unmistakable notification. "*If I'm working out on my own, I already have it set to a particular degree angle. When I get to that, there's an audible noise and, you know, I know that I'm getting the depth that I want.*" (AC2) Because he would not always have someone around to inform him when the light was green, he suggested feedback as a combination of lights and sound.

3) Interaction: For three participants, feedback issues went beyond being difficult to see, and became about the safety of performing squats while wearing MuscleMemory. Because of the light indicator, the squatter has to look to the side to see if the light flashed green. One athlete and one coach pointed out the potential for a spinal injury. "*Your neck dictates body position. So, if it's only lights, if somebody goes down in the bottom of a squat and they are looking over at the side of their knee to see if they're at parallel or not, that's going to screw up their lift. If they're going to get out of position and potentially put themselves in a dangerous position.*" (C5)

VII. Discussion

As the first exploratory study investigating the perceived benefits of MuscleMemory, a wearable, ambient squat sensing technology, we found it could be used as a learning tool for people first learning how to squat, an extra set of eyes for coaches leading a large class, and a form of objective feedback in cases where it is hard to determine if someone is low enough in their squat. Feedback from participants helped us identify future needs, requirements, and applications of our design to determine actual benefits versus *perceived* benefits.

A. Adoption of New Technologies

While only one coach mentioned using Wodify, we see an increased presence of technology in group-based, high intensity exercise programs. Indeed, Wodify reports that roughly

25% of the communities currently use Wodify to assist athletes monitor their progress and provide coaches with an overview of athlete performance. Based on this and industry interest in health management technologies (e.g., wearable watches tracking health metrics), we think it is likely that athletes and coaches would adopt other technologies that could track their athletes' performances.

Since six participants used Coach's Eye while in the gym, we were not surprised by their suggestions for combining MuscleMemory with a mobile application. While Coach's Eye provides subjective, post-squat feedback, MuscleMemory provides real time, objective feedback and, in future iterations, could instantly inform a coach that an athlete was having a problem and log information for later reflection.

Safety was constantly mentioned when we talked about MuscleMemory. They noted the importance of proper form and gaze free from distractions. Therefore, mobile applications that are used *in situ* may not be appropriate for high intensity exercise communities. Functionally, MuscleMemory met more needs than we anticipated, however with respect to form, we need to consider an enclosure that is not considered a crutch and feedback that does not compromise squat mechanics. Though we built MuscleMemory using neoprene knee sleeves that athletes were already wearing in the gyms [10], some participants had problems with bulkiness and reliance that can result from overuse. From this, we think exploring multiple enclosures, as used for PT Viz [4], would reduce over reliance. To reduce the bulkiness of our design, we could use an accelerometer and sticker circuits, a simple and flexible alternative to breadboards [25].

When we designed MuscleMemory, we thought an audible cue would be an annoyance for athletes when multiple athletes were present. We chose lateral, visual feedback so athletes could use the lights to encourage each other. We found, however that participants were more interested in how the coach could use MuscleMemory to help athletes, than how athletes could use it to help each other. Eight of the fourteen participants requested audio feedback so they would know when they have reached depth without compromising form. In future iterations, we will explore various methods of feedback to identify what is appropriate for this community.

The Fixometer[2] is an exemplar example of our design consideration. Form-wise, because the NODE[4] is attached directly to the kettlebell, it is not a distraction to the athlete and therefore does not add any extra risk to the exercise. Functionally, it provides useful feedback - to the athlete and observers - about an athlete's performance in a competition setting by beeping and lighting up depending on an athlete's action. As one participant mentioned, the Fixometer is often used in competitions, where settings are a lot more structured. We must consider feedback appropriate in the context of noisy gyms. Despite the proliferation of phones, ***we encourage the design community to consider safety, form, and function when designing technologies used in high intensity exercise communities***.

B. Aiding Squats

We found that coaches and athletes thought MuscleMemory could be used as a learning tool. Instead of using – and potentially over relying on – an object like a box, it has the potential to help athletes recognize how low to squat without an object on which to sit. While five of the eight athletes mentioned depth while squatting, it was not their biggest focus. This may be due to the complexity of the movement or that individuals can't see their depth. As C1 mentioned., sometimes his athletes tell him "*Well, Coach, I can't see my depth. I don't know if I'm going low enough.*" MuscleMemory provides an abstraction for squat depth similar to abstractions for heart rate provided by Sweat Atoms [19], Social Fabric Fitness [8], and Open Heart Helmet [9]. In the context of community, athletes did not express a concern sharing data about their squat depth, similar to findings of [8] where runners were not concerned with their biometric data being displayed.

Participants said the objectiveness of the prototype would keep them accountable and hold them to a certain standard when squatting. Instead of viewing a coach as "nit-picky," users could see that their squats were not deep enough, and understand why a coach is providing certain feedback. Though one participant said that depth feedback was like a "*pat on the head*," similar to YourWellness [18], we believe athletes will find it motivating. ***We encourage designers to develop a system that is flexible and encouraging enough for athletes to incrementally improve their squats.***

C. Continuity of Coaching

C3 discussed the difficulty of anticipating how many athletes would be in the gym at a given time, and how useful it would be if he could access information on athletes he did not normally coach. By tracking long-term movement patterns, a newer coach could be familiar with an athlete's squats regardless of previous interactions. In a sense, we are providing a system that facilitates continuity of care for athletes in high intensity exercise communities. The medical community has well-documented and researched practices to provide patients a consistent standard of care [26]. In this community, however, if a new coach comes into the gym or an athlete changes gyms, there is nothing to provide athletes with consistent coaching experiences. As C5 mentioned in the case of Bob Joe, it would be beneficially to provide mechanisms for coaches to share information. They could use MuscleMemory as a training tool to come to a consensus on helping certain athletes, similar to Abaris, an independent monitoring app that provided therapists feedback to unify their assessment techniques [3]. When designing future feedback systems for this community, ***it is imperative that the system provides information on which coaches can collaborate on the feedback needs (e.g., does not reach full depth) and styles (e.g., what cues work) of particular athletes.***

D. Limitations

Here we address four main limitations with our study. First, feedback about our prototype could be overly positive due to the communities' existing practices. Second, our participant demographics were not diverse. Eleven out of fourteen participants were 22-28 years of age, however our sample is representative of other studies in these communities [6], [27], [28]. Third, while participants were interviewed as either a coach or an athlete, four out of eight of the athletes we interviewed were also coaches. Some of their responses may have been a result of their coaching experiences instead of their experiences as athletes. Fourth, no participants performed squats while wearing MuscleMemory - they observed a researcher wearing it while squatting. Perceived usability may change after interacting with it. Despite these limitations, we believe we established a desire and design space for squat sensing technology in high intensity exercise programs.

E. Future Work

Overall, we found athletes and coaches wanted different methods of feedback. To ensure safety of the user, future work will explore different forms of feedback most useful in the context of group-based, high intensity exercise communities. We concluded from coaches that squats below parallel are more involved than depth and that a wearable should not cause someone to compromise form for the sake of depth. We will pursue different methods for sensing proper squat form such as using accelerometers. Athletes may get the most out of a wearable that detects distance between knees, stance, and gaze along with depth. Lastly, we will explore different wearable components. As some participants mentioned, neoprene knee sleeves should not be continuously worn.

F. Conclusion

Our work describes feedback for a wearable technology that senses squats below parallel. Wearers are encouraged to reach full depth so they can receive all the health benefits of squats. We found our technology has the potential to improve how coaches provide feedback to their athletes, how athletes perform squats, and how information is shared between coaches. Future work should deploy MuscleMemory in these communities to evaluate real over perceived benefits.

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