TingleTouch: Touch Guidance through Electrical Stimulation in Resistance Training

ANONYMOUS AUTHOR(S)

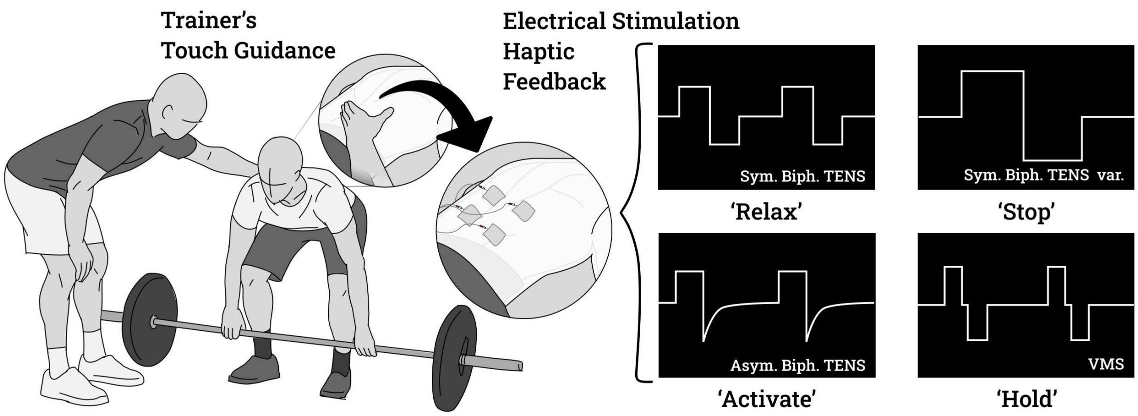


Fig. 1. *TingleTouch* explores how electrical stimulation can replicate a trainer's touch guidance in resistance training. Based on interviews and sports mechanics, we identified four key instructional messages and designed corresponding haptic feedback patterns using distinct EMS signals. ① *Relax* (Symmetrical Biphasic Transcutaneous Electrical Nerve Stimulation (TENS)), ② *Stop* (Symmetrical Biphasic TENS variation), ③ *Activate* (Asymmetrical Biphasic TENS), and ④ *Hold* (Variable Muscle Stimulation (VMS)).

In resistance training, trainers employ touch guidance to help trainees control posture and activate muscles. Haptic feedback can extend this support to solitary workouts, but translating the nuances of touch into effective haptic patterns remains challenging. In this paper, we categorize the instructional messages conveyed through trainers' touch guidance and design electrical stimulation patterns to replicate them. A preliminary study with six trainers and six trainees identified four core messages underlying touch guidance. We then designed electrical stimulation patterns for each message and refined them with two sports scientists and a UX designer, ensuring usability and grounding. Finally, sixteen gymgoers evaluated these patterns in an exercise context. Participants reliably distinguished the feedback and used the instructed muscles accordingly, achieving accuracies of 97.14% and 99.22% across two sessions, cross-checked with EMG and pose estimation. These findings demonstrate that the proposed electrical stimulation feedback is intuitive and learnable.

CCS Concepts: • **Human-centered computing → User studies**; *Empirical studies in HCI*.

Additional Key Words and Phrases: Resistance Training, Mind-Muscle Connection, User-Centered Design, Electrical Stimulation

Manuscript submitted to ACM

ACM Reference Format:
Anonymous Author(s). 2026. *TingleTouch*: Touch Guidance through Electrical Stimulation in Resistance Training. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '26), May 13–17, 2026, Barcelona, Spain.* ACM, New York, NY, USA, 24 pages. https://doi.org/10.1145/3613904.3642575

1 INTRODUCTION

In resistance training, proper muscle activation, form control, and movement safety are often supported by direct physical cues from personal trainers. These cues—commonly referred to as "hands-on correction and spotting" [4], "tactile cues" [37], "tactile motion instruction" [48], or "touch training" [10]—are collectively described in this work as *touch guidance*.

Touch guidance enhances training performance by reinforcing the mind-muscle connection [5, 44], improving muscle-specific focus [37], and signaling that movement execution is being monitored [29, 41]. It is especially helpful for novice trainees learning complex movements. However, such guidance is typically limited to in-person training sessions and may be constrained by ethical concerns, gender sensitivity, or lack of access to professional coaching.

To address these limitations, we envision touch-equivalent guidance through haptic feedback, enabling effective instruction even in solitary training environments. Electrical stimulation is particularly well suited for this purpose, as it can deliver surface tactile sensations [52], deep pseudo-kinesthetic sensations [23, 28], and perform isometric muscle contraction [45]. These characteristics allow stimulation intensities to be adjusted to reflect different coaching intentions, similar to real trainer interactions.

In this paper, we propose *TingleTouch*, a haptic feedback design that delivers the intended message of touch guidance through electrical stimulation. The goal of this study is to understand the semantics of touch guidance and translate them into distinguishable and learnable haptic patterns. Our research is structured around two main questions:

RQ1. What messages do trainers communicate through touch guidance?

RQ2. How can these messages be transformed into replicable haptic feedback?

To explore these questions, we first conducted qualitative interviews with six personal trainers and six trainees to understand existing touch guidance practices. We then synthesized six key instructional intentions, which were consolidated into four core messages—*Relax, Stop, Activate,* and *Hold.* Each message was translated into a distinct electrical stimulation pattern using the Chattanooga Intelect Mobile 2 Combo device, ensuring clinical safety and technical fidelity.

To evaluate our haptic feedback design, we conducted a user study with sixteen gymgoers. The study confirmed that the electrical stimulation patterns were intuitive and could be learned quickly, as participants reliably identified the intended messages after brief familiarization.

This paper bridges sports science and haptic technology by formalizing the instructional role of touch in training and demonstrating how these cues can be digitized for remote delivery. The key contributions of this work are:

- Identification of six trainer messages underlying touch guidance practices through qualitative interviews and a focus group.
- Consolidation of these messages into four key categories and their translation into electrical stimulation haptic feedback patterns, refined with input from sports science and UX experts.
- Experimental validation of the feedback design's recognizability and learnability in an exercise context through a user study with active gymgoers.

2 RELATED WORKS

2.1 Touch Guidance in Resistance Training

Touch guidance is a fundamental and indispensable element in physical education due to their inherently physical nature and the difficulty of conveying all instructions in words [26]. Hands-on guidance in personal training is employed to aid in movement sequencing and coordination while also ensuring active involvement from both the trainer and the trainee throughout the session [4]. Previous research revealed that the touch guidance used in personal training improves trainees' performance through the mind-muscle connection. The mind-muscle connection refers to the practice of imagining the contraction of specific muscles while performing exercises, combining mental imagery with physical action [6]. Researchers [5, 37] explored how focus on specific muscles via tactile or auditory guidance during exercises (e.g., bench presses, arm curls) affects their muscle activation and found that it increased muscle activity. Moreover, tactile cues can provide an intuitive explanation of the location of the target muscle to novice trainees [49]. In fact, prepping muscles with touch guidance has been shown to increase and accelerate muscle activation compared to no stimulation [37, 45].

Despite the positive effects of touch guidance, touch has been pathologized in the sports community due to the risk of being accused of sexual harassment [26]. This negatively impacts trainees, as they are unable to receive detailed and personalized guidance, as revealed in our preliminary interviews with them. We envision that future resistance training will become more personalized and less invasive through the integration of haptic technology.

2.2 Haptic Wearables in Sports and Fitness Context

The sense of touch, haptics, involves tactile sensations felt on the skin (e.g., pressure, vibration, temperature change) and kinesthetic sensations related to the awareness of body position and movement when muscles and joints are engaged by external force [21]. Haptic researchers used various technologies (e.g., vibrotactile [38], electrical [56], magnetic [39], pneumatic actuators [11]) to replicate these natural touch sensations into controllable tactile (i.e., cutaneous) and kinesthetic (i.e., proprioceptive) feedback [1].

In the sports and fitness context, haptic wearables have been used in various ways, such as tracking biomedical parameters and performance [17, 50, 53], providing motion guidance [33, 57] and error notifications [16], enhancing workout intensity [51, 55], and simulating physical interactions in VR exergames [24, 51]. Regarding the stimulation method, vibrotactile [31] and electrical stimulations [33] were explored.

Vibrotactile Stimulation: Vibrotactile stimulation was used to provide tactile feedback in various sports training, such as skating [50], snowboarding [47], running [53], golf [57], climbing [16], and weightlifting [25] for its compact size, robustness, and ease of manipulation. Some researchers [16, 50, 57] used vibration to signal movement errors. For example, Stewart et al. [50] enabled roller derby skaters to monitor their performance using a vibrotactile pulse that reflected the inconsistency of their arm swinging motions. Similarly, Woźniak et al. [57] attached vibrotactile motors on the novice golfers' elbows and knees to notify the foot misalignment and elbow position error, and Feeken et al. [16] proposed shoe-based wearables with vibration patterns to alert climbers to insufficient leg power or rushed movements. Meanwhile, some researchers [30, 47] convey directional guidance through vibrotactile feedback. They created a tactile illusion of a stroking sensation by sequentially activating multiple vibration motors [18, 47]. This induced sensory saltation, which was used to guide directions or represent a pushing or pulling sensation [48].

Spelmezan [47], for example, placed vibration motors around the shoulders and thighs to guide turning (left or right) and weight shifting (forward or backward).

Electrical Stimulation. Unlike vibration, electrical stimulation can simulate both tactile and pseudo-kinesthetic sensations [28, 45] by varying pulse widths and intensities. Shorter pulse widths (50-125 µs) and lower intensities provide tactile feedback on the skin, while longer pulse widths (150-350 µs) and higher intensities cause muscle contraction [45]. The former is commonly known as Transcutaneous Electrical Nerve Stimulation (TENS), and the latter is referred to as Electrical Muscle Stimulation (EMS).

Both sensations have been conventionally used in rehabilitation for different purposes—TENS to alleviate pain and EMS to induce muscle contraction for post-injury strengthening [23]. Building on this, the HCI and sports communities have repurposed them for various applications. Researchers applied TENS to provide real-time haptic feedback on the skin surface in the virtual environment for immersive game experiences [56] and directional guidance for navigation, using sensory saltation [52]. Meanwhile, EMS is used to increase muscle activity for effective workouts in both real [9, 34] and virtual environments by supporting or impeding muscle contraction [7, 24]. Especially in resistance training, EMS has shown promising results in promoting muscle growth [19, 43], so EMS training with full-body suits has been increasing [14].

While both vibration and electrical stimulation have been extensively explored in sports and fitness contexts, research comparing vibrotactile and electrical stimulation reported that participants found electrical stimulation more effective for muscle distinction and more accurate for shape recognition [45, 52].

Our research explores electrical stimulation haptic feedback as a substitute for physical touch guidance. While it is less explored for delivering motion instructions, electrical stimulation offers a unique ability to provide a wide range of tactile [56] and kinesthetic [28] sensations with greater accuracy than vibration [52]. This makes it a promising alternative for delivering precise and customized instructions, similar to the touch guidance provided by personal trainers.

2.3 Haptic Feedback Design for Motion Instruction

Many studies have explored haptic feedback design to evoke different emotions (positive or negative) for notification purposes [42], including with a social robot [46], mobile phones [40], social communication platforms [2], and mid-air haptics [36]. However, only a few have used it to correct users' posture during physical activities (Section 2.2). Spelmezan et al. [47, 48] was the first to design haptic feedback for motion instruction. They first categorized tactile instructions in snowboarding into five types (stretching or flexing, shifting lower body weight left or right, leaning upper body left or right, moving forward or backward, and turning upper body left or right). Then, they devised two concepts: using a single vibration as a push and pull metaphor and triggering three vibration motors in a row for sensory saltation of stroking sensation. McDaniel et al. [30] aimed to generalize these concepts to a variety of body movements beyond specific sports by mapping both fundamental movements and vibration directions to the three primary body planes: the sagittal plane (flexion and extension), the frontal plane (abduction and adduction), and the horizontal plane (rotation). More recently, Ushiyama and Lopes [52] suggested using electrotactile in place of vibrotactile to provide more accurate feedback during yoga and walking.

Building on previous research, we investigate how haptic feedback can be used to deliver motion instructions for resistance training. We also test a variety of electrical stimulation signals, including both TENS and EMS, to translate these instructions into feedback. To the best of our knowledge, this integrated approach has not been explored before.

3 UNDERSTANDING TOUCH GUIDANCE

Personal trainer's touch guidance is discussed in various related works in sports [4, 10] and HCI communities [48], but the specific touch methods and their intentions remain unclear. To understand current practices, challenges, and differences in training experiences with and without touch guidance, we conducted preliminary interviews with both trainers and trainees.

3.1 Methods

Three interviews were conducted: 30-minute semi-structured individual interviews with six trainees, 60-minute semi-structured individual interviews with six trainers, and a 2-hour focus group interview (FGI) with six trainers. The focus group interview aimed to gain a deeper understanding of the complexity and variability of touch guidance practices revealed in the individual interviews with trainers (Figure 2). All interviews were conducted online via Google Meet.

Participant. We recruited participants by posting in a university's online student community, reaching out to local fitness centers, and using snowball sampling. For trainers, we additionally recruited participants through referrals from trainees. Six trainees (3 females and 3 males) have engaged in weightlifting workouts for 1-20 years ($M : 5.33, SD : 7.26$) and worked out with a personal trainer for 3-16 months ($M : 10.17, SD : 4.75$). Six trainers (2 females and 4 males) have 6-20 years of resistance training experience ($M : 10.67, SD : 5.01$) and 2-10 years of teaching experience ($M : 6.17, SD : 2.71$). Lastly, six trainers (3 females and 3 males) for the FGI have 5-22 years of resistance training experience ($M : 10.40, SD : 6.15$) and 2-10 years of teaching experience ($M : 5.67, SD : 3.39$). For fresh perspectives, two trainers were newly recruited from different gyms, while four were the same participants from the individual interviews. Participants were compensated based on minimum and hourly wage for their expertise, 10 USD per hour for trainees and 20 USD per hour for trainers.

Interview Procedure. Interviews with trainees began with a broad discussion of how their exercise experiences differed with and without trainers to objectively assess the perceived impact of touch guidance. We initially waited to see if the topic of touch guidance naturally came up. Next, we asked about trainees' workout experiences with and without touch guidance from trainers. We then asked whether they desired such touch guidance during solitary workouts.

Individual interviews with trainers focused on questions about the standard practices of touch guidance. These questions included subtopics such as the different contact areas, types of tactile stimuli, contact timing, accompanying voice guidance, as well as their perceived usefulness and associated precautions.

The FGI with trainers began with a brief 10-minute orientation and ice-breaking session. Following this, we first collected the names of weightlifting exercises that participants have applied touch guidance. Then, we selected frequently mentioned exercises and asked the participants to act out and describe their teaching workflow. After observing and listening to their teaching procedures, we asked follow-up questions (e.g., frequent mistakes made by trainees without touch guidance) to help them verbalize their true intentions. Participants were also asked to talk about the differences in their teaching methods.

***Analysis*.** We transcribed all interview recordings for analysis. After initial coding, we extracted key quotes and analyzed the data using thematic coding [3]. After the first author developed an initial codebook, we defined and refined themes through discussions. This process continued until no further insights emerged. Common themes identified from trainee interviews included the effects of touch guidance, solo training strategies, and criteria for selecting trainers. Themes from trainer interviews included social and physical barriers, prerequisites for haptic wearables, and the diversity of touch guidance. The focus group interview analysis categorized perspectives on shared intentions among trainers regarding touch guidance.

3.2 Findings from Trainee Interviews

The Effect of Touch Guidance. Trainees reported that touch guidance played a critical role in their understanding of muscle activation and movement during workouts. Compared to verbal instructions or visual demonstrations, tactile feedback helped them identify which muscles to engage and when to activate them. All trainees acknowledged a significant difference between trainer-led and solitary workouts, particularly in workout intensity, concentration, and comprehension.

Solo Training Strategies. Trainees used various strategies to compensate for the absence of real-time touch guidance in solo workouts. Many trainees (5 out of 6) relied on self-touch to recall trainer cues. Trainee P2 described: *"When I work out by myself, I try to recall and focus on the muscle my trainer touched and check if it's properly engaged during the workout, between repetitions, or after completing the exercises. [...] I usually do this in workouts like Lat Pull Down or Dumbbell Row."*

However, they acknowledged that this method was limited in exercises involving large or complex movements, as they could not easily reach the target muscles. Some trainees also relied on alternative cues, such as focusing on movement patterns learned in trainer-led sessions.

In addition, some trainees sought external tools to aid their solo training. They mentioned using mirrors for visual feedback, recording videos for self-assessment, or applying resistance bands to simulate the feeling of external guidance. Despite these adaptations, trainees emphasized that none of these strategies fully replicated the benefits of direct touch guidance.

Criteria for Selecting Trainers. Tactile instruction played a role in how trainees evaluated and selected trainers. Some participants (P1, P3, P4) preferred trainers of the same gender to receive more detailed guidance. For example, all trainees received tactile instruction during Deadlifts, but in Bench Presses and Squats, where target muscles were near private areas, only participants with same-gender trainers received tactile instructions.

Trainees also assessed trainers based on their ability to communicate physical cues effectively. Beyond technical expertise, they valued trainers who provided clear and comfortable touch guidance without hesitation or uncertainty. This reinforced their trust in the trainer's knowledge and ability to enhance their workout experience.

3.3 Findings from Trainer Interviews

Social and Physical Barriers in Touch Guidance. Trainers highlighted several challenges in using touch guidance, both physical and social. From a physical standpoint, they were limited by the reach of their hands, particularly in large compound movements. Trainers often touch only one side of the trainee's body or use resistance bands as a substitute to convey the same cues.

Social barriers also influenced the use of touch guidance. Trainers were cautious about respecting personal boundaries, particularly when working with trainees of the opposite gender. While touch was used more freely for back and shoulder exercises, it was often modified or avoided in exercises where target muscles were near sensitive areas. Similar concerns were reflected in trainee interviews, with some trainees preferring same-gender trainers for this reason.

The Diversity of Touch Guidance. Trainer interviews revealed significant variability in how touch guidance was applied. Unlike verbal or visual instructions, touch cues lacked standardized methods, resulting in diverse approaches among trainers. For example, the same stroking motion was used to reinforce proper posture in some cases and to relax overactive muscles in others (Figure 2.ⓐ).

All trainers noted that they had not received formal training in touch guidance, instead developing their own techniques through observation and hands-on experience. As a result, they employed a variety of methods—including tapping, pressing, pinching, squeezing, and poking (with fingers or a pen)—to enhance muscle awareness (Figure 2.ⓑ).

Nevertheless, this diverse approach also aimed to provide a more customized intensity based on the trainee's condition. Trainer P3 explained: *"As trainees' senses become more refined, it's important for trainers to adjust the level of stimulation. If it's too weak, they can't feel it, and if it's too strong, it can cause sharp pain, distracting them from the workout."*

In this context, trainers expected new technology to provide a diverse range of tactile stimuli with adjustable intensity, ensuring adaptability to various training needs and preferences.

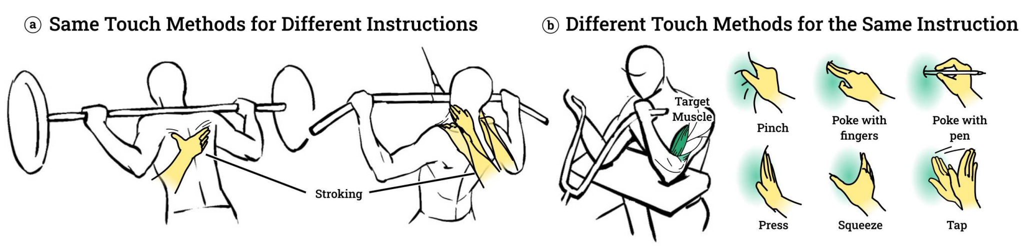


Fig. 2. Diversity of touch methods.

3.4 Findings from Focus Group Interview: Six Key Messages in Touch Guidance

Given the variation in touch guidance, trainers in the focus group discussed the key messages they aimed to convey to trainees. As shown in Figure 3, six key messages in trainers' touch guidance were identified based on various training examples shared during the FGI.

- ***MSG ① 'Relax' to restrict overused muscles.*** Trainers frequently touch adjacent muscles instead of the target muscles to restrict their engagement. Muscles like trapezius, arm muscles, and anterior thigh muscles are usually well-developed in the trainees' daily lives and have a tendency to overpower the target muscles, such as latissimus dorsi and hamstring muscles. So, trainers touch these overactive muscles to remind trainees to disengage them in workouts for balanced muscle development (Figure 3.ⓐ-ⓒ).
- ***MSG ② 'Stop Here' to set limits on movement range.*** Trainers also use their hands as static markers to indicate the workout goal. They place their hands at the end of correct motions, providing a reference for the precise form (Figure 3.ⓓ-ⓕ). For example, Trainer P4 mentioned, *"Placing the hands next to the (inner side of)*

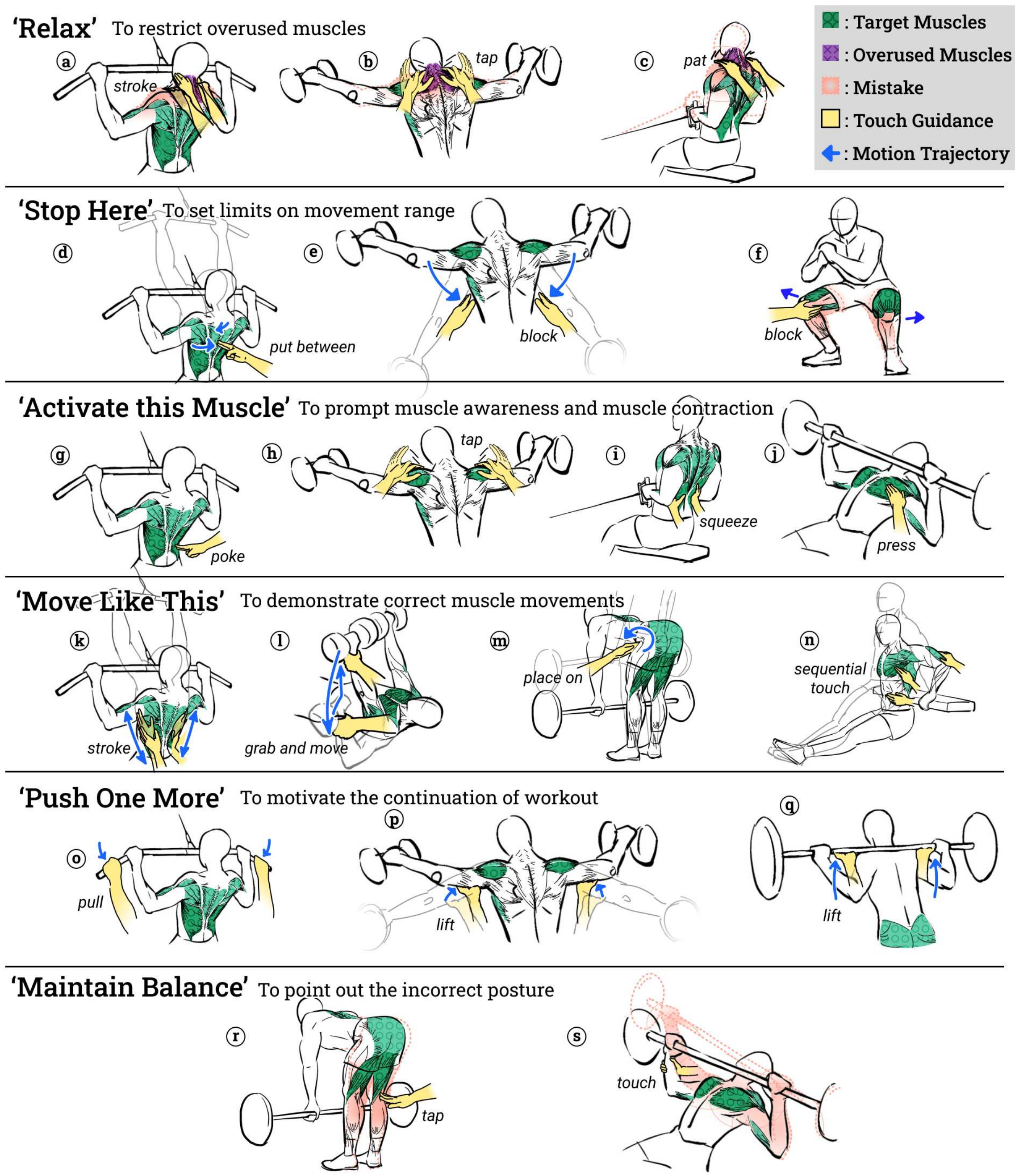


Fig. 3. Six messages in touch guidance and various examples.

knees (during squats) helps trainees maintain outward tension on their knees. This is particularly beneficial for those who have knee caving issues."

- ***MSG ③ 'Activate this Muscle' to prompt muscle awareness and muscle contraction.*** The most commonly mentioned touch guidance involved touching the target muscle area to help trainees develop a heightened awareness of their muscle movements. Trainers noted that this guidance is frequently used with beginners who struggle to identify which muscles to engage during exercises (Figure 3.ⓖ-ⓙ).
- ***MSG ④ 'Move Like This' to demonstrate correct muscle movements.*** When teaching new exercises, trainers often use their hands to demonstrate proper muscle movement. This guidance may focus on illustrating the movement of a specific muscle or demonstrating how multiple muscles engage in a sequence (Figure 3.ⓚ-ⓝ).
- ***MSG ⑤ 'Push One More' to motivate the continuation of workout.*** Trainers stated that assisting touch motivates trainees and helps target muscle overload. In exercises like Side Lateral Raise, they may support by lifting the trainee's arm or body as a variation of spotting [1]. However, due to safety and privacy concerns, direct contact is rare and usually limited to novices using lightweight equipment (Figure 3.ⓞ-ⓠ).
- ***MSG ⑥ 'Maintain Balance' to point out the incorrect posture.*** Touch guidance was also used to draw trainees' attention to imbalances. It's common for people to lose balance during exercise, whether due to the complexity of movements, such as weight shifts, or innate physical traits like limb length discrepancy. To address this, trainers gently touch the side that's off-balance, signaling the need for correction (Figure 3.ⓡ,ⓢ).

3.5 Summary

Ultimately, a common finding across all interviews was the importance of touch guidance in both solitary and trainer-led workouts, as well as the need for alternative methods of delivering it. Also, the interviews revealed that touch guidance conveys a broader range of messages beyond muscle awareness, and that specific touch guidance vary among trainers. Lastly, the focus group interview identified six key messages that trainers aim to convey through touch: ① *Relax*, ② *Stop Here*, ③ *Activate This Muscle*, ④ *Move Like This*, ⑤ *Push One More*, and ⑥ *Maintain Balance*.

4 DESIGNING HAPTIC FEEDBACK

To explore replicable haptic feedback for conveying the six key messages from the preliminary study, we designed initial patterns using electrical stimulation as an exemplary approach. We then refined these patterns in consultation with external specialists: two sports scientists and a UX designer.

The sports scientists, a certified weightlifting instructor with four years of teaching experience, specialize in sports rehabilitation using electrical stimulation. The UX designer has eight years of experience in UX design, focusing on healthcare technology. All three experts have experience in providing and receiving touch guidance during resistance training.

Electrical Stimulation as Haptic Feedback. The preliminary study results suggest the need for diverse sensations with adjustable intensity. Among various haptic technologies that meet these criteria—including vibrotactile feedback [16, 25] and shape memory alloys [20, 32]—we selected electrical stimulation as the exemplary haptic feedback method. This choice stems from its superior accuracy compared to vibration-based feedback [45, 52] and its unique capability to provide both surface-level tactile stimulation and deep muscle stimulation [23, 28, 45]. These stimuli can replicate trainers' diverse touch techniques, from light tapping to grabbing and pushing. Furthermore, electrical stimulation is a

[1]https://en.wikipedia.org/wiki/Spotting_(weight_training)

well-established technology in the healthcare industry, widely applied in fitness training, physical therapy [13], and rehabilitation [15].

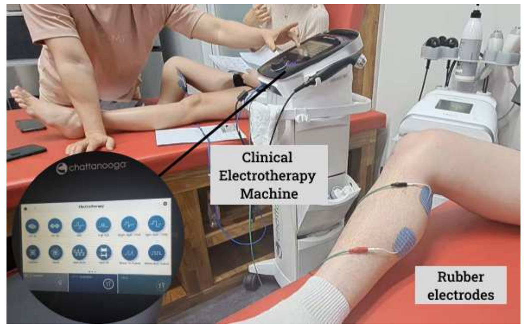


Fig. 4. Electrical stimulation test setup: 2"x2" self-adhesive electrodes were placed at the start and end points of the participant's gastrocnemius muscle. After calibrating the intensity for each person, various clinical electrotherapy settings were applied.

Procedure. For the initial haptic feedback design, we began by exploring various electrical stimulation patterns and created six distinct feedback types. Using an iterative process of elimination and discussion, we matched each feedback type to the most appropriate message. As shown in Figure 4, we utilized the Chattanooga Intelect Mobile 2 Combo[2], a device widely recognized as the gold standard in rehabilitation. To ensure safety, one of the authors, certified in rehabilitation with electrical stimulation, trained the team, and the study was approved by our Institutional Review Board. We tested various electrotherapy settings on the calf muscle, as it has demonstrated a fast response in previous research [45].

Fig. 5. Review process: ⓐ haptic feedback experience, ⓑ discussion.

After designing the initial feedback, we invited an external experts for a review. This review was conducted in two sessions (Figure 5). In the first session, they experienced the initial haptic feedback we designed and discussed its suitability and feasibility for the use in workouts. In the second session, we discussed the technical requirements and design challenges for wearables using electrical stimulation. The review process took six hours in total, and experts were compensated with 100 USD.

[2]https://www.chattanoogarehab.com/intelect-mobile-2-combo-15-1204-int

4.1 Initial Haptic Feedback Design

Table 1 presents our initial haptic design for the six trainer messages. Those were developed based on three distinct waveforms: ***Symmetrical Biphasic TENS (Transcutaneous Electrical Nerve Stimulation)***, which smoothly induces muscle contraction, preventing sudden spasms and making it suitable for long-term use; ***Asymmetrical Biphasic TENS***, which provides deeper localized stimulation of muscles; and ***Variable Muscle Stimulation***, which enhances muscle activation while preventing neural and muscular adaptation and reducing fatigue [8, 13].

- ***Symmetrical Biphasic TENS***: This waveform has a short symmetric pulse duration and stimulates nerve fibers in the skin and muscles, depending on the voltage. It effectively induces muscle contraction while minimizing skin sensation, ensuring a comfortable experience. In addition, its balanced current delivery prevents static charge accumulation in tissues, reducing skin irritation and allowing for long-term use.
- ***Asymmetrical Biphasic TENS***: This waveform has a short asymmetric pulse duration that targets both the skin and muscles. Due to its brief pulse, it remains tolerable even at higher intensities, producing a sensation similar to an intermittent, slight pinch. It is particularly effective for activating specific peripheral nerves, making it beneficial for muscle re-education and pain relief. Also, it is widely used for compensating for muscle weakness.
- ***Variable Muscle Stimulation (VMS)***: VMS is a symmetrical biphasic waveform with a 100 μsec interphase interval, minimizing skin load. By continuously varying frequency, intensity, and pulse width, it prevents neural and muscular adaptation while reducing fatigue. This dynamic stimulation enhances muscle activation, promotes blood flow, and supports tissue recovery, making it effective for both athletic training and rehabilitation therapy.

By adjusting parameters such as frequency, intensity, and cycle duration, we generated six distinct sensations. Considering individual differences in sensitivity to electrical stimulation due to muscle mass and fatigue, we calibrated the intensity for each participant, ensuring it was noticeable during movement but neither painful nor uncomfortable. After confirming that all six sensations were distinguishable, we mapped each haptic feedback to its corresponding message through discussion.

Feedback	**Waveforms**	**Variation**	**Intensity**	**Sensation**	**Message**
Feedback ①	Sym. Biph. TENS	NA	10.5mA	gentle vibrations in large area	*Relax*
Feedback ②	Sym. Biph. TENS	Frequency: 200 pps Burst Frequency: 2bps	14.5mA	strong tapping on localized area	*Stop Here*
Feedback ③	Sym. Biph. TENS	Frequency Sweep On	12.0mA	tightening of the large area followed by tapping on localized area	*Activate This Muscle*
Feedback ④	Asym. Biph. TENS	Burst Frequency: 1bps	13.0mA	intermittent slight pinch sensations on the area	*Move Like This*
Feedback ⑤	VMS	NA	13.0mA	strong muscle contraction and soft to no relaxation	*Push One More*
Feedback ⑥	VMS	On/Off Cycles: 1 sec	20.0mA	strong and fast muscle contraction and relaxation	*Maintain Balance*

Table 1. Six feedback configurations with their corresponding messages. Low and high intensity are specific to each participant, while the listed intensity is the median of the authors.

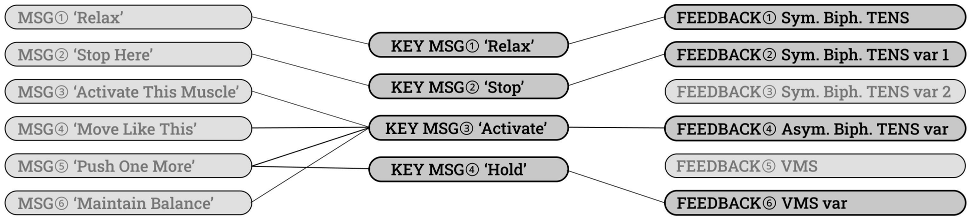


Fig. 6. Summary of the design process: Four key messages were distilled from the initial six messages and remapped to the appropriate electrical stimulation haptic feedback with experts.

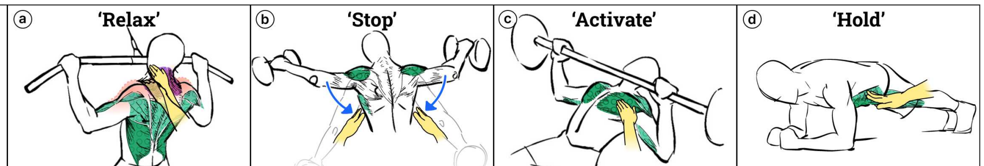
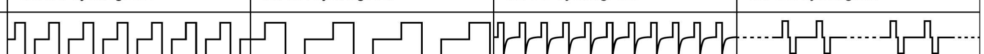
	ⓐ 'Relax'	ⓑ 'Stop'	ⓒ 'Activate'	ⓓ 'Hold'
Touch Guidance				
Purpose	To restrict overused muscles	To set limits on movement range	To prompt muscle awareness and muscle contraction	To prompt maintaining an already activated muscle
Preset	Symmetrical Biphasic TENS	Symmetrical Biphasic TENS	Asymmetrical Biphasic TENS	Variable Muscle Stimulation
Setting	Pulse Duration: 300 µs Frequency: 50 pps Burst frequency: off On/Off Cycling: Off	Pulse Duration: 300 µs Frequency: 20 pps Burst frequency: 2 bps On/Off Cycling: Off	Pulse Duration: 300 µs Frequency: 80 pps Burst Frequency: 1 bps On/Off Cycling: Off	Pulse Duration: 300 µs Frequency: 60 pps Burst Frequency: off On/Off Cycling: 1 s
Signal				
Sensation	Gentle stimulation over a broad area	Intense stimulation concentrated in a localized region	Intermittent, mild stimulation in the targeted area	Rapid and forceful muscle contraction followed by relaxation

Fig. 7. **The final four haptic feedback designs** are: ⓐ ***Relax* feedback**, which provides a gentle vibration over a large area with a tingling sensation, ⓑ ***Stop* feedback**, which delivers strong tapping in a localized area with an alarming effect, ⓒ ***Activate* feedback**, which creates intermittent light pinching, resembling a heartbeat, and ⓓ ***Hold* feedback**, which induces rapid and strong muscle contraction and relaxation, mimicking a firm gripping sensation. The listed intensities are the median of the authors, and will be calibrated for each participant in the user study.

4.2 Final Haptic Feedback Design

The sports scientists emphasized that, from a muscle kinematics perspective, although the six messages serve distinct purposes and meanings in weight training, some elicit the same type of muscle activation when conveyed through haptics. This redundancy suggested that certain messages could be effectively combined without compromising their intended function. The UX designer also expressed concern about cognitive load, noting that users would need to distinguish between six different feedback types while simultaneously performing cognitively and physically demanding resistance training tasks. Consequently, we consolidated the six messages into four based on muscle activity and remapped the haptic feedback to more accurately convey the updated messages (Figure 6). In detail, *'Move Like This,'*, *'Maintain Balance'*, and *'Push One More'* messages could be grouped under the single message *'Activate This Muscle,'* as all these messages involve muscle contraction. Specifically, moving involves sequences of different muscle contractions, and maintaining balance requires alternating contractions of muscles on opposite sides. However, during discussions about the success or failure of attempting one more repetition (*'Push One More'*), we identified a unique aspect. The sports scientists informed us the goal of touching a trainer's body or the bar when a trainee can no longer lift is not to make them complete another repetition, but to encourage them to push their muscles to the limit. In this regard, the *'Push One More'* message differs from the *'Activate This Muscle'* message, as it focuses on "maintaining an already activated muscle" rather than "initiating the activation", as explained by the sports scientists. Based on this insight, we added new *'Hold'* message. The sports scientists emphasized that this instruction is essential in various exercises, such as holding at the point of maximum muscle contraction for a few seconds during a Side Lateral Raise and performing isometric exercises like Plank and Crunch, where the muscle length remains constant. The four key messages distilled from the original six are as follows (Figure 7):

- **KEY MSG ①. *'Relax'* to restrict overused muscles**: retained
- **KEY MSG ②. *'Stop'* to set limits on movement range**: renamed from MSG ② *'Stop Here'*
- **KEY MSG ③. *'Activate'* to prompt muscle awareness and muscle contraction**: combined MSG ③ *'Activate This Muscle'* + MSG ④ *'Move Like This'* + MSG ⑤ *'Push One More'* + MSG ⑥ *'Maintain Balance'*.
- **KEY MSG ④. *'Hold'* to prompt maintaining an already activated muscle**: derived from MSG ④ *'Push One More'*

With the updated key messages, we revisited the characteristics of each haptic feedback and reassigned them accordingly. We standardized the intensity of all feedback types to that of *Activate* to enable fair comparison across different feedback patterns, while ensuring that the intended haptic design—distinguished by variations in pulse duration, frequency, burst frequency, and on/off cycles—was not overshadowed.

The haptic feedback for ***'Relax'*** was retained, as the Symmetrical Biphasic TENS preset is the most commonly used to induce relaxation in patients during rehabilitation. Also, the feedback for ***'Stop'*** messages was retained, as it renders a strong, blunt sensation in a localized area, similar to a trainer's hand. As to the ***'Activate'*** message, instead of the previous Symmetrical Biphasic TENS with sweeping frequency, the Asymmetrical Biphasic TENS feedback was selected. This feedback was originally designed for the merged message *Move Like This'*, but we found that its rhythmic asymmetric pattern would be a better match for the *Activate'* message, as its intermittent, mild stimulation can enhance awareness in the targeted area. Finally, we thought Variable Muscle Stimulation preset (feedback ⑥) effectively conveyed the message ***'Hold'***, as the muscle contraction induced by high-intensity electrical stimulation helps maintain muscle engagement, and the subsequent relaxation helps gradually release the tension. The 'On' time of the cycle would be adjusted based on the exercise type and the trainee's personal goals, while the 'Off' time remains fixed at 1 second.

4.3 Summary

In summary, we designed the initial haptic feedback and refined them with external experts. We first condensed the original six messages of touch guidance into four key messages (① *Relax*, ② *Stop*, ③ *Activate*, ④ *Hold*) to follows sports mechanics and reduce cognitive load and made adjustments to the initial haptic feedback designs to reflect the changes.

5 ASSESSING HAPTIC FEEDBACK DESIGN AND LEARNABILITY

We conducted a user study to evaluate the perceptibility and appropriateness of the proposed haptic feedback patterns in an exercise context. We chose biceps curls as the representative task because they involve a simple, single-joint motion with a clear movement range. The task design reduced variation due to participants' skill levels [54] and ensured that the study measured the clarity of feedback rather than task complexity.

5.1 Methods

We employed a within-subject design so that each participant experienced all four feedback types (*Relax, Stop, Activate, Hold*), reducing inter-participant variability. To minimize carryover effects such as learning, fatigue, or residual electrical stimulation sensations, participants completed two sessions separated by 48 hours, with the order of feedback randomized in each session.

We measured participants' accuracy in recognizing feedback messages. After each stimulus, participants verbally reported the perceived message and performed the corresponding movement. These behavioral responses were confirmed with electromyography (EMG) and pose measurements to ensure that the intended muscle activity and posture aligned with the instruction, providing consistency between perception and execution.

Participant. We recruited sixteen participants (eight female, eight male) through the university's student community website. All participants reported exercising at least once a week and had prior experience with touch guidance. Physiological response to electrical stimulation can differ across individuals due to body composition, particularly body mass index (BMI) [35]. To account for this variability, we measured each participant's height and weight to compute BMI ($M = 22.33, SD = 1.77$).

Data Collection. EMG signals were recorded with the Delsys Trigno Base Station[3] to estimate muscle activation in response to electrical stimulation. Supplementary pose estimation data were collected using a laptop-mounted webcam (USB 2.0 HD UVC Webcam) to verify participants' movements.

Custom software developed in Python was used to process and synchronize EMG and pose data. EMG signals were accessed through the Delsys Data Collection API [12] and band-pass filtered at 20–450 Hz to reduce motion artifacts and high-frequency noise, retaining the frequency range most relevant to muscle activation. Pose estimation was implemented with OpenCV's MediaPipe library, which processed live video streams in real time to calculate joint angles between the upper and lower arms. System timestamps were logged with each stream to enable synchronization on a common time scale.

Study Procedure. For each participant, one EMG sensor was attached to the belly of the biceps (Figure 8. ⓐ), and two electrode patches were placed at the muscle's origin and insertion (Figure 8. ⓑ). Electrode patches and the EMG sensor were applied by a sports specialist who had participated in the feedback design process to ensure safety and accurate data acquisition. In addition, a webcam was positioned at the side of the participant for pose estimation.

The study was conducted in two sessions separated by a 48-hour interval to minimize memory effects and enable the assessment of intra-rater reliability. In the *first session*, participants completed *three phases: calibration, learning, and testing*. In the *second session*, participants repeated the *testing phase*, followed by a *post-hoc interview* and completion of the *NASA Task Load Index (TLX)* questionnaire [22].

① *Calibration phase:* First, we calibrated intensity levels for each participant, as sensitivity to electrical stimulation varies with body composition, particularly BMI. Calibration ensured that all participants received feedback at a perceptible yet comfortable intensity level, allowing fair comparison across conditions. In this phase, participants kept their arms relaxed at their sides and were encouraged to move them freely to explore how the stimulation felt, while the experimenter adjusted the intensity of the *Activate* feedback. The other three feedback types (*Relax, Stop, Hold*) were then matched to this calibrated intensity. We collected the intensity data for all participants after the calibration (Table 2).

[3] https://delsys.com/support/trigno-base-station/

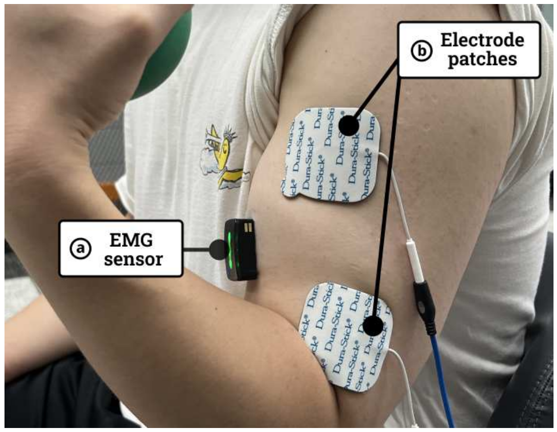


Fig. 8. User Study Setup: ⓐ is an EMG sensor(Delsys Trigno Avanti Sensor), and ⓑ is the rubber electrode patches

Participant	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
BMI	25.1	20.1	25.9	17.8	28.8	22.8	18	18	27.2	21.8	24.7	30.6	29.2	19.7	15.6	28.7
Intensity	7	13	9	5	11	8	6	6	6	3	6	6	8	7	7	8

Table 2. Participants' BMI and Intensity

② *Learning phase:* After calibration, participants learned the mapping between electrical signals and their corresponding messages. This familiarization step ensured that recognition performance in the subsequent test could be fairly evaluated. Participants experienced each haptic feedback twice (1 minute per exposure with a 30-second rest) and were instructed to memorize it. They were also taught how to respond to each message, as illustrated in Fig. 9. Then, before the *test phase*, participants took a 15-minute break to avoid potential effects of muscle fatigue or activation from the calibration and learning phases.

③ *Test phase:* In the test phase, participants performed biceps curls while holding a weighted ball. Because the purpose of this study was to examine participants' perception and response to haptic feedback rather than maximal strength performance, we used relatively light weights (1,000 g for males and 450 g for females). Different weights were assigned to balance the relative difficulty across genders.

Participants received randomized haptic feedback and were asked to report the perceived message and perform the corresponding action. The test phase of each session included two sets of 12 randomized trials, with all four feedback types presented an equal number of times. Across the two sessions, each participant therefore completed four sets (48 trials in total). Each set lasted approximately 10 minutes, followed by a 3-minute rest. Each trial followed a fixed sequence: ⓐ participants continuously performed arm curls as the default state; ⓑ after 3 seconds, the electrical stimulation feedback was delivered for 5 seconds; ⓒ upon perceiving the signal, participants executed the corresponding action and continued it even after the stimulation ended; ⓓ EMG data were recorded until 5 seconds after the termination of stimulation; ⓔ participants were asked which message they believed they had received and provided a verbal response; and ⓕ the procedure was reset, with participants returning to the default arm curl activity. Based on the

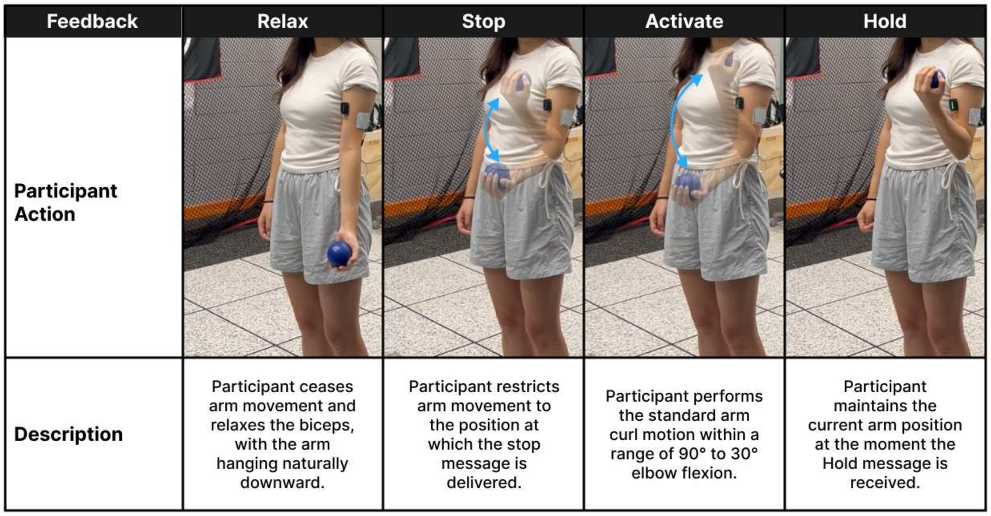


Fig. 9. Participant Actions by Feedback Messages

per-participant averages, the mean duration of one arm curl repetition was 1.757 seconds ($SD = 0.443$), corresponding to 36.36 repetitions per minute.

At the end of the second session, participants provided feedback on their experience in a post hoc interview. Their perceived workload was also assessed using the NASA Task Load Index (TLX) [22].

Across the two sessions, the experiment lasted a total of approximately three hours per participant, consisting of a 15-minute introduction, a 10-minute calibration and learning phase (including EMG and electrode patches placement), a 15-minute rest period before testing, about 30 minutes of testing per session, 10 minutes for the NASA-TLX survey, and a 30-minute post-hoc interview. Each participant received $30 as compensation for their time.

5.2 Results

Figure 9 illustrates participants performing the guided exercises for each haptic message, and Figure 10 is the corresponding EMG and pose estimation data.

EMG and Pose Estimation: The EMG and pose estimation graphs were used to cross-check participants' verbal responses with physiological and kinematic evidence. These data capture muscle activation both during EMS delivery and after the stimulation ceased, thereby indicating whether participants executed the instructed movement with the intended target muscle.

For the *Relax* condition (Figure 10.ⓐ), EMG signals converged toward zero, confirming minimal muscle activity. Correspondingly, the joint angle between the upper and lower arm remained close to 180°, indicating a fully extended, resting posture.

In the *Stop* condition (Figure 10.ⓑ), EMG amplitude oscillated as the muscle alternated between contraction and relaxation, producing a waveform shape similar to that of *Activate* but with a smaller peak magnitude. Pose estimation

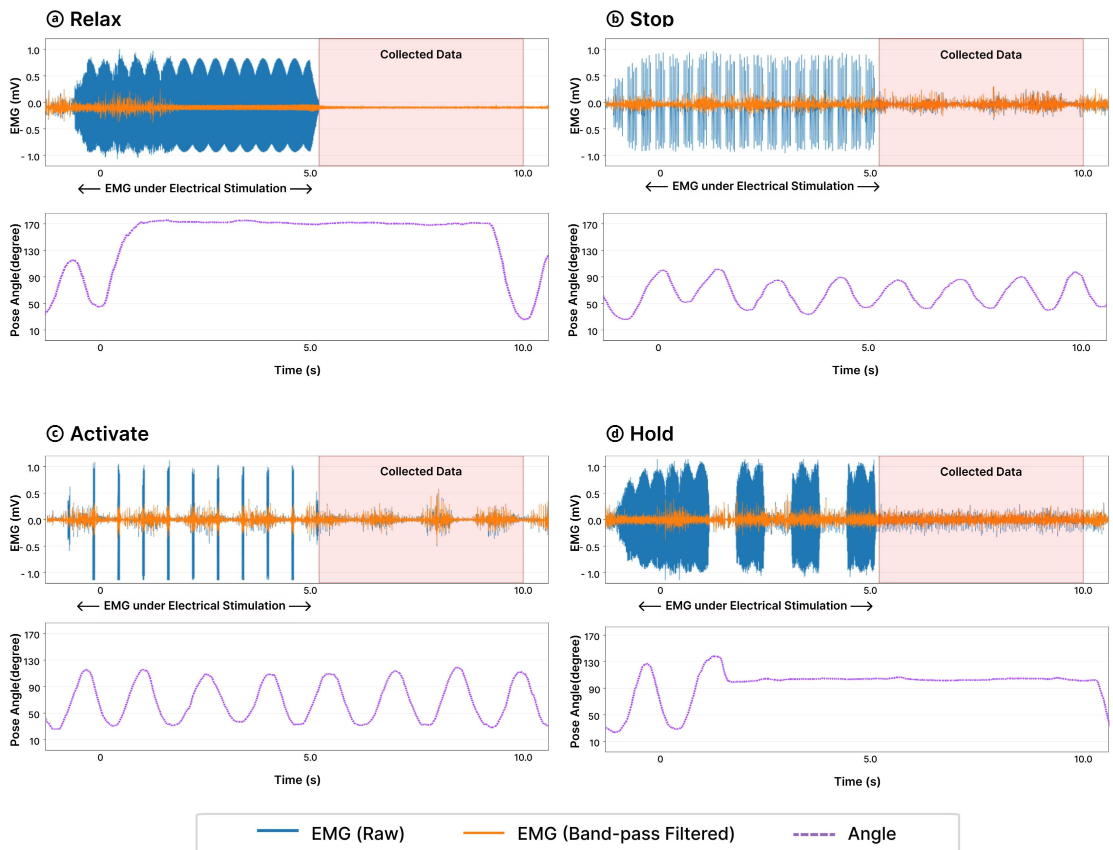


Fig. 10. Raw and band-pass filtered EMG waveforms together with pose angle trajectories, presented for each of the four feedback messages.

showed reduced movement range compared to *Activate*; for example, when participants received a stop cue at 50°, their arm remained constrained between approximately 90° and 50°.

The *Activate* condition (Figure 10.ⓒ) yielded the largest EMG amplitudes in our dataset (with peaks up to 1.2 mV across participants), reflecting strong voluntary contraction in response to stimulation. The pose data confirmed a wide and repetitive motion cycle, with elbow angles alternating between roughly 90° and 30°.

Finally, in the *Hold* condition (Figure 10.ⓓ), EMG traces resembled those of *Relax* in their stability, but appeared thicker and of higher amplitude, reflecting sustained muscle contraction. Pose estimation showed that once participants received the hold cue, their elbow angle stabilized at the instructed position, producing a flat trajectory over time.

Verbal Response Accuracy in Haptic Feedback Recognition: Overall, participants demonstrated very high recognition accuracy for the four haptic feedback messages, averaging 97.14% in Trial 1 ($SD = 4.49$) and 99.22% in Trial 2 ($SD = 1.68$). All participants achieved a perfect score on at least one of the two sessions, and seven participants reached 100% accuracy across both sessions. A paired-samples t-test indicated that the difference between the two trials was not

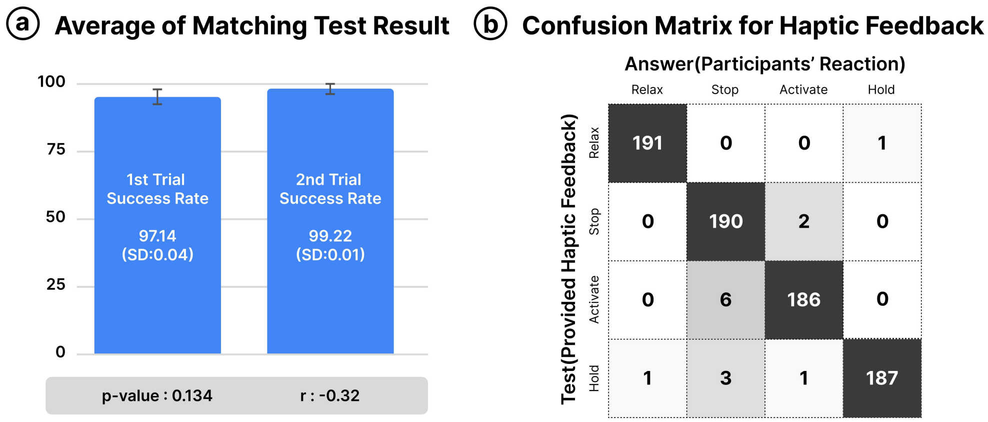


Fig. 11. User Study Results: ⓐ **average matching test result**, and ⓑ **confusion matrix for haptic feedback recognition** The error bars correspond to the 95% bootstrap confidence intervals.

statistically significant, $t(15) = -1.58$, $p = .134$, $r = -.32$, confirming that recognition performance remained stable across sessions without evidence of learning or fatigue effects.

To further examine consistency, intra-rater reliability was assessed across the two sessions. Agreement was very high, $AC1 = .96$, 95% CI [.94, .98], with an observed agreement of $P_o = .964$ and expected chance agreement of $P_e' = .036$ ($N = 384$ paired ratings). These values indicate that participants' recognition decisions were highly reproducible across repeated exposure.

Cross-check with EMG and Pose Data: Participants' verbal responses (Figure 11.ⓑ) were verified against their EMG signals (Figure 10) and pose data. Multimodal measurements confirmed the verbal responses in the vast majority of trials, with discrepancies observed in only 8 of 384 instances (2.08%). In these cases, participants verbally identified the feedback correctly, but EMG or pose traces did not fully align with the instructed movement, suggesting execution errors rather than misperception.

Message-wise Analysis: When broken down by feedback type, verbal recognition accuracy was consistently high: *Relax* (190/192, 98.96%), *Stop* (191/192, 99.48%), *Activate* (186/192, 97.40%), and *Hold* (187/192, 96.88%). Cross-checked with EMG and pose data, the corresponding accuracy rates were *Relax* (188/192, 97.92%), *Stop* (189/192, 98.44%), *Activate* (184/192, 95.83%), and *Hold* (185/192, 96.35%).

A total of eight mismatches were identified across all feedback types. These included two cases for *Relax* (P7: ambiguous motion; P8: delayed recognition due to loss of concentration), two cases for *Stop* (P5 and P6: signal was recognized but action was performed as *Hold*), two cases for *Activate* (P10: concentration lapses leading to delayed execution in two trials), and two cases for *Hold* (P7: ambiguous motion; P9: confused response resulting in unclear movement).

Error Types: Categorizing the causes of discrepancy, five cases were due to ambiguous motion (P5, P6, P7×2, P9), and three were attributed to lapses in concentration (P8, P10×2). These results suggest that most mismatches originated from motor execution or attentional factors rather than failures of perception.

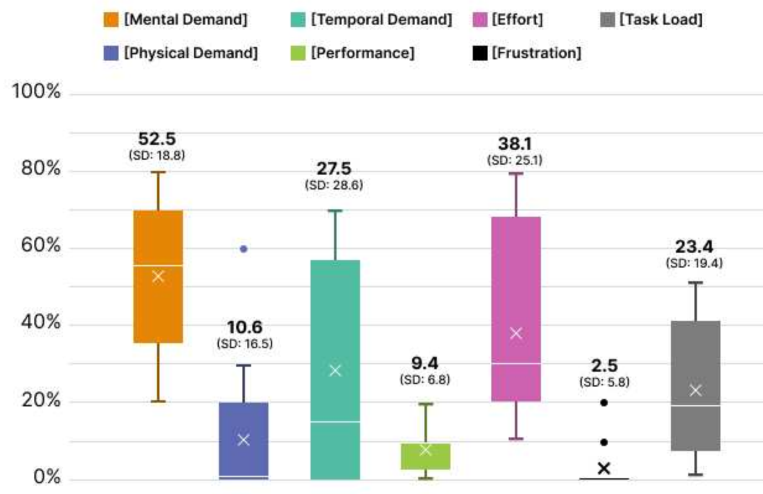


Fig. 12. The NASA Task Load Index score for electrical feedback

Task Workload: Applicability in Actual Resistance Training. Participants' workload was assessed using the NASA-TLX (Figure 12). The overall workload score was $M = 23.4$ ($SD = 19.4$) on an 11-point Likert scale, indicating a moderate level of task demand. Among the six subscales, Mental Demand ($M = 52.5$, $SD = 18.8$) and Effort ($M = 38.1$, $SD = 25.1$) were relatively high, while Physical Demand remained low ($M = 10.6$, $SD = 16.5$). Several participants (P2, P3, P8–P14, P16) reported no discomfort from electrical stimulation during biceps curls, and one participant (P13) described the sensation as comfortable. In addition, P3, P4, and P13 noted that once the feedback became familiar, they could detect the stimulation automatically, even with reduced attention.

Interview Findings. Participants reported that the four electrical stimulation feedback patterns became distinguishable after 10 minutes of training, and none requested additional learning time. In addition, all participants indicated willingness to use a wearable that provides electrical stimulation as an alternative to touch guidance. Some participants (P3, P4, P5) also noted that when their attention drifted slightly during exercise, the electrical stimulation feedback helped them refocus. As P3 explained, "The stimulation made me stop zoning out and think about what it meant and how to respond. That process pulled me back into the exercise and helped me concentrate more on my actions."

Distinct Associations for Relax, Stop, and Activate; Mixed Perceptions of Hold. For the ***Relax*** feedback, participants associated the sensation with comfort and physical therapy experiences, describing it as "comforting" (P9, P11, P12), "intuitive" (P14), and "distinctive" (P12, P13). The ***Stop*** feedback produced periodic tapping, which participants interpreted as attention-grabbing, with some describing it as "urgent tapping" (P11) or as something that "attracts attention" (P7, P16). The ***Activate*** feedback was perceived as motivating and concentrated on the target muscle, described as "like a heartbeat" (P8, P10, P15) and "intuitive" (P6, P14). Meanwhile, the ***Hold*** feedback elicited mixed perceptions. Participants found it "encouraging (P13, P14)" because it directly contracts the muscle, mimicking the sensation of someone grabbing the arm (P15), while some participants confused it with *Relax*. Some participants (P11, P14, P16) suggested that extending the on-period of the stimulation cycle would make the grasping-like sensation in the *Hold* message more appropriate.

Nevertheless, quantitative results showed consistently high recognition accuracy for *Hold* (96.88% verbal; 96.35% EMG/Pose), as illustrated in Figure 11, indicating that these perceptual ambiguities did not substantially impair overall performance.

Future Expectations for Haptic Wearables. Participants suggested that future systems could be improved by incorporating human-like features and multi-sensory instruction. Specifically, they expressed interest in wearables that, in addition to providing haptic guidance, offer encouragement, analyze motion with error feedback, monitor physiological activity, track workout progress, and adapt workout routines.

5.3 Summary

Our study demonstrated that the proposed electrical stimulation haptic feedback patterns are easy to learn and can be reliably recognized during exercise. Participants consistently distinguished the four messages with high accuracy across sessions, supported by both behavioral and physiological data, and performance remained stable.

Interview findings further revealed that while *Relax*, *Stop*, and *Activate* were generally perceived as intuitive and distinct, the *Hold* feedback elicited more mixed impressions despite strong quantitative performance. Participants suggested refinements of *Hold* and incorporating trainer-like features. Overall, the results indicate that the proposed patterns are a promising modality for wearable exercise guidance.

6 DISCUSSION

We investigated how electrical stimulation can encode trainers' touch guidance into compact, learnable haptic messages for resistance training. Below, we discuss design implications of using electrical stimulation as a communication channel, opportunities for gym wearables grounded in our findings, envisioned workflows, and limitations.

Electrical Stimulation as a Communication Channel for Coaching Cues

Our findings indicate that four electrical stimulation patterns—*Relax, Stop, Activate, Hold*—were rapidly learned and consistently recognized during movement (overall 98.18% across sessions; cf. Sec. 5). This suggests that electrical stimulation can provide a meaningful non-verbal channel for coaching cues, extending its role beyond conventional rehabilitation contexts [13, 15].

Two design takeaways emerge: First, calibrated intensity is essential. Participants varied in electrical sensitivity (Table 2), and we therefore standardized per-person intensity during calibration. In practice, electrical stimulation based guidance should always include a brief onboarding to set perceptible-but-comfortable levels and to align perceived salience across patterns. In addition, Message–sensation mapping should consider cognitive load and biomechanics. Consolidating six intentions into four messages reduced discrimination burden while preserving functional distinctions (Sec. 4). Notably, *Hold* achieved high accuracy but elicited more mixed perceptions than other messages; several participants suggested lengthening the on-period to better convey 'maintain' rather than 're-initiate' contraction. This indicates that timing parameters (burst/on–off ratios) are a primary lever for semantic clarity.

Although electrical stimulation was broadly tolerated—several participants reported no discomfort and one described it as comfortable—future systems should include gentler presets or fallback modalities for sensitive users. Rather than positioning electrical stimulation as the only option, **haptic fusion** (e.g., vibrotactile or SMA) may diversify the 'haptic vocabulary' for different bodies, exercises, and contexts [20, 25, 32]. Where high-intensity *Variable Muscle Stimulation (VMS)* is undesirable, alternative cues could preserve semantics without increasing discomfort.

Beyond Touch Guidance: Companion Roles for Gym Wearables

Interviews indicated that trainees value not only corrective touch but also the *feeling of being attended to*. Post-hoc interview reflected interest in "trainer-like" support—encouragement, simple feedback on **exercise execution**, and lightweight progress tracking. This suggests an opportunity to position haptic wearables as **companions** rather than mere notifiers: combining concise electrical signals with minimal verbal prompts or affective touch for motivation [58], while offering trainers utilities such as structured summaries or checklists [27]. The design challenge is to provide these features without overloading users during effortful movement.

Design Implications and Envisioned Workflows

While our empirical evaluation focused on controlled exercises (biceps curls with arm-mounted electrode patches), the findings point toward broader possibilities for designing future workout experiences. The following are speculative design implications that extend from our findings and participants' expectations.

We envision electrical stimulation based haptics being integrated into a four-stage workout journey:

- **Pre-Exercise:** A brief calibration step ensures comfort and recognizability of signals across individuals. An optional *Activate* signal could serve as a muscle priming cue.
- **During Exercise:** Compact electrical cues (*Relax, Stop, Activate, Hold*) may supplement verbal or visual instructions. Simple sensing (e.g., IMU or camera) could support logging of repetitions and form deviations, enabling trainers to review or intervene remotely.
- **Post-Exercise:** electrical stimulation feedback such as *Relax* could be applied for cool-down or recovery, while lightweight visual summaries highlight errors and improvements across sessions.
- **Daily Life:** Gentle, low-frequency haptic nudges could serve as motivational reminders aligned with planned workout routines.

These envisioned workflows illustrate how electrical stimulation feedback might extend beyond isolated lab tasks into everyday training contexts. By framing electrical stimulation wearables as *companions*—balancing precise physical cues with lightweight motivational and organizational features—future systems could better approximate the social and instructional value of human trainers while minimizing cognitive load during exercise.

Limitations and Future Work

Our study involved sixteen university participants (mean age 22.1; balanced gender) and focused on biceps curls with arm-mounted electrode patches under controlled loads. While this setting allowed us to carefully examine the recognizability of electrical stimulation feedback, the findings may not directly extend to multi-joint or whole-body lifts, alternative muscle groups, or older and clinical populations. Future work includes developing a portable electrical stimulation prototype and exploring generalization across a wider range of exercises (e.g., squats, rows) and naturalistic gym environments. In addition, our qualitative interviews with trainers were conducted within a single national context; cross-cultural replication could reveal further intentions and boundaries in touch guidance.

7 CONCLUSION

Haptic technologies present an opportunity to transform the touch guidance provided by personal trainers during resistance training into haptic feedback for solitary workouts. In this paper, we explore how diverse touch guidance messages can be translated into haptic sensations using electrical stimulation. A preliminary study with trainees and trainers identified six common intentions behind touch guidance practices and highlighted the demand for such haptic wearables in gym settings. After designing the initial electrical stimulation patterns for each message, we refined them in collaboration with a sports scientist and a UX designer, consolidating the designs into four key messages with distinct haptic feedback. A user study with sixteen active gymgoers confirmed the learnability and practical applicability of the designed feedback and provided valuable insights for future refinement. This research encourages designers, developers, and sports practitioners to envision future workouts with haptic wearables by analyzing current touch guidance practices and proposing electrical stimulation settings for diverse haptic sensations.

REFERENCES

[1] Adilzhan Adilkhanov, Matteo Rubagotti, and Zhanat Kappassov. 2022. Haptic devices: Wearability-based taxonomy and literature review. *IEEE Access* 10 (2022), 91923–91947.

[2] Pengcheng An, Ziqi Zhou, Qing Liu, Yifei Yin, Linghao Du, Da-Yuan Huang, and Jian Zhao. 2022. VibEmoji: Exploring user-authoring multi-modal emoticons in social communication. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. 1–17.

[3] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

[4] Douglas Brooks. 2004. *The complete book of personal training*. Human Kinetics.

[5] Joaquin Calatayud, Jonas Vinstrup, Markus Due Jakobsen, Emil Sundstrup, Mikkel Brandt, Kenneth Jay, Juan Carlos Colado, and Lars Louis Andersen. 2016. Importance of mind-muscle connection during progressive resistance training. *European journal of applied physiology* 116, 3 (2016), 527–533.

[6] Joaquin Calatayud, Jonas Vinstrup, Markus D Jakobsen, Emil Sundstrup, Juan Carlos Colado, and Lars L Andersen. 2017. Mind-muscle connection training principle: influence of muscle strength and training experience during a pushing movement. *European journal of applied physiology* 117 (2017), 1445–1452.

[7] Joey Campbell and Mike Fraser. 2019. Carrot & Stick: Electrical Muscle Stimulation output generated through incentivized/de-incentivized exergames. In *Proceedings of the 31st European Conference on Cognitive Ergonomics*. 188–191.

[8] Chattanooga. 2023. *Introducing the Chattanooga VMS White Paper*. Technical Report. Chattanooga Rehabilitation. https://www.chattanoogarehab.com/us/blog/introducing-the-chattanooga-vms-white-paper/ Accessed: 2025-02-01.

[9] Chia-Yu Cheng, Yu Chen, Sitaresmi Wahyu Handani, Avijit Balabantaray, and Mike Y Chen. 2024. Paired-EMS: Enhancing Electrical Muscle Stimulation (EMS)-based Force Feedback Experience by Stimulating Both Muscles in Antagonistic Pairs. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*. 1–7.

[10] James Crossley. 2012. *Personal training: theory and practice*. Routledge.

[11] Alexandra Delazio, Ken Nakagaki, Roberta L Klatzky, Scott E Hudson, Jill Fain Lehman, and Alanson P Sample. 2018. Force jacket: Pneumatically-actuated jacket for embodied haptic experiences. In *Proceedings of the 2018 CHI conference on human factors in computing systems*. 1–12.

[12] Delsys. 2024. *Example-Applications*. https://github.com/delsys-inc/Example-Applications.git

[13] Josimari M DeSantana, Deirdre M Walsh, Carol Vance, Barbara A Rakel, and Kathleen A Sluka. 2008. Effectiveness of transcutaneous electrical nerve stimulation for treatment of hyperalgesia and pain. *Current rheumatology reports* 10, 6 (2008), 492–499.

[14] Stav Dimitropoulos. 2022. Can electrical stimulation improve your gym workout? *BBC News* (2022). https://www.bbc.com/news/business-62887379 Accessed: 2024-07-02.

[15] Roger M Enoka, Ioannis G Amiridis, and Jacques Duchateau. 2019. Electrical stimulation of muscle: electrophysiology and rehabilitation. *Physiology* (2019).

[16] Corinna Feeken, Merlin Wasmann, Wilko Heuten, Dag Ennenga, Heiko Müller, and Susanne Boll. 2016. ClimbingAssist: direct vibro-tactile feedback on climbing technique. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*. 57–60.

[17] FitBit. 2007. FitBit. Fitness Tracker and Haptic Wearable. Retrieved October 25, 2023 from https://www.fitbit.com/

[18] Frank A Geldard. 1975. *Sensory saltation: Metastability in the perceptual world*. Lawrence Erlbaum.

[19] Julien Gondin, Patrick J Cozzone, and David Bendahan. 2011. Is high-frequency neuromuscular electrical stimulation a suitable tool for muscle performance improvement in both healthy humans and athletes? *European journal of applied physiology* 111 (2011), 2473–2487.

[20] Nur Al-huda Hamdan, Adrian Wagner, Simon Voelker, Jürgen Steimle, and Jan Borchers. 2019. Springlets: Expressive, flexible and silent on-skin tactile interfaces. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–14.

[21] Blake Hannaford and Allison M Okamura. 2016. Haptics. *Springer handbook of robotics* (2016), 1063–1084.

[22] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[23] August Heidland, Gholamreza Fazeli, André Klassen, Katarina Sebekova, Hans Hennemann, Udo Bahner, and Biagio Di Iorio. 2013. Neuromuscular electrostimulation techniques: historical aspects and current possibilities in treatment of pain and muscle waisting. *Clin Nephrol* 79, Suppl 1 (2013), S12–S23.

[24] Seokhyun Hwang, Jeongseok Oh, Seongjun Kang, Minwoo Seong, Ahmed Ibrahim Ahmed Mohamed Elsharkawy, and SeungJun Kim. 2024. Ergopulse: Electrifying your lower body with biomechanical simulation-based electrical muscle stimulation haptic system in virtual reality. In

Proceedings of the CHI Conference on Human Factors in Computing Systems. 1–21.

[25] Hye-Young Jo, Chan Hu Wie, Yejin Jang, Dong-Uk Kim, Yurim Son, and Yoonji Kim. 2023. TrainerTap: Weightlifting Support System Prototype Simulating Personal Trainer's Tactile and Auditory Guidance. In *Adjunct Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology*. 1–3.

[26] Gretchen A Kerr, Ashley E Stirling, Amanda L Heron, Ellen A MacPherson, and Jenessa M Banwell. 2015. The importance of touch in sport: athletes' and coaches' reflections. *Int'l J. Soc. Sci. Stud.* 3 (2015), 56.

[27] Jiha Kim, Younho Nam, Jungeun Lee, Young-Joo Suh, and Inseok Hwang. 2023. Demonstrating ProxiFit: Proximal Magnetic Sensing using a Single Commodity Mobile toward Holistic Weight Exercise Monitoring. In *Adjunct Proceedings of the 2023 ACM International Joint Conference on Pervasive and Ubiquitous Computing & the 2023 ACM International Symposium on Wearable Computing*. 151–156.

[28] Ernst Kruijff, Dieter Schmalstieg, and Steffi Beckhaus. 2006. Using neuromuscular electrical stimulation for pseudo-haptic feedback. In *Proceedings of the ACM symposium on Virtual reality software and technology*. 316–319.

[29] Scott A Mazzetti, William J Kraemer, JEFF S Volek, NOEL D Duncan, NICHOLAS A Ratamess, AL Gomez, ROBERT U Newton, KEIJO Hakkinen, and STEVEN J Fleck. 2000. The influence of direct supervision of resistance training on strength performance. *Medicine and science in sports and exercise* 32, 6 (2000), 1175–1184.

[30] Troy McDaniel, Daniel Villanueva, Sreekar Krishna, and Sethuraman Panchanathan. 2010. MOVeMENT: A framework for systematically mapping vibrotactile stimulations to fundamental body movements. In *2010 IEEE International Symposium on Haptic Audio Visual Environments and Games*. IEEE, 1–6.

[31] Eleonora Mencarini, Amon Rapp, Lia Tirabeni, and Massimo Zancanaro. 2019. Designing wearable systems for sports: a review of trends and opportunities in human–computer interaction. *IEEE Transactions on Human-Machine Systems* 49, 4 (2019), 314–325.

[32] Sachith Muthukumarana, Don Samitha Elvitigala, Juan Pablo Forero Cortes, Denys JC Matthies, and Suranga Nanayakkara. 2020. Touch me gently: recreating the perception of touch using a shape-memory alloy matrix. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–12.

[33] Arinobu Niijima and Yuki Kubo. 2023. Assisting with Fingertip Force Control by Active Bio-Acoustic Sensing and Electrical Muscle Stimulation. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–13.

[34] Arinobu Niijima and Shoichiro Takeda. 2025. Improving Putting Accuracy with Electrical Muscle Stimulation Feedback Guided by Muscle Synergy Analysis. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. 1–11.

[35] Catarina Nordander, Julian Willner, G-Å Hansson, Britt Larsson, Jeannette Unge, L Granquist, and Staffan Skerfving. 2003. Influence of the subcutaneous fat layer, as measured by ultrasound, skinfold calipers and BMI, on the EMG amplitude. *European journal of applied physiology* 89, 6 (2003), 514–519.

[36] Marianna Obrist, Sriram Subramanian, Elia Gatti, Benjamin Long, and Thomas Carter. 2015. Emotions mediated through mid-air haptics. In *Proceedings of the 33rd annual ACM conference on human factors in computing systems*. 2053–2062.

[37] Kazushige Oshita. 2021. Tactile cue by touching the agonist muscle increases the muscle activity during arm curl exercise. In *11th Asian-Pacific Conference on Medical and Biological Engineering: Proceedings of the Online Conference APCMBE 2020, May 25-27, 2020*. Springer, 295–300.

[38] Young-Woo Park, Chang-Young Lim, and Tek-Jin Nam. 2010. CheekTouch: an affective interaction technique while speaking on the mobile phone. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*. 3241–3246.

[39] Fabrizio Pece, Juan Jose Zarate, Velko Vechev, Nadine Besse, Olexandr Gudozhnik, Herbert Shea, and Otmar Hilliges. 2017. Magtics: Flexible and thin form factor magnetic actuators for dynamic and wearable haptic feedback. In *Proceedings of the 30th annual ACM symposium on User interface software and technology*. 143–154.

[40] Shafiq Ur Réhman and Li Liu. 2010. ifeeling: Vibrotactile rendering of human emotions on mobile phones. *Mobile Multimedia Processing: Fundamentals, Methods, and Applications* (2010), 1–20.

[41] Matthew R Rhea, Daniel M Landers, Brent A Alvar, and Shawn M Arent. 2003. The effects of competition and the presence of an audience on weight lifting performance. *The Journal of Strength & Conditioning Research* 17, 2 (2003), 303–306.

[42] Nihar Sabnis, Dennis Wittchen, Gabriela Vega, Courtney N Reed, and Paul Strohmeier. 2023. Tactile Symbols with Continuous and Motion-Coupled Vibration: An Exploration of using Embodied Experiences for Hermeneutic Design. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–19.

[43] Nejc Šarabon, Žiga Kozinc, Stefan Löfler, and Christian Hofer. 2020. Resistance exercise, electrical muscle stimulation, and whole-body vibration in older adults: systematic review and meta-analysis of randomized controlled trials. *Journal of Clinical Medicine* 9, 9 (2020), 2902.

[44] Brad J Schoenfeld and Bret Contreras. 2016. Attentional focus for maximizing muscle development: The mind-muscle connection. *Strength & Conditioning Journal* 38, 1 (2016), 27–29.

[45] Jessica Sehrt, Leonardo Leite Ferreira, Karsten Weyers, Amir Mahmood, Thomas Kosch, and Valentin Schwind. 2024. Improving Electromyographic Muscle Response Times through Visual and Tactile Prior Stimulation in Virtual Reality. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*. 1–17.

[46] Sichao Song and Seiji Yamada. 2017. Expressing emotions through color, sound, and vibration with an appearance-constrained social robot. In *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. 2–11.

[47] Daniel Spelmezan. 2012. An investigation into the use of tactile instructions in snowboarding. In *Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services*. 417–426.

[48] Daniel Spelmezan, Mareike Jacobs, Anke Hilgers, and Jan Borchers. 2009. Tactile motion instructions for physical activities. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 2243–2252.

[49] Justin L Staker, Amanda J Evans, Laura E Jacobs, Thomas P Ebert, Noah A Fessler, Gaura Saini, and Paula M Ludewig. 2022. The effect of tactile and verbal guidance during scapulothoracic exercises: An EMG and kinematic investigation. *Journal of Electromyography and Kinesiology* 62 (2022), 102334.

[50] Craig D Stewart, Penny Traitor, and Vicki L Hanson. 2014. I'd Tap That! providing real time feedback on roller derby skills. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems*. 2221–2226.

[51] Teslasuit. 2017. Teslasuit. Haptic suit. Retrieved October 25, 2023 from https://teslasuit.io/

[52] Keigo Ushiyama and Pedro Lopes. 2023. FeetThrough: Electrotactile Foot Interface that Preserves Real-World Sensations. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology*. 1–11.

[53] Frederik Mørch Valsted, Christopher VH Nielsen, Jacob Qvist Jensen, Tobias Sonne, and Mads Møller Jensen. 2017. Strive: exploring assistive haptic feedback on the run. In *Proceedings of the 29th Australian conference on computer-human interaction*. 275–284.

[54] Jason Vance, Gabriele Wulf, Thomas Töllner, Nancy McNevin, and John Mercer. 2004. EMG activity as a function of the performer's focus of attention. *Journal of motor behavior* 36, 4 (2004), 450–459.

[55] Nicolas Wirtz, Christoph Zinner, Ulrike Doermann, Heinz Kleinoeder, and Joachim Mester. 2016. Effects of loaded squat exercise with and without application of superimposed EMS on physical performance. *Journal of sports science & medicine* 15, 1 (2016), 26.

[56] Anusha Withana, Daniel Groeger, and Jürgen Steimle. 2018. Tacttoo: A thin and feel-through tattoo for on-skin tactile output. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology*. 365–378.

[57] Mikołaj P Woźniak, Julia Dominiak, Michał Pieprzowski, Piotr Ładoński, Krzysztof Grudzień, Lars Lischke, Andrzej Romanowski, and Paweł W Woźniak. 2020. Subtletee: Augmenting posture awareness for beginner golfers. *Proceedings of the ACM on Human-Computer Interaction* 4, ISS (2020), 1–24.

[58] Yiran Zhao, Yujie Tao, Grace Le, Rui Maki, Alexander Adams, Pedro Lopes, and Tanzeem Choudhury. 2023. Affective Touch as Immediate and Passive Wearable Intervention. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 6, 4 (2023), 1–23.