README // about these slides

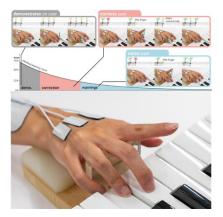These are the slides for the talk presented at CHI 2025 by Siya Choudhary and Yun Ho.
All the links in this PDF are clickable and lead you to YouTube videos, paper, etc.
You can watch the talk here: https://youtu.be/3Ki59Zt63_E?si=3m7gnSW4awgpB7u2
You can watch the video here: https://www.youtube.com/watch?v=VqqpRu269QE
If you need a PPTX/editable version for your class, email us hci@uchicago.edu
More information on this paper (or others of our lab) at: https://lab.plopes.org/#adaptiveEMS

Adaptive Electrical Muscle Stimulation Improves Muscle Memory

Siya Choudhary*, Romain Nith*, Yun Ho*, Jas Brooks, Mithil Guruvugari, Pedro Lopes. In Proc. CHI'25 (paper)
* authors contributed equally

Electrical muscle stimulation (EMS) can assist in learning motor skills. However, existing EMS systems provide static demonstration—actuating the correct movements, regardless of the user's learning progress. Instead, we propose a novel adaptive-EMS that changes its guidance strategy based on the participant's performance. The adaptive-EMS dynamically adjusts its guidance: (1) demonstrate by playing the entire sequence when errors are frequent; (2) correct by lifting incorrect fingers and actuating the correct one when errors are moderate; and (3) warn by lifting incorrect fingers when errors are low. We found that adaptive-EMS improved learning outcomes (recall) compared to traditional EMS—leading to improved "muscle memory".
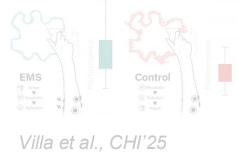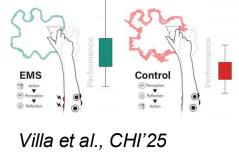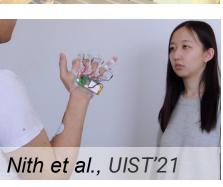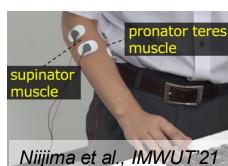
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advanced technologies but we still rely on watching and copying

combination (index and pinky)

Takahashi et al., CHI'21

Tamaki et al., CHI'11

EMS — Performance
- Action
- Perception
- Reflection

Control — Performance
- Perception
- Reflection
- Action

Villa et al., CHI'25

Hassan et al., IMWUT'17

Pfieffer et al., CHI'19 LBW

Nith et al., UIST'21

Niijima et al., UbiComp'24

Tatsuno et al., WHC'17

Faltaous et al., it'21

Guidance
Disambiguation

Pfeiffer et al., CHI'16

pronator teres muscle
supinator muscle

Niijima et al., IMWUT'21

Ebisu et al., SA'16

download the interactive assistance to our body

combination
(index and pinky)

Takahashi et al., CHI'21

Tamaki et al., CHI'11

EMS | Control

Villa et al., CHI'25

Hassan et al., IMWUT'17

Pfieffer et al., CHI'19 LBW

Nith et al., UIST'21

Niijima et al., UbiComp'24

Tatsuno et al., WHC'17

Faltaous et al., it'21

Guidance
Disambiguation

Pfeiffer et al., CHI'16

pronator teres
muscle
supinator
muscle

Niijima et al., IMWUT'21

Ebisu et al., SA'16

Watch: https://www.youtube.com/watch?v=C6rj64TgsDI

melody downloads
to hand!

Niijima et al., UbiComp'24

combination (index and pinky)

Takahashi et al., CHI'21

Tamaki et al., CHI'11

Villa et al., CHI'25

Hassan et al., IMWUT'17

Pfieffer et al., CHI'19 LBW

Nith et al., UIST'21

Niijima et al., UbiComp'24

Tatsuno et al., WHC'17

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Pfeiffer et al., CHI'16

pronator teres muscle

supinator muscle

Niijima et al., IMWUT'21

Ebisu et al., SA'16

combination (index and pinky)

Takahashi et al., CHI'21

Tamaki et al., CHI'11

EMS — Performance

Control — Performance

Villa et al., CHI'25

Hassan et al., IMWUT'17

Pfieffer et al., CHI'19 LBW

Nith et al., UIST'21

Niijima et al., UbiComp'24

Tatsuno et al., WHC'17

Faltaous et al., it'21

Guidance
Disambiguation

Pfeiffer et al., CHI'16

pronator teres muscle
supinator muscle

Niijima et al., IMWUT'21

Ebisu et al., SA'16

practice by **feeling one's body moving** rather than just by seeing other bodies

combination (index and pinky)

Takahashi et al., CHI'21

Tamaki et al., CHI'11

EMS — Performance — Control — Performance

Villa et al., CHI'25

Hassan et al., IMWUT'17

Pfieffer et al., CHI'19 LBW

Nith et al., UIST'21

Niijima et al., UbiComp'24

Tatsuno et al., WHC'17

Faltaous et al., it'21

Guidance — Disambiguation

Pfeiffer et al., CHI'16

pronator teres muscle — supinator muscle

Niijima et al., IMWUT'21

Ebisu et al., SA'16

combination (index and pinky)

Takahashi et al., CHI'21

Tamaki et al., CHI'11

EMS
Action
Perception
Reflection
Performance

Control
Perception
Reflection
Action
Performance

Villa et al., CHI'25

Hassan et al., IMWUT'17

Pfieffer et al., CHI'19 | BW

Nith et al., UIST'21

Niijima et al., UbiComp'24

Tatsuno et al., WHC'17

all these assistive systems by means of interactive muscle stimulation work in the **same way = they do all the work for the user**

Faltaous et al., it'21

Guidance
Disambiguation

Pfeiffer et al., CHI'16

supinator muscle

Niijima et al., IMWUT'21

Ebisu et al., SA'16

our proposal: **adaptive**

static EMS

adaptive EMS

error

error

75%

idealized learning curve

50%

25%

demonstration

0%

75%

idealized learning curve

50%

25%

demo.

correction

warnings

0%

Watch: https://www.youtube.com/watch?v=VqqpRu269QE

error

75%

idealized learning curve

50%

25%

0%

demo.   correction

Watch: https://www.youtube.com/watch?v=VqqpRu269QE

error

75%
50%
25%
0%

idealized learning curve

demo. correction warnings

Watch: https://www.youtube.com/watch?v=VqqpRu269QE
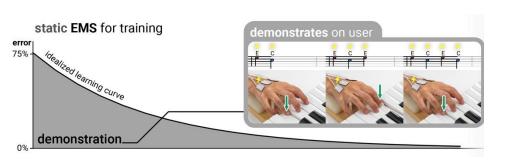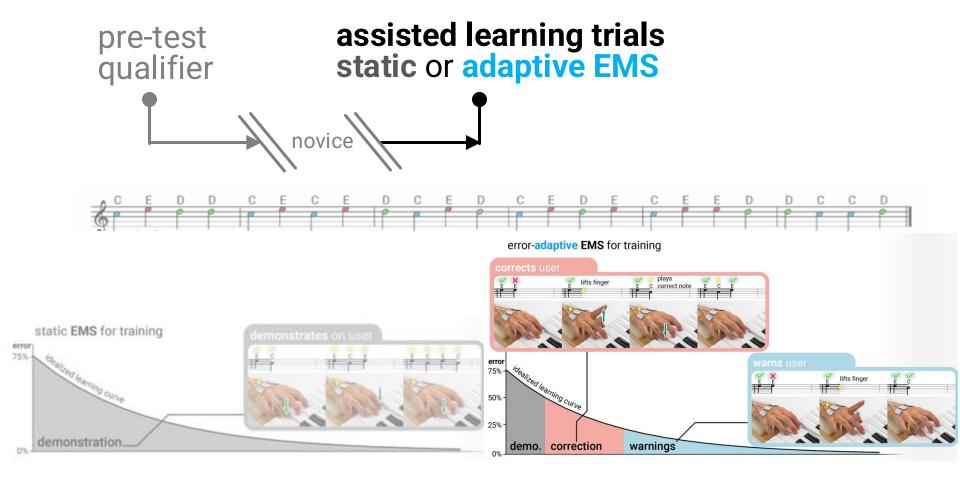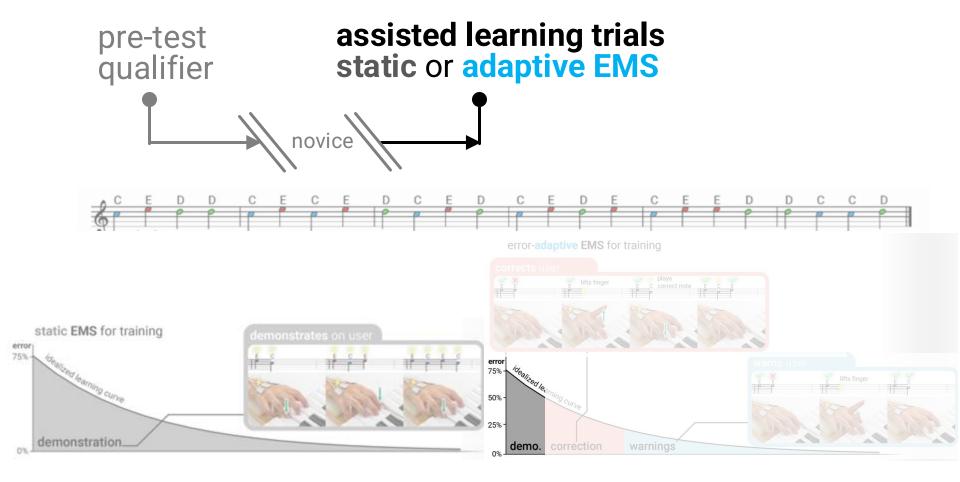
C E D D C E C E D C E D C E D E C E E D D C C D

user study

learning with **adaptive** vs. **static** muscle stimulation

study design

pre-test
qualifier

assisted learning trials
static

novice

study design

study design

study design

pre-test
qualifier

assisted learning trials
static or **adaptive EMS**

novice

study design

pre-test
qualifier

assisted learning trials
static or **adaptive EMS**

novice

study design

study design

study design

results

number of errors in post-test

results

number of errors in post-test

preference

results

number of errors in post-test
static
adaptive

preference
static | adaptive
0% 20% 40% 60% 80% 100

+ adaptive-EMS **enhanced the participants' learning experience**. (P1-3, P6-9, P12, P14)

+ adaptive was more **engaging** (P1, P2, P8, P10, P11, P13, P15)

+ adaptive-EMS "reduced guesswork" (P9)

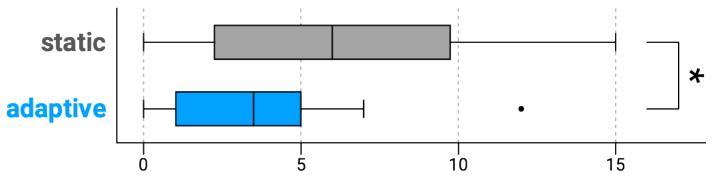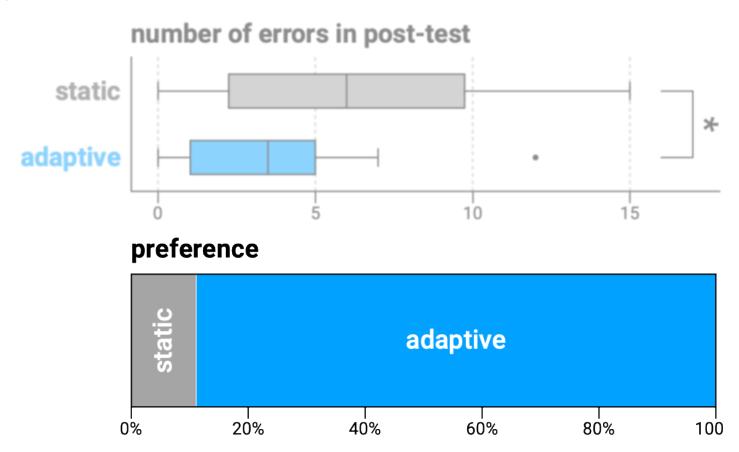**+** adaptive-EMS helped to identify and improve mistakes (P6)

results

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+ adaptive-EMS "reduced guesswork" (P9)

+ adaptive-EMS helped to identify and improve mistakes (P6)

- adaptive-EMS needs more context for corrections (P5)

results

- adaptive-EMS needs more context for corrections (P5)

results

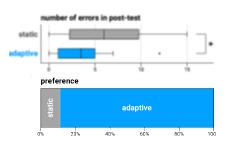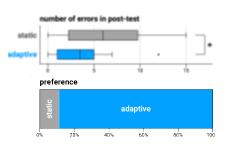number of errors in post-test

preference

+ adaptive-EMS **enhanced the participants' learning experience**. (P1-3, P6-9, P12, P14)
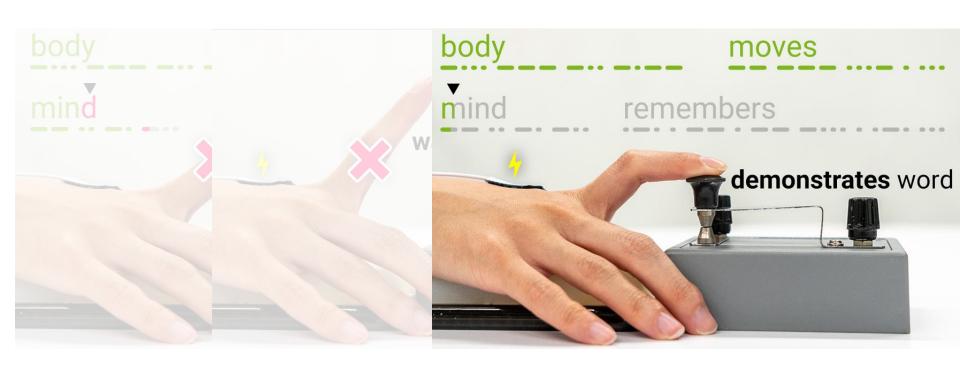
+ adaptive was more **engaging** (P1, P2, P8, P10, P11, P13, P15)

+ adaptive-EMS "reduced guesswork" (P9)

+ adaptive-EMS helped to identify and improve mistakes (P6)

- adaptive-EMS needs more context for corrections fix (P5)

- adaptive-EMS can interfere when correcting (P10, P13)
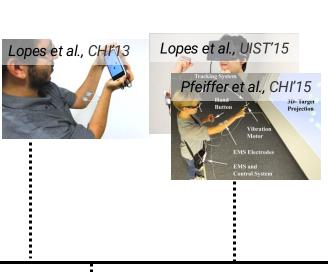
Reducing potential interferences caused by corrective movements

Watch: https://www.youtube.com/watch?v=VqqpRu269QE

conclusion & take-aways

Lopes et al., CHI'13

Lopes et al., UIST'15

Pfeiffer et al., CHI'15

Pfeiffer et al., AVRST'17

Lopes et al., CHI'17

Pfeiffer et al., AH'14

Um et al., UbiComp'24

Hwang et al., CHI'24

Cheng et al., CHI'24

Lopes et al., CHI'13

Lopes et al., UIST'15

Pfeiffer et al., CHI'15

Tracking System

Hand Button

3D- Target Projection

Vibration Motor

EMS Electrodes

EMS and Control System

Pfeiffer et al., AVRST'17

Lopes et al., CHI'17

Tatsuno et al., WHC'17

Hassan et al., IMWUT'17

Niijima et al., IMWUT'21

pronator teres muscle

supinator muscle

Faltaous et al., it'21

Nith et al., UIST'21

Colley et al., TEI'18

Tanaka et al., CHI'22

Pfeiffer et al., AH'14

Pfeiffer et al., CHI'16

Guidance

Disambiguation

Lopes et al., CHI'16

Ebisu et al., SA'16

Kasahara et al., CHI'19

Electrodes

Virtual Scene

Seated VR User

Cheng et al., CHI'24

Niijima et al., UbiComp'24

Nith et al., CHI'24

Lopes et al., CHI'13

Lopes et al., UIST'15

Pfeiffer et al., CHI'15

Pfeiffer et al., AVRST'17

Lopes et al., CHI'17

Tatsuno et al., WHC'17

Hassan et al., IMWUT'17

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Pfeiffer et al., AH'14

Pfeiffer et al., CHI'16

Lopes et al., CHI'16

Ebisu et al., SA'16

Kasahara et al., CHI'19

Cheng et al., CHI'2...

Niijima et al., UbiComp'24

Nith et al., CHI'24

CHI 2025

Hapticus: Exploring the Effects of Haptic Feedback and its Customization on Motor Skill Learning: Tactile, Haptic, and Somatosensory Approaches

- Papers

👤 Kyungyeon Lee , Daniel S Yang , Kriti Singh , Jun Nishida

Understanding the Influence of Electrical Muscle Stimulation on Motor Learning: Enhancing Motor Learning or Disrupting Natural Progression?

- Papers

👤 Steeven Villa , Finn Jacob Eliyah Krammer , Yannick Weiss , Robin Welsch , Thomas Kosch

PiaMuscle: Improving Piano Skill Acquisition by Cost-effectively Estimating and Visualizing Activities of Miniature Hand Muscles

- Papers

👤 Ruofan Liu , Yichen Peng , Takanori Oku , Chen-Chieh Liao , Erwin Wu , Shinichi Furuya , Hideki Koike

Improving Putting Accuracy with Electrical Muscle Stimulation Feedback Guided by Muscle Synergy Analysis

- Papers

👤 Arinobu Niijima , Shoichiro Takeda

Lopes et al., CHI'13
Lopes et al., UIST'15
Pfeiffer et al., AVRST'17
Lopes et al., CHI'17
Niijima et al., IMWUT'21
Choudhary et al., CHI'25
Colley et al., TEI'18
Tanaka et al., CHI'22
Kasahara et al., CHI'19
Cheng et al., CHI'24
Niijima et al., UbiComp'24
Nith et al., CHI'24
Ebisu et al., SA'16

human computer
integration lab
THE UNIVERSITY OF CHICAGO

thanks for listening, questions?

adaptive electrical muscle stimulation
improves muscle memory

siya choudhary*, **yun ho***, romain nith*, jas brooks, mithil guruvugari, pedro lopes

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