Actuating Myself: Designing Hand-Games Incorporating Electrical Muscle Stimulation

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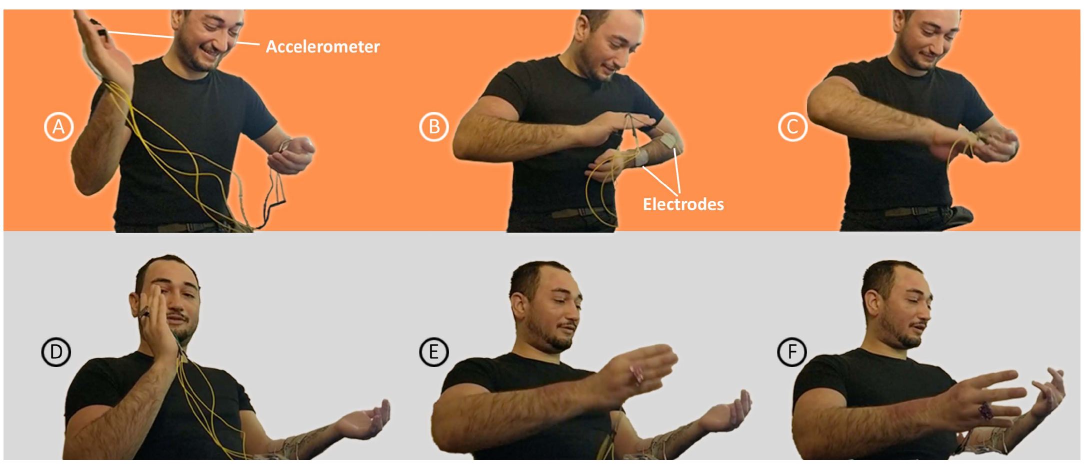

Figure 1: (A, B and C) shows a participant playing *Slap-me-if-you-can.* (A) participant (with an accelerometer) about to slap their EMS hand with electrodes. (B) EMS hand moves towards their body to avoid the non-EMS hand's hit. (C) shows a game round where the non-EMS hand hits their EMS hand. (D, E and F) shows a participant playing *3-4-5* (EMS Hand = "odds" and non-EMS hand = "evens"). (D) the participant is thinking of the number to roll with the non-EMS hand. (E) The non-EMS hand rolls a four while the EMS hand is actuated. (F) The EMS hand rolls three and "wins" the game round (sum of 7(=4+3)).

ABSTRACT

Motor movements are performed while playing hand-games such as Rock-paper-scissors or Thumb-war. These games are believed to benefit both physical and mental health and are considered cultural assets. Electrical Muscle Stimulation (EMS) is a technology that can actuate muscles, triggering motor movements and hence offers an opportunity for novel play experiences based on these traditional hand-games. However, there is only limited understanding of the

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design of EMS games. We present the design and evaluation of two games inspired by traditional hand-games, "Slap-me-if-you-can" and "3-4-5", which incorporate EMS and can be played alone, unlike traditional games. A thematic analysis of the data collected revealed three themes: 1) Gameplay experiences and influence of EMS hardware, 2) Interaction with EMS and the calibration process and, 3) Shared control and its effect on playing EMS games. We hope that an enhanced understanding of the potential of EMS to support hand-games can aid the advancement of movement-based games as a whole.

CCS CONCEPTS

• **Human-centered computing** → *Human computer interaction (HCI)*; Interaction paradigms;

KEYWORDS

Movement-based games, Electrical Muscle Stimulation, Bodily games, Game design, Integrated Play, Hand games, EMS Games

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1 INTRODUCTION

There are many traditional hand-games [8, 14, 21]. These games see players move their hand(s) and generally require two players. There are endurance games such as Hot-hands[1] and Thumb-war[2], finger-counting games such as Odds-and-evens[3], Morra[4]; and chance games such as Rock-paper-scissors[5]. These hand-games are often played by children, across various cultures [7]. They are believed to help the early development of sensory skills [36] and are valuable to shape cognitive, physical and social skills [21].

The Human-Computer Interaction (HCI) game community is interested in designing Movement-based Games [3, 12, 19, 23, 29, 33, 34], partially because they offer mental and physical health benefits [1, 4, 15, 20, 28, 31, 33, 38]. Movement-based games are digital games in which the player's motor movements influence the game's outcome [32]. These movements can now be actuated using Electrical Muscle Stimulation (EMS). This technology induces a small amount of electricity into the body using electrodes attached, making the muscles contract and thus moving the body involuntarily [22] (Fig. 1). We believe there is an opportunity with EMS to create hand-games that can be played with oneself. However, designing games by incorporating EMS is not well understood.

In this paper, we present two EMS hand-games (Fig. 1), *Slap-me-if-you-can* and *3-4-5*. We articulate the technical setup, design and present preliminary findings in the form of three themes by analysing player interviews: a) Gameplay experiences and influence of EMS hardware, b) Interaction with EMS and the calibration process and, c) Shared control and its effect on playing EMS games. We believe that while such games could be played if no co-players are available, they can also be played to understand one's own body, which is beneficial for our overall well-being [9, 27]. Ultimately, we hope that understanding the design of games incorporating EMS extends our knowledge of movement-based games.

2 RELATED WORK

Our article builds primarily on prior social science work on playing traditional games involving bodily movement and prior theoretical work on movement-based games in HCI.

2.1 Playing Traditional Games

Traditional games involving bodily movements are associated with benefitting mental skills, sharpened motor skills, improved control and balance, enhanced hand-eye coordination, increased spatial awareness and enhanced social skills [16–18, 21]. *Hand-games* are examples of traditional games played across continents, and various cultures [7]. *Rock-paper-scissors*, *Odds-and-evens*, to name a few, are examples of games involving hand movements. These games are characterised to have simple rules, rely on quick hand movements, require a minimum of two players and do not need any other game objects to play. Research suggests that these games can teach life lessons and help develop fond memories essential for the healthy and holistic development of an individual [21].

2.2 Movement-based Games in HCI

Playing games involving bodily movements require players to exert physical effort [30, 32]. When it comes to digital movement-based games, we often find them using a screen; however, we are intrigued by the simplicity of hand-games and therefore are interested in screenless movement-based games. For example, *i-dentity* [11] is a collaborative movement-based four-player game (three spies, one interrogator). The interrogator needs to find the leader of the spies. The game conceals their identity when the leader moves by lighting up the PlayStation Move controllers of both the spies and their leader. We used this design tactic in our EMS games by concealing information on how the EMS hand moves by not using visual output.

We also learnt from previous movement-based games work that considered ambiguity [13, 30]. *Intangle* [10] is an example of a PlayStation Move controller only game that utilises ambiguity in the form of computer instructions that guide players and challenge them to press buttons on another player's controller who is not easily reachable. The randomness of the computer's instructions facilitates ambiguity and always ends by entangling the players' bodies in various ways, facilitating a physical challenge. While ambiguity is facilitated using an external device in this game, we utilise the player's body to make it challenging for the player to predict their ambiguous hand movements.

These games explored the design of movement-based games, but they require another player and hence cannot be played alone. We acknowledge that there have been preliminary explorations of games using EMS [24, 25]. However, these games have been part of a contribution [26] that does not explore or contribute to the design

[1] https://www.youtube.com/watch?v=8YMo4TBSBNc
[2] https://en.wikipedia.org/wiki/Thumb_war
[3] https://en.wikipedia.org/wiki/Odds_and_evens_(hand_game)
[4] https://en.wikipedia.org/wiki/Morra_(game)
[5] https://en.wikipedia.org/wiki/Rock_paper_scissors

of movement-based games, thus highlighting the opportunity to understand the **design of games by incorporating EMS**.

3 HAND-GAMES INCORPORATING ELECTRICAL MUSCLE STIMULATION

We designed two games inspired by traditional hand-games: *Slap-me-if-you-can* and *3-4-5*. In this section, we describe the technical setup and then articulate the design.

3.1 Technical Setup

The prototype employs a custom device, as shown in Fig. 2 (see Appendix A2 for the schematic diagram). The essential components are: a) Accelerometer (GY-BNO08X) that player holds in their non-EMS hand (see (Fig. 2A). b) Digital push-button (Fig. 2A) - players press before starting each round of play, c) EMS device built as outline on [6] and, d) Electrodes that are colour coded to help players in attaching them to their body (Fig. 2).

3.2 Designing *Slap-me-if-you-can*

Slap-me-if-you-can is a *reaction* type of a hand-game. Playing the original *Hot-hands* game requires two players, and two game rounds are explained using Fig. 3. Each round begins with a player counting down from three. Doe's hands, which are placed below John's, try to slap John's hands as quickly as possible at the end of the countdown, while John needs to react quickly and avoid Doe's slap. Here, the focus is on listening to the countdown carefully and paying attention to when it ends.

Our version of the *Hot-hands* game can be played by a single player. The starting position of the players' hands is shown in Fig. 1A. The countdown from three with which players know that the game begins when playing the original version is replicated with the players pushing a digital push button (Fig. 2A). This action triggers a red coloured electrode attached to their *flexor digitorum profundus* muscle on the anterior part of their forearm (Fig. 2C). This electrode makes their wrist gently curl three times inwards, standing for the 3-2-1 countdown. The game's goal is for the player to slap their EMS hand with their non-EMS hand, in which they hold an accelerometer. Electrodes (black colour to indicate ground (anode) and green colour for the cathode – Fig. 2B) are used to overlap the *extensor carpi radialis longus* and *extensor carpi ulnaris* muscles on the posterior part of the player's forearm. We chose these muscles as actuating them turns their wrist and forearm such that it either moves away from or towards the player's torso, depending on the muscular structure of the player's hand. The choice of the muscle is how we made the player's movement ambiguous, which resulted in the concealing of the EMS hand's movement until the actual movement occurred during gameplay. A player's hands scores points in the following way: a) If a player's non-EMS hand can slap their EMS hand, then the non-EMS hand gets one point and, b) If the EMS hand can dodge the slap, then the EMS hand gets one point.

Players are free to choose the number of rounds, and they note their score mentally. The intensity and the duration of the actuation remain the same throughout the game.

3.3 Designing *3-4-5*

3-4-5 is a number-counting *hand-game*. It is inspired by the traditional game of *Odds-and-evens* that is played with at least two players. A two-player version is described using Fig. 4 (A, B, C).

Our version of the *Odds-and-evens* game can be played by one player. We actuate the middle and ring fingers of the EMS hand, showing either a 3, 4 or 5 (hence the game's name). The starting position of the player's hands is shown in Fig. 1D. Unlike the traditional game where the fists of both the players are closed, the EMS hands need to be kept open in this game as the EMS can only actuate finger movements such that they curl and close inwards, determining the remaining fingers as the rolled number. The start is the same as in section 3.2, i.e., pressing the button, which makes their wrist gently curve three times inwards metronomically. The player then moves their non-EMS hand to show a number, which sends an input to the accelerometer. This input to the accelerometer triggers the two electrodes attached to the player's left posterior forearm, i.e., the *flexor digitorum profundus* muscle, to facilitate motor movement of the ring and index finger. The EMS hand can roll three numbers: a) When both electrodes are triggered, the EMS hand rolls a "3" by closing the middle and ring finger, b) when only one electrode is triggered, the EMS hand rolls a "4" by closing either the middle or ring finger and, c) when no electrode gets triggered, the EMS hand rolls a "5" as no finger closes.

The fingers shown by the hands are added to decide if the hand associated with "evens" or "odds" won. Player's make a mental note of their score. Also, there is no game audio of any sort besides the clicking of the mechanical relays that trigger the EMS channels, which will be replaced with solid-state relays in a future version.

3.4 Study Design and Analysis

An informal pilot study was conducted with four participants within our lab. The mean age is 24.5 years, and the standard deviation is 4.97 years. The study began by explaining the basic principles behind EMS. Then, calibration began: the electrodes were initially placed on the locations shown in Fig. 2(B, C and D). The calibration was done by turning the intensity dial-up or down on the EMS device. They were also able to adjust the placement of the electrodes to suit their body such that they facilitated the desired movement for each game. The calibration could either be done by turning the intensity dial-up or down using a store-bought EMS or connect to the custom EMS device directly and trigger the electrodes by pressing the digital push button. Upon playtesting both the games, each participant was interviewed for approximately 20 minutes to understand their experiences using the laddering technique [37]. Interviews were transcribed and consisted of 252 units of data. Each data unit consists of a question asked by the interviewer and the answer given by a participant. An inductive thematic analysis [2] was performed by the first and fourth author to deduce 53 codes (see A1), which we grouped into three themes as discussed in section 4.

4 DISCUSSING PLAYER EXPERIENCES AS THEMES

Overall, participants liked playing the EMS games. P1 reported, *"it was scary at first, to be honest, but it felt nice over time, in a weird way"*. We note that three of four participants liked *3-4-5* over

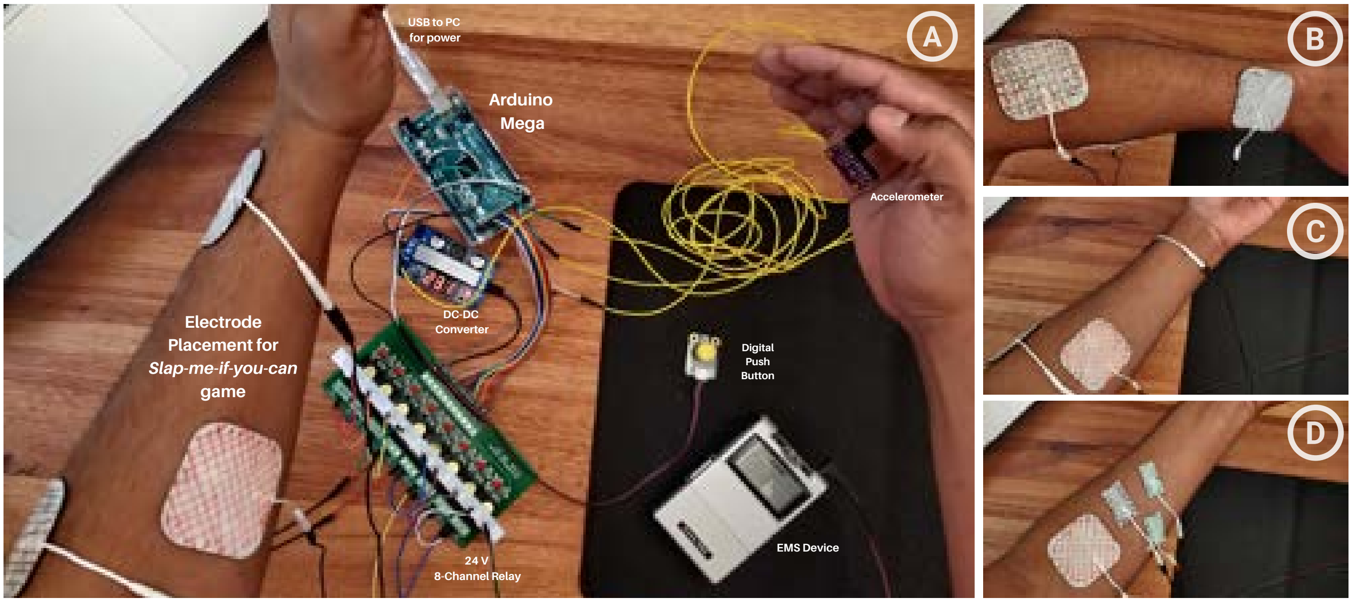

Figure 2: (A) - game setup and components. Initial electrode placement for *Slap-me-if-you-can* (B and C), *3-4-5* (D).

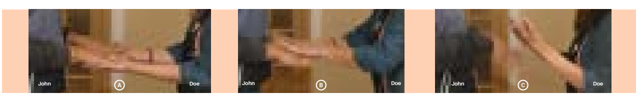

Figure 3: (A, B, C) - Original version of *Hot-hands.* (A) - Starting position of John and Doe. (B) - Doe successfully slaps John. (D) - John dodged Doe's slap. (D, E, F) - Original version of the Odds-and-evens game.

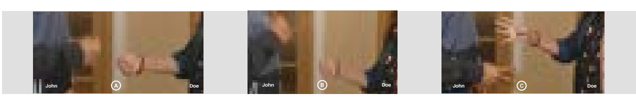

Figure 4: (A, B, C) - Original version of the Odds-and-evens game. (D and E) - John ("odds") and Doe ("evens") shaking fists. (C) - John rolls a "2" and Doe rolls a "4", a total of 6 (=4+2), thus Doe wins this round of play.

Slap-me-if-you-can due to the delay caused by the EMS hand while moving it. In this section, we unpack the player experience by articulating three overarching themes: a) Gameplay experiences and influence of EMS hardware, b) Interaction with EMS and its calibration process and, c) Shared control and its effect on playing EMS games.

4.1 Gameplay Experiences and Influence of EMS Hardware

In this theme, we discuss the gameplay and the effect of the hardware on participants' experiences while playing the EMS games. This theme has two sub-themes: a) Tactics of playing EMS games and b) Tactics and EMS specificities.

4.1.1 Tactics of playing EMS games. All the participants had fun playing the EMS games but had preferences of their own. P3 specifically spoke about competitiveness and said, *"I enjoyed playing both the games, but I liked 3-4-5 more because it required me also to think and not just move my hand"*. P1 added and said, *"I think mentally outperforming a machine is more interesting than physically outperforming it because a machine can usually outperform a human mind"*. P2 said, *"I think the Slap-me-if-you-can game was more interesting as I was able to figure out how the 3-4-5 game works easily"*. Their "bodily stiffness" enhanced this randomness in *3-4-5* during gameplay. P1 said, *"In 3-4-5 I noticed that it was ambiguous as to what the machine was trying to get my hand to do. I probably was trying too hard to keep my arm in a certain position"*. For *3-4-5*, participants strategised in multiple ways. P1 was prepping before the game round and said, *"I was thinking of what number to roll with my non-EMS hand and already kept my fingers ready because the EMS cannot see me, unlike if I was playing this game with someone else"*. P3, who initially started playing a game of three rounds, lost two and immediately increased the number of rounds to five and said, *"the EMS hand cannot stop me if I change rules mid-game"*.

4.1.2 Tactics and EMS specificities. Two participants reported an element of surprise when experiencing the hardware during gameplay and in different ways. P1 spoke about the sound produced by the mechanical relays in the custom EMS circuit and said, *"it is nice feedback because the sound produced indicates that the accelerometer got detected and the electrodes are about to pass electricity through my body"*. P3 described how she was surprised by the way electrodes moved the hand while playing *Slap-me-if-you-can* and said, *"When I play this game with my friends, I usually move my hands downwards. The EMS moving my hand either towards me or away from me was surprising"*.

4.2 Interacting with and the Calibration Process Using EMS

This theme discusses the emotions experienced by interacting with the EMS and describes how players felt about the calibration process. It has two sub-themes: a) Interacting with electrical muscle stimulation and 2) Calibration process as a form of playfully learning about oneself.

4.2.1 Interacting with Electrical Muscle Stimulation. P1 felt a sense of weird fun and said, *"it was a really weird feeling and I found it funny. It's like laughing when you make yourself dizzy by spinning around"*. P1 also spoke about their journey from being scared to comfortable and later experimental and said, *"there's a little bit of an apprehension, but then after a bit it felt nice. After feeling this, I was doing it just for fun stimulating my own hand beyond the game"*. P3 reported on her experiences with EMS and said, *"It was nerve wracking at first. However, it was fun as well, not being able to know what to expect."* P2 spoke about their expectation they had before coming into the study and said, *"I expected the EMS to have a mind of its own and it'll just keep moving my hand, however, after playing the games, I realised I had a wrong notion"*.

4.2.2 Calibration process as a form of playfully learning about oneself. All participants agreed that the calibration process was essential to calibrate the electrodes on their forearm for different games and helped learn about the relationship between these muscles and body movement. P2 said, *"it was interesting to know that different areas of my hand muscles did different things to my hand movement. This also helped me understand my body biologically"*. P3, who studies physiology, was surprised and said, *"It never occurred to me how many different movements you could get by stimulating just the lower part of your arm"*. P4 said, *"calibration is interesting in itself because you're learning about how your bodies are connected to itself"*. Participants also spoke about how the calibration process makes the invisible, visible, i.e., clarified to them about how the EMS worked. P1 said, *"I did appreciate that you let me get a comfortable sense of how high I wanted the voltage to be before I started playing the game. It just felt safer and helped me ease into the study"*.

4.3 Shared Control and its Effect on Playing EMS Games

In this theme, we discuss participants' experiences sharing their control over their body with the EMS and how it affected their experience. It has two sub-themes: a) Sharing control and the dilemma of ownership and 2) Effect of shared control on interpreting the game outcome.

4.3.1 Sharing Control and the dilemma of ownership. Participants spoke about how they tested the amount of control they had over the EMS. P2 said, *"I tried to resist the movement being created by the electrical stimulation. Although I was resisting, I could still feel it fight a little bit against my control"*. We note that P2 wanted to know they were in control and said, *"I feel like if you don't have any control over your arm, it's a bit scary"*. P1 shared this sentiment and said, *"it does make you feel a bit more relaxed knowing you still have control of your own body"*. When EMS actuated the movement, participants were unsure of who was controlling their arm. P1 said, *"it was odd to watch your body move and not entirely be sure about whether you were doing it or the computer was doing, or like, sorry the EMS was doing it"*. P1 said, *"occasionally I would catch myself asking, was that me or the EMS? Do I know what is about to happen?"*. P3 added and said, *"I think it just sort of didn't feel like it wasn't me"*.

4.3.2 Effect of shared control on interpreting the game outcome. Participants also spoke about how sharing control with the EMS affected their experience of playing the games. P1 said, *"I didn't feel in control of my arm. Although again, I felt like I relinquished control purposely and made my arm relax so that EMS could have better control over my game"*. While participants acknowledged that it was their arm, they referred to it as someone or something else when speaking during the interview and playing the game. P3 said, *"I don't know if you noticed, but at one point, I said, oh, 'he won' when the EMS had won. So, I think I just sort of see the computer as this other being and in this case a boy/man I suppose [laughs out loudly]"*. This led to players thinking about alternative game strategies. P1 said, *"Confusing to be honest, because I had to remember that I had to do something with his hand rather than throw it. So, I decided ahead of time what number I was going to roll. I could then focus on seeing what the other hand resulted in"*.

5 LIMITATIONS AND FUTURE WORK

We acknowledge a slight delay in slap while playing *Slap-me-if-you-can* because of using mechanical relays, which could have resulted in participants liking *3-4-5* more. Therefore, we are working towards reducing the hardware's delay and improving the competitiveness of the *Slap-me-if-you-can*. We will also design the electrode triggering algorithm to represent behaviours better when playing the original *Hot-hands* game for future work. The algorithm could include features such as the EMS hand not reacting sometimes or recognise fake slaps by the right hand. Moreover, we understand that our findings could be skewed due to the novelty of playing such games. The existing technical setup is not very portable and hinders studying these games outside a lab setting, enhancing our understanding of EMS game experiences in-the-wild [5, 35]. Therefore, we are in the process of minimising the technical setup to make it wearable.

6 CONCLUSION

In conclusion, with the design of these two games inspired by traditional hand-games, game designers could gather insights into understanding EMS games. We showed that these games that traditionally require two players can now be played using our own body by sharing bodily control with an EMS. Furthermore, we articulated the experiences of participants playing the games as themes. Ultimately, by understanding the design of EMS games, we aim to extend our knowledge on designing movement-based games.

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A APPENDIX

Figure A1: Groupings of themes and codes codes we deduced from thematically analysing the interview data.

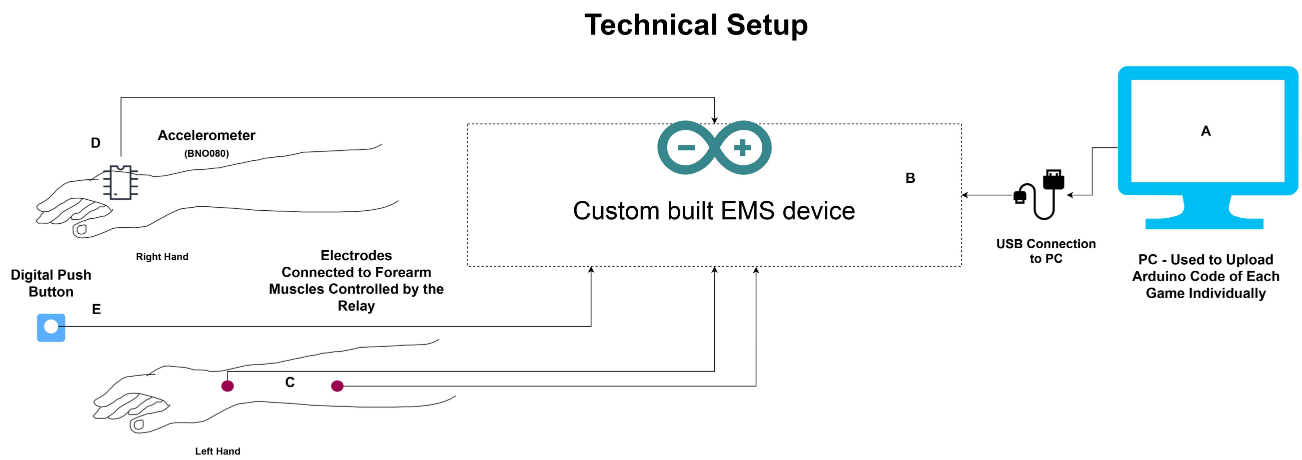

Figure A2: Shows a schematic diagram. (A) PC - the unit is used to upload game code and power the EMS that has a microcontroller (B). The electrodes on the player's left forearm (C) are connected to the EMS. (D) and (E) are the accelerometer and button connected to the microcontroller.