ICE IS NICE: A MODULAR GAMIFIED RESEARCH AND TRAINING PLATFORM FOR PEDIATRIC UPPER LIMB PROSTHETIC CONTROL

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ABSTRACT

Training for children who are prescribed myoelectric upper limb prostheses presents unique challenges in maintaining attention, motivation, and ultimately providing an enjoyable experience that is effective in developing the core motor skills required for device operation. From a clinical perspective, patient engagement is critical for maximizing functional outcomes, and from a research perspective, it can be vital to ensuring the quality of collected data. Therefore, our goal was to develop a training and research platform designed to both collect high-quality data from actively engaged participants and to provide them with a fun and engaging way to practice actuating the muscles relevant to myoelectric prosthetic control. "*Ice is Nice"* is a side scrolling video game that prompts children to perform a variety of movements with their missing hand, and the game is controlled using real-time measurement of their muscular activity. Our system is agnostic to muscle measurement systems, capable of using electromyography, force myography, and ultrasound-based control, among many others. As the game is played, data is logged to capture metrics relevant to game proficiency, human motor learning, and machine learning performance. Therefore, we suggest *"Ice is Nice"* provides a research and training platform with significant potential to support numerous follow-on studies conducted with children and adults. These studies aim to develop robust prosthetic control strategies, understand the effects of motor learning on prosthetic operation, and examine the functional capabilities of individuals operating upper limb prostheses.

INTRODUCTION

The main goal of upper limb prostheses is to assist in the functional execution of everyday tasks, though they are also beneficial in the psychosocial domain as well by promoting social inclusivity and giving the user a greater degree of independence [1]. However, abandonment rates are high in pediatric populations and exceed those found in adult populations, with an estimated 35-45% of prescribed devices being abandoned [2].

Children present with challenges associated with prosthesis prescription and usage that differ from those faced by their adult counterparts. For example, the vast majority of upper limb deficiencies in children are congenital, in contrast to adult populations where the majority of upper limb amputations are acquired, resulting from trauma, disease progression, or infection [3]. These differences in etiology are particularly relevant to the use and potential abandonment of modern myoelectric prosthetic systems, which require the user to intentionally and skillfully control their residual muscles. As most pediatric prosthesis wearers will never have used the muscles in their affected limb to control an intact hand, the muscle activity from which prosthetic control signals are derived, may be very different in these groups of prosthesis wearers. In our previous work, we have shown that children born without a hand retain a motor representation of their missing limb that presents itself as coordinated patterns of muscle activation while attempting to make different hand movements [3], [4]. These findings were observed in children who had not undergone any prior training in envisioning their missing hand or performing imagery tasks. We argue that, like learning any new motor skill, training and practice will improve these children's coordination and proficiency in performing such tasks and ultimately provide tremendous potential towards improved dexterous prosthetic control and functional outcomes.

Modern myoelectric training encourages wearers to make muscle contraction patterns that are separable in feature space [5], [6]. This theoretically results in more accurate classifications for pattern recognition systems as the acceptable margin for error increases but does not necessarily reflect biomimetic control. The shortcoming associated with this form of training is that this type of instruction often leads to an internal focus of attention (focusing on one's own body movements, muscle contractions) rather than an external focus of attention (focusing on the effects of one's movements, prosthetic movement). Previous research has shown that having an internal focus of attention results in less effective movements and motor learning, as it may impede with the body's natural and automatic control processes [7], [8]. In the context of prosthetic control, the end result is an observable decline in pattern recognition performance in the time following internally focused training [9].

Our objective was to develop a research and training platform intended for use among pediatric prosthesis wearers. "*Ice is Nice*" is a gamified platform which prompts users to practice making common grasping movements using their missing hand and uses the derived affected muscle activity as game control signals, thus providing the possibility for training with an external focus of attention. The long-term goal is to provide users with a low-stakes, yet engaging training environment that also enables researchers and clinicians to attain high quality data that quantifies training progression, game performance improvements, and the associated improvements in machine learning performance.

METHODS

Game Walkthrough

"*Ice is Nice*" is a side scrolling game that prompts children to perform different hand motions while recording relevant motor learning and machine learning metrics in the background. Upon starting the program, the user is brought to the main menu (Figure 1a). The user is then directed towards the administrator menu (Figure 1b). This interface allows the researcher to choose anywhere from two to five hand motions from a pool of ten that they wish the participant to practice. These motions were selected from the ten most commonly used in tasks of daily living [10]. The researcher is then directed towards the next screen (Figure 1c), where they may specify the total number of movement repetitions that the participant will be instructed to perform along with the frequency at which each occurs. This allows the researcher to emphasize specific hand motions, perhaps ones that the participant has difficulty performing. After completing this step, the researcher hands off control to the participant, allowing them to select their preferred character (a caribou or seal, Figure 1d, described further below). Following the character selection, the game begins. The character automatically walks across the screen and encounters an obstacle (an iceberg or hole in the ice, Figure 2a). The participant is then prompted to perform a movement and hold it. If held long enough, the character successfully jumps over the obstacle and walks towards the next one (Figure 2b).

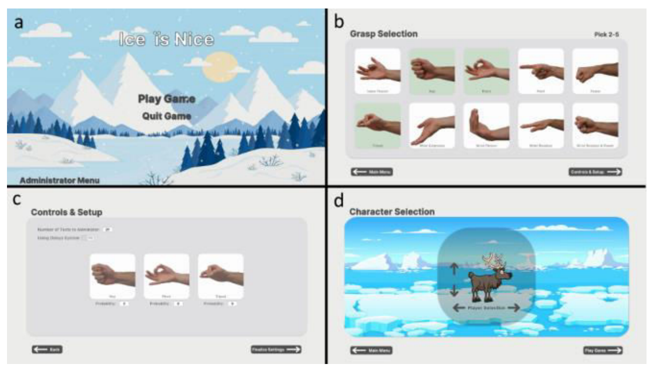

Figure 1: Upon program startup, the user first sees (a) the main menu. Next, the administrator menu is brought up for the researcher to (b) select desired motions and (c) specify how many total movements the participant will be instructed to complete along with the individual motion frequency. The participant may then (d) choose the character they wish to play as.

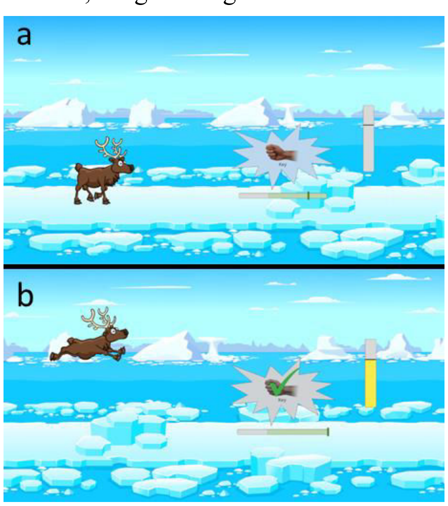

Figure 2: The user first (a) approaches an obstacle and is prompted to make a hand motion. Upon successfully holding the motion long enough, (b) the character jumps over the obstacle.

Game and Controller Design

Controlling one's affected muscles to operate a prosthesis, like any other learned motor skill, requires practice, repetition, and time. Our primary motivation was to ensure that this learning process is an engaging, motivating, and enjoyable experience. Several key design requirements shaped our final system.

Game control, involving the classification of hand movements, was designed to be hardware agnostic. This was achieved by integrating a real-time pattern recognition script with the game through a localhost TCP connection, using code written in MATLAB and Unity software. The latency of this connection was measured to be less than 1ms. The game received real-time input classification data from MATLAB representing predicted grasps as whole numbers ranging from zero to ten, inclusive (Table 1). A majority voting post-processing technique was employed to improve classification stability, where each new prediction was placed into a buffer of length n and the prediction that occurred most frequent was the selected output control for the game. Thus, the game was able to take input derived from pattern recognition predictions in MATLAB based on a wide range of signals commonly used in the control of upper limb prostheses, including EMG, FMG, sonomyography, and others [11]. For example, to assess feasibility, we implemented a game control system that used surface electromyography (sEMG). Using our Delsys Trigno system, MATLAB recorded inputs from eight EMG electrodes at 2000Hz. We used a Linear Discriminant Analysis classifier that was trained on five features from the Hudgins feature set in the time-domain [12]. Hand grasp classifications were transmitted to Unity in real-time, and by using the majority voting scheme described above, the game successfully registered the attempted hand grasp to control the game. It was verified that this process retained communication response times below the commonly implemented maximum acceptable delay of 300ms [13].

Table 1: The provided numbering convention must be adhered to when connecting a custom real-time classification script to the game.

Grasp Name	Grasp ID
Index Flexion	0
Key	1
Pinch	2
Point	3
Power	4
Tripod	5
Wrist Extension	6
Wrist Flexion	7
Wrist Rotation	8
Wrist Rotation & Power	9
Rest	10

<u>Promoting Engagement During Training</u>

Particular attention was given to the game's design to maintain player engagement throughout. This is evident in the game's presentation and various mechanics, all designed to minimize the potential for player frustration and sustain engagement when misclassifications inevitably occur. For example, the game incorporates cartoonish graphics, lively animations, and vibrant color palettes to enhance visual appeal and retain attention. Additionally, players are provided with the opportunity to choose from a diverse range of characters and variations (Figure 3). A game mechanic designed to reduce the potential for frustration allows players to skip a prompted grasp motion by pressing the spacebar, ensuring they do not get stuck if they fatigue or are unable to perform a particular missing hand movement. Finally, the game provides ongoing positive feedback throughout.

Figure 3: A few of the character choices are shown in the above image.

Visual positive feedback was a key design criteria guiding game development. This was of particular importance as, in addition to fostering engagement beyond that of neutral or negative feedback[14], [15], the inclusion of visual feedback often results in the participant producing higher quality training and performance data [16]. One form of positive feedback employed throughout the game is a green checkmark displayed when the user successfully completes the required hand motion. This is paired with a horizontal progress bar and a vertical points bar (Figure 2). Together, the user is prompted to make the specified hand motion with an image of it, and a horizontal progress bar begins to advance, allowing the participant to prepare and time the start of their missing hand movement (muscle contraction). When this progress bar reaches the green colored region, the participant will begin receiving points for maintaining the appropriate missing hand movement. The vertical progress bar then gradually advances (fills up) as more points are required. Once a target amount is reached, a large green check mark is shown, the character jumps over the obstacle, and the game advances to the next hand movement.

Finally, to promote engagement and encourage the development and refinement of hand movement proficiency, the game provides the opportunity to adjust the difficulty of gameplay. Here, we implemented three adjustable parameters: one affecting the time a participant has to prepare for the required hand movement, another determining how long they must hold the movement (contract their muscles), and one more affecting the time between required movements. These settings were implemented to ensure that training sessions could be tailored to reflect the user's goals, whether it to emphasize making separable and consistent muscle contractions or to challenge the participant in terms of more rapidly achieving various hand movements.

DISCUSSION AND FUTURE WORK

"*Ice is Nice*" is a research and training platform designed for children (or adults) to practice the motor skills necessary for controlling pattern recognition-based prosthetic control systems. It enables researchers and clinicians to collect high-quality data that is captured in the background as the user interacts with a side-scrolling gameplay environment. It was designed to engage participants during training, which may be otherwise tedious, and also provide opportunities to challenge participants through difficulty adjustments while minimizing the potential for frustration. Furthermore, the system was designed to be agnostic to prosthetic control systems, accepting number-coded hand grasp data. That is, any control system or software capable of exporting real-time movement predictions following our number-coded list can be accepted by "*Ice is Nice*" (in Unity). It can then be placed in its buffer, and use the built-in majority voting scheme to control the gameplay. We are now beginning testing with able-bodied cohorts and children with unilateral congenital below elbow deficiency operating the game using electromyography and ultrasound-based control systems. Additional game modifications that will be released in our next software update includes visually distinct, 'levels' of gameplay with preset degrees of difficulty, and alternative post-processing techniques. We aim to further evaluate the motor learning and training effects with use of our system, as well as refine it toward a stand-alone platform alongside a low-cost EMG band for take-home training applications.

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