Avaler's Adventure: an Open Source Game for Dysphagia Therapy

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Abstract

The ability to swallow is paramount for the human experience. Normal swallow function relies upon the coordination of swallowing with the respiratory system to ensure that food is directed away from the airway and towards the stomach. Dysphagia, also known as trouble swallowing, occurs when there is a disruption in normal swallow function. Speech-Language Pathologists, who provide therapy to patients with dysphagia, often integrate video games and biofeedback into treatment designed to rehabilitate swallow function. We created a modern, open source game suite that is well suited for various patient demographics[1]. We believe that the game suite will be motivating to patients and allow Speech-Language Pathologists to document objective gains toward the patient's therapy goals.

keywords: dysphagia, swallow therapy, video games, speech pathology

1 Introduction & Background

Normal swallowing is a complex collaboration between the brain, nerves, and muscles for safe and efficient transportation of food through the digestive system. Normal swallow function relies upon the coordination of swallowing with the respiratory system to ensure that food is directed away from the airway and towards the stomach. Dysphagia, also known as trouble swallowing, occurs when there is a disruption in normal swallow function.

Dysphagia affects about 15 million Americans, with almost one million more cases reported each year [2]. Dysphagia often occurs when there is damage to the nervous system such as a stroke, brain injury, Parkinson's disease, or problems affecting the head and neck such as cancer or trauma [1]. Dysphagia can lead to serious health complications including malnutrition, dehydration, reduced quality of life, prolonged hospital stays, increased healthcare costs, dysphagia-associated respiratory compromise, and even death [4].

Patients experiencing dysphagia often require specialized therapy treatments to rehabilitate swallow function. Speech-Language Pathologists (SLPs) are the medical professionals responsible for the evaluation and treatment of swallow disorders. Treatment provided by SLPs has shown to be effective in dysphagia management. While the effectiveness of swallowing therapy is widely known, the effect that video games have on patient progress is not fully understood.

In the past several years therapy games have entered the market. Stepp et al. created a video game for rehabilitation of dysphagia patients using surface electromyography (sEMG) biofeedback, but they concluded that further study was needed to make a conclusion about the effectiveness [8]. One study aimed at rehabilitation of stroke patients (not strictly limited to swallowing therapy) using video games concluded that the games provide "an element of accomplishment," which resulted in patients "sticking to their therapy more than any method they had previously tried" [3]. This becomes an important factor in patient retention when it comes to therapy and encourages patients to continue attending their therapy sessions.

Another similar study that focused on swallowing therapy for stroke patients concluded that the use of video games resulted in "larger differences in hyoid bone displacement and FOIS scores (before and after treatment) in the experimental group than in the

[1]The source code can be accessed at https://github.com/TennisGazelle/Avalers-Adventure

control group" [5]. A study where patients used the SilverFit Rephagia system reported, "on average, the patients improved 3 steps on the 7-point FOIS score" [6]. The differences in hyoid displacement and Functional Oral Intake Scale (FOIS) scores demonstrate how patients may be encouraged to excel at a higher standard than if they had not used video games. These studies observed increased patient motivation, so we suspect that video games can be an incentive for improving patient health.

Surface Electromyography (sEMG) is an existing technology widely used in rehabilitative medicine. During swallowing, muscle activity is detected via an electrode placed on the front of the patient's neck. Specialized software translates this muscle activity signal into a visual representation on a screen in a motivating game-like environment.

The aim of this project was to create a novel biofeedback system integrating video games for use in dysphagia rehabilitation. The intended users of these games include patients with dysphagia, Speech-Language Pathologists, and rehabilitation professionals. We followed these requirements along with use cases to create a game suite that fits the needs of the users. Using these requirements, we created hardware, high-level, medium-level, and detailed designs. The user interface snapshots show the features of the game suite as shown in Figure 1.

Figure 1: This figure shows gameplay of Island Expedition, one of the games in the suite. The game is set to typical swallow mode. There is a graph in the upper left-hand corner that displays the throat pressure values read from the sEMG.

This paper discusses the development of the game suite, which required collaborating with medical practitioners and implementing software engineering methods. The rest of this paper is organized in the following manner: Section 2 presents the methods and tools to develop the game suite, Section 3 presents the results and discusses the findings, Section 4 discusses future work and concludes.

2 Implementation

In order to create a game suite that is useful for the patients and Speech-Language Pathologist in dysphagia therapy, we needed to determine what the requirements of the system should be. We began by contacting SLPs affiliated with our university for Stakeholder Interviews. The feedback from these interviews and related sources were used to construct the business, technical, and functional requirements.

2.1 Stakeholder Interviews

Speech-Language Pathologists (SLP) working at the University of Nevada-Reno Speech and Hearing Clinic were interviewed regarding existing therapeutic gaming systems. This allowed us to clarify project requirements, determine game suite expectations, as well as provide strengths and limitations of existing systems.

One strength of existing systems is that patients often tended to work harder when given on-screen biofeedback of their performance. Additionally, existing systems allow for capture and tracking of objective treatment data. Patients and clinicians can see progress over time.

Per SLP report, limitations of existing systems do not allow for a single session to include different types of swallow exercises, variation of time intervals between exercise repetitions, nor a varying amount of pressure for each exercise task. The SLPs emphasized the importance of patient selection and candidacy for game use. Current systems are "kid-like" and may not support adult interests.

The SLPs suggested that games be less predictable so that patients continue to be challenged over time and across treatment sessions. The SLPs suggested that environments most salient to the patient may encourage maximal effort during exercise. The cost of the system, patient comfort, and ease of use were also important issues. They suggested using colors and contrast more effectively as well as adding an auditory component.

We also interviewed Computer Science and Engineering faculty who had had experience in creating games with similar architecture. They suggested researching "one-switch" games, which are games that are controlled using only one input, such as Angry Birds. We were also encouraged to use Unity to develop the game and gave some advice on best rendering techniques. Lastly, it was recommended that we transfer the data using a stateless UDP connection.

2.2 Business Requirements

The high-level business requirements outline the goals of the game suite:

- **BR1 – Interactivity:** The game suite shall provide patients with an interactive form of dysphagia therapy.
- **BR2 – Patient Progress:** The game suite shall allow SLPs to monitor and record patient progress.
- **BR3 – Configurable Nature:** The game suite shall be configurable to be played with various types of dysphagia treatments and adjustable to suit patient abilities.
- **BR4 – Game Themes:** The game suite should have various themes to suit different patient demographics and interests.
- **BR5 – Improvements:** The game suite should improve on the shortcomings of the current application, including updated graphics, motivational themes, and patient feedback integration.

2.3 Technical Requirements

The technical requirements included below describe functional and non-functional requirements of the system. The former describes how components of the system should work, the latter describes how the system should work as a whole [7]. The sequence diagram in Figure 2 choreographed the main interaction between the SLPs, patients, and game suite. An example of the virtual state machines emulated in our game engine is demonstrated in the state diagram in Figure 3. These requirements and diagrams were considered during each phase of implementation.

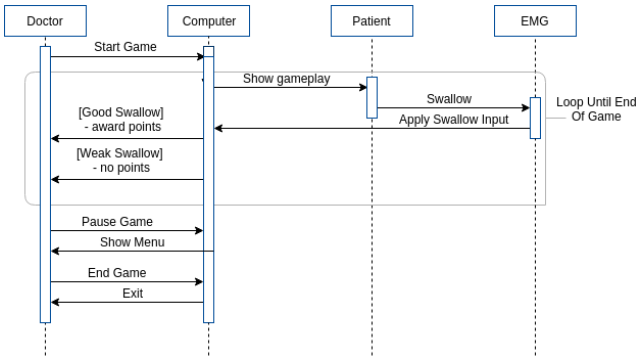

Figure 2: Sequence diagram of the gameplay, which shows the sequence of events from when the game is started until the game exits.

2.3.1 Functional Requirements

The functional requirements were constructed to define how the various components of the system would work individually and within the game suite.

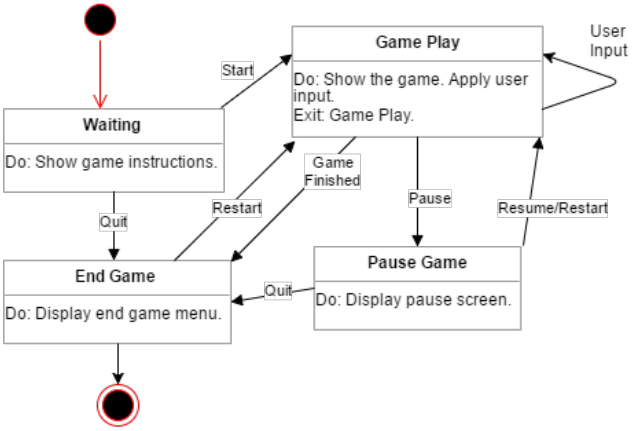

Figure 3: This state diagram represents the behavior of the game suite in response to the available events.

- **FR1 – Data Simulator**: A python script shall be able to simulate three different waveforms of data (typical swallow, effortful swallow, Mendelsohn Maneuver), and be able to generate noise. Both waveform and noise shall be as close to real-world data as possible
- **FR2 – Networked Data Stream**: A script shall be able to transmit data from the sEMG over the network using UDP to a Unity receiver.
- **FR3 – Game Input**: The game shall have one input to control the game. This single input will control the avatar movement. If the input received matches the specified threshold, the avatar will collect the reward. Otherwise, the avatar will continuously move towards screen right.
- **FR4 – Assessment of Player Strength**: Before playing the game the patient shall perform at least three typical swallows to determine their baseline strength, and at least three effortful swallows to determine their maximum strength level.
- **FR5 – Game Parameter - Wait for Input**: The game shall be configurable such that the avatar will stop and wait for the user to meet the threshold or the avatar will continue moving past the reward if the threshold is not met. This parameter may be set by the user.
- **FR6 – Game Parameter - Effortful Swallow**: The game shall be configurable such that the avatar will move towards the reward proportionally to their swallow strength. A non-effortful swallow is considered 40%-80% from the predefined baseline of a typical swallow; an effortful swallow is considered 80% of typical swallow effort.
- **FR7 – Game Parameter - Mendelsohn Maneuver**: The game shall be configurable such that the avatar will "float" downwards, at a lower veloc-

ity when the patient is exercising a "Mendelsohn Maneuver", or elongated, non-ballistic swallow, for endurance training.

- **FR8 – Game Parameter - Reward Frequency**: The game shall distribute the rewards according to the rest duration set by the SLP.
- **FR9 – Game Parameter - Difficulty**: The game shall be configured such that it may accept a target difficulty set from baseline data or set manually by the SLP.

2.3.2 Non-Functional Requirements

The non-functional requirements were constructed to describe how the system and its components should work.

- **NFR1 – Continuous Movement:** In order to promote consistency during therapy sessions, the avatar should move continuously according to the parameters set by the SLPs. The continuous manner of the game promotes proper and timely repetitions, but this feature shall be configurable by the SLP.
- **NFR2 – Reward Tally:** The collected number of rewards shall be recorded on the screen and will be continuously updated as the player collects more rewards.
- **NFR3 – Proportional Jump Height:** The avatar's movement towards the target shall be proportional the relative swallowing effort being recorded by the graph at that time.
- **NFR4 – Player Error Handling:** The game will continue if the player misses a reward due to inadequate pressure measurements. The SLP should have the ability to choose whether the avatar waits at or bypasses rewards.

2.4 Use Case Models

The use cases define how the system responds when interacting with different roles [7]. The use cases are demonstrated in Figure 4 and comprise the following list:

- **UC1 – Load the Game Suite:** The SLP opens the game and is greeted with a welcome screen.
- **UC2 – Initialize the Game Suite:** The SLP sets the game parameters according to the patient's abilities. Random mode allows for dynamic parameter values so that frequency of swallow, target value, and swallow type vary.
- **UC3 – Select the Game Theme:** The SLP chooses a game theme after initialization. During this phase, the SLP can go to the previous screen or continue to the start of the game.

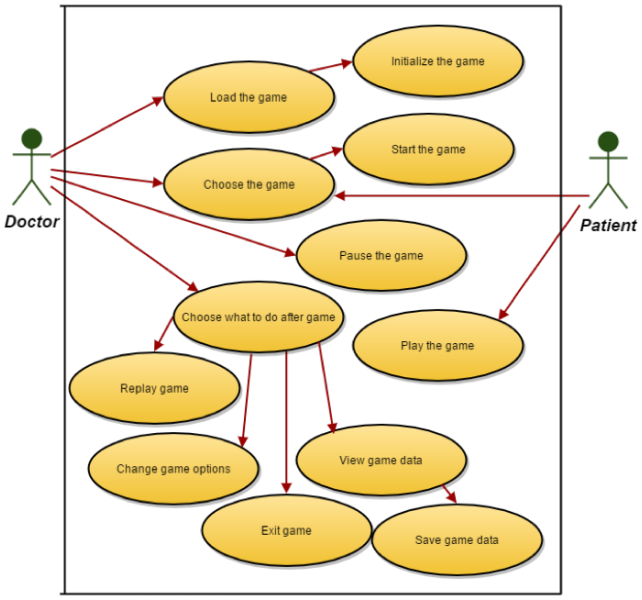

Figure 4: The use case models demonstrate the actions that can be taken by an actor and the outcomes of these actions.

- **UC4 – Begin the Game:** After the parameters are set, the game is loaded and the SLP has the ability to start or quit the game.
- **UC5 – Play the game:** Once the game has begun the patient will need to swallow with enough pressure to meet their target value as they approach rewards. The game will behave accordingly to the configuration by bypassing or waiting at missed rewards.
- **UC6 – Pause the game:** The SLP may pause the game during gameplay. The avatar and other game components will freeze and the pause menu will appear. The menu shows the option to resume, end the exercise, or return to the main menu.
- **UC7 – Exit the game:** After the exercise has been completed, the end game scene displays the exercise results. The SLP may then choose to replay the game, change the game options, end the game, or return to the main menu.
- **UC8 – Replay the game:** The SLP selects to replay the game after the completion of an exercise. Upon selection, they will be returned to the initial game screen.
- **UC9 – End the game:** The SLP chooses to end the game after the results have been displayed. The game suite will close completely.

3 Results

By taking the stakeholder interviews and technical requirements into account, we created a game suite

that is well suited for various patient demographics. The design is described in terms of the high-level and detailed design. The hardware design and user interface design are also included.

High-Level Design: The game suite is a side-scrolling game where the character moves laterally across the screen and towards the reward based on the amount of pressure read from the sensor. When the target value of swallowing pressure is reached, the patient collects the reward. This follows model-view-controller architecture.

Detailed Design: The SLP must set the parameters before the game can begin. These game parameters affect the level of difficulty so that the game is tailored to the patient. The custom parameters include the target baseline value, the percentage of the baseline required for success, each swallow exercise duration, and each rest duration. There four game modes include (1) typical swallow, (2) effortful swallow (swallowing with more pressure), (3) Mendelsohn Maneuver (swallowing and sustaining the pressure), and (4) random (targets require patient to gauge target and swallow type).

Hardware Design: The hardware was designed to maintain the same levels of re-usability and accuracy as existing systems, but at a fraction of the cost. To produce the prototype of the game suite, force sensitive pressure sensors were used to obtain raw pressure feedback. These sensors are practical for simulating swallow pressure wave-forms, which makes them useful for demonstration purposes.

We then configured an Electromyography (sEMG) device, which is attached to the patient's throat in order to record swallow pressure. The electrodes on these devices are attached to the patient's throat with adhesive pads. The sEMG was used to test the game suite and will be used in future patient studies. Placement and configuration of the sEMG affect the accuracy of the input, so further work is needed to produce hardware consistent enough for patient studies. The output is fed to a single board computer (SBC), such as an Arduino. The configuration of the hardware is shown in Figure 5.

Further development of the hardware design would enable SLPs to distribute one to each patient, thus enabling them to practice at home and on their own time.

The system includes several components:

- **sEMG Device** reads pressure data from the electrodes attached to the patient's throat.
- **Arduino SBC** serializes the raw data from the sEMG.
- **Central gaming device** runs the game suite and connects the Arduino and other peripherals.
- **Output units** include a monitor that displays the user interface and speakers for aural feedback.

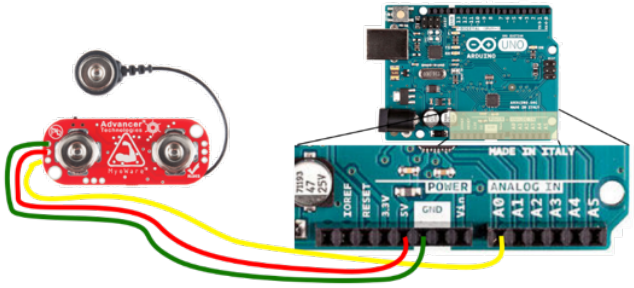

Figure 5: This is a wiring diagram of an Electromyography Device (sEMG) to the analog inputs of an Arduino Atmega 2560. The Arduino converts the raw data to digital and transmits it serially.

User Interface Design: Avaler's Adventure features three game themes, each customizable for the patient's needs and abilities. The settings menu where the SLP can set the game parameters can be found in Figure 6. The user interface is displayed in Figure 7. This figure shows the game in Mendelsohn Maneuver mode, where the patient must sustain their swallow over time. The increased pressure will cause the balloon to remain in the air after swallowing, which will result in the collection of several rewards.

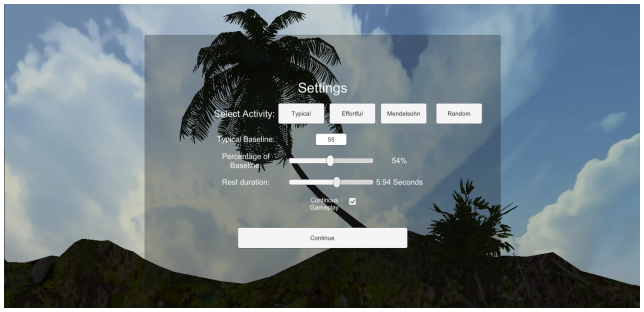

Figure 6: The settings menu interface allows the SLPs to customize the game settings to suit their patient's needs. Upon further development, the fields would populate automatically using the patient's established baseline behavior.

4 Conclusion and Future Work

Avaler's Adventure is a game suite developed for Speech-Language Pathologists and their patients that

Figure 7: The Mendelsohn Maneuver mode differs in target objective from the ballistic-calibrated game plays. Since the patient must sustain their swallow, clustering rewards encourages the patient to maximize their swallow duration.

resolves shortfalls of existing systems and brings modern gaming to the medical office. We successfully created a visually motivating, cost-effective, and dynamic game suite. The suite is completely customizable to fit the needs of the patient. We pioneered our own software and hardware, which enables collaboration and scalability. Our prototype was tested and well received by our University of Nevada Reno Speech Pathology colleagues and is being prepared for patient trials.

Patients may find themselves collecting treasure, flying a hot air balloon, or even catapulting rocks into structures, all while completing their usual therapy. Future patient studies will reveal whether patients work harder and stay focused longer during their therapy sessions. Similar experiments have reported that games have produced better therapy sessions for a variety of conditions, so it is likely that the use of Avaler's Adventure will produce similar results for patients with dysphagia.

The game suite can be run on most platforms and is prepared for collaboration, thus enabling its use by a wider community of SLPs and their patients. We developed the suite on an open platform to capitalize on the benefit of an open source community. Developers will be able to improve the game suite by adding more features, importing their own assets, or configuring their own hardware.

The game suite is being prepared for patient studies, which will require refinement of the hardware. We anticipate that custom hardware would make the sensors affordable enough for patients to use at home. Future work may include the addition of more auditory features, game themes, and levels of difficulty. One exciting component of our future work includes the development of an app that can be accessed remotely by both patients and medical professionals.

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